Standards in Sustainable Engineering and Design

A thesis submitted for the degree of Doctor of Philosophy

by

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June 2012

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ABSTRACT

The financial and environmental costs associated with the manufacture and consumption of products may be reduced through design for efficient production, service life extension and post-consumer value recovery. In response to today's need to design with consideration for the whole product life cycle, British Standards Institution (BSI) published BS 8887-1 (2006) Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE). Original research into the distribution and use of this first part of the MADE series is reported in this thesis.

The organizations that accessed BS 8887-1 were categorised using their Standard Industrial Classification (SIC) code. The results are presented graphically in multilevel charts using the hierarchical structure of the SIC system. The study found that the majority of standards users that purchased or downloaded BS 8887-1 were companies in the manufacturing sector and particularly electronics producers. Educational institutions also showed high levels of interest in the standard.

For the first time, the use of BS 8887-1 in practice has been investigated. The purpose was to discover if, why and how it is being used and to identify examples of its application in design practice. This was accomplished through semi-structured interviews with design practitioners from both industry and academia, thus helping to explain the results of the earlier SIC study. The information gathered through the interviews shows how BS 8887-1 has informed the design process and how it has been used in combination with various design and management techniques e.g. Advanced Product Quality Planning (APQP).

These studies suggest that demand for the standard has been stimulated by the introduction of Extended Producer Responsibility (EPR) legislation, especially the Waste Electrical and Electronic Equipment (WEEE) directive. Importantly, the use of BS 8887-1 has been found to be helpful in winning new business and reducing the costs associated with manufacture, product maintenance and waste management. Based on the result of the qualitative research, a new model of the use of standards in the New Product Development (NPD) process is presented.

The research was proposed by the Chairman of the BSI technical committee responsible for the BS 8887 series. The beneficiaries are BSI, industry and academia, since the investigation has shown BS 8887-1 to be of value, and has informed the continuing development of this series of standards. The thesis concludes by arguing for BS 8887 to become the basis of an International Organization for Standardization (ISO) standard in order to reach a wider audience. It also identifies a need for the standard's design requirements to be supported with additional supplementary interpretation expanding on, and adding detail to, the information in the standard itself. Influenced by this research, at the time of writing a new BSI working group was being formed to consider developing BS 8887 as an ISO standard. BSI had also begun the process of commissioning a handbook to assist designers in the practical application of BS 8887 in industrial design.

"We are living on this planet as if we had another one to go to."

[Connett, 1997]

ACKNOWLEDGEMENTS

I would like to thank:

My supervisors Prof. David Harrison and Rev. Dr. Brian Griffiths for their guidance and support throughout my Ph.D. studies.

My family and especially my mother Sandra Witherick as without her unfaltering faith, secretarial support and financial backing I would not have completed a Ph.D. Thanks are also owed to my brother Philip Plant, for proof reading my work, and to my wife Ruth Plant, for checking my references and citations (any errors left in are all mine!). I would also like to thank Graham Witherick, Christopher Plant and Olive Coward for their encouragement.

The TDW4/7 Committee and particularly Sarah Kelly, Colin Ledsome and Dr. Ben Walsh for their help in connection with BSI and standards-related issues.

My friends and colleagues at Brunel University, especially Dr. Rebecca DeCoster, Dr. Gareth Hay, Dr. Busayawan Lam, Daniel Lockton, Dr. Verity Parker, Dr. Alexandre Pelegrini, Dr. Darren Southee, Dr. Yanmeng Xu, and Richard Young.

My examiners and viva chairman Dr Peter Evans, Dr Winifred Ijomah and Dr ShengFeng Qin.

The Ormsby Trust which funded the majority of my time as a Post Graduate Researcher in the Cleaner Electronics Research Group.

All the people who contributed to this research by allowing me to interview them.

NOTE

A website was created to publicise the advances made during this research. The address of the site is:

AlexPlant.co.uk

LIST OF RESEARCH OUTPUT

Journal Papers

De Coster, R. J., Bateman, R. J. and Plant, A. V. C. (2012) 'Supply Chain Implications of Sustainable Design Strategies for Electronics Products', *International Journal of Advanced Logistics,* (Pending).

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and De Coster, R. J. (2011) 'Design for Life (and beyond)' *The Journal of the Institution of Engineering Designers*, March/April.

Plant, A. V. C., Harrison, D. J. and Griffiths, B. J. (2011) 'Raising the standard: A Review of Standards and Legislation in Sustainable Product Design', *The Journal of the Institution of Engineering Designers,* January/February.

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2010) 'Design Standards for Product End-of-Life Processing', *International Journal of Sustainable Engineering*, 3 (3), pp. 159-169.

Conference Papers and Presentations

De Coster, R. J., Bateman, R. J. and Plant, A. V. C. (2011) ‘Sustainable Design Strategies for Electronics Products Utilising Life Cycle Assessment (LCA)’, *21st International Conference on Production Research*, Stuttgart, Germany, 31 July – 4 August.

Plant, A. V. C., Harrison, D. J. and Griffiths, B. J. (2011) ‘Case Studies in the Application of Sustainable Design Standards’, *16th Sustainable Design Network (SDN) Seminar: Sustainable Consumption*, Nottingham Trent University, 4 April.

Plant, A. V. C., Harrison, D. J. and Griffiths, B. J. (2010) ‘Applying BS 8887-1 Annex-C Life Cycle Considerations Materials and Components Sourcing’, MA Sustainable Design Lecture, Brunel University, Uxbridge, 24th November.

Plant, A. V. C., Harrison, D. J. and Griffiths, B. J. (2010) ‘Implementation of BS 8887-1 Design for Manufacture, Assembly, Disassembly and End-of-life Processing’, BA Sustainable Design Lecture, Brunel University, Uxbridge, 13th October.

De Coster, R. J., Bateman, R. J. and Plant, A. V. C. (2010) ‘Sustainable Development Strategies for Product Provision and Manufacturing Approaches’, *15th Cambridge International Manufacturing Symposium: Innovation in Global Manufacturing – New Models for Sustainable Value Capture*, Institute for Manufacturing (IfM), University of Cambridge, 23-24 September. Available at: http://www.ifm.eng.cam.ac.uk/cim/symposium2010/proceedings/15_decoster.pdf.

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and De Coster, R. J. (2010) ‘Design for Manufacture and Sustainability in New Product Development’, *15th Cambridge International Manufacturing Symposium: Innovation in Global Manufacturing – New Models for Sustainable Value Capture*, Institute for Manufacturing (IfM), University of Cambridge, 23-

24 September. Available at:

http://www.ifm.eng.cam.ac.uk/cim/symposium2010/proceedings/17_plant.pdf.

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2010) 'Economic Benefits of Sustainable Design Standards in Industry', TDW/4/7 Technical Product Realization, British Standards Institution, BSI House, Chiswick, 13th July.

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2010) 'Economic Benefits of Sustainable Design Standards in Industry', *Research Student Conference 2010 (ReSCon),* Brunel University, 21-23 June pp. 82-83 (Prize awarded for oral presentation).

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2010) 'Sustainable Design Standards: Industrial Acceptance and Implementation', *Design School Research Student Conference 2010' (DeSReS),* Loughborough University, 21 April. Available at: http://www-staff.lboro.ac.uk/~cvijg/desresconference/DeSReS%202010%20Proceedings%20Web.pdf.

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2010) 'Novel Methods to Support Application of Standards in Sustainable Design', *Advanced Manufacturing and Enterprise Engineering (AMEE) and Design – Joint Research Seminar*, Brunel University, Uxbridge, 10th February.

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2009) 'An Analysis of organizations that Purchased BS 8887-1', TDW/4/7 Technical Product Realization, British Standards Institution, BSI House, Chiswick, 14th December.

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2009) 'Life cycle Considerations Material and Component Sourcing', BA Sustainable Design Lecture, Brunel University, Uxbridge, 7th December.

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2009) 'Life cycle Considerations Material and Component Sourcing', MA Sustainable Design Lecture, Brunel University, Uxbridge, 19th November.

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2009) 'An Investigation into Standards in Sustainable Design and Manufacture', *Sustainable Innovation 2009: Towards a Low Carbon Innovation Revolution,* Farnham Castle, 26-27 October pp. 163-168. Available at:

http://bura.brunel.ac.uk/bitstream/2438/3931/4/SI09%20Paper%20Alex%20Plant%20(3).pdf.

Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2009) 'An Analysis of organizations that have Purchased BS 8887-1', *Research Student Conference 2009 (ReSCon),* Brunel University, 22-24 June pp. 160-162.

Plant, A. V. C., Harrison, D. J. and Griffiths, B. J. (2008) 'Environmentally Sensitive Design Research Project Structure', TDW/4/7 Technical Product Realization, British Standards Institution, BSI House, Chiswick, 5th December.

Plant, A. V. C., Harrison, D. J. and Griffiths, B. J. (2008) 'Environmentally Sensitive Design Research Project Structure', *Advanced Manufacturing and Enterprise Engineering (AMEE) and Design – Joint Research Seminar*, Brunel University, Uxbridge, 26th November.

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ACRONYMS AND ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
AMEE	Advanced Manufacturing and Enterprise Engineering (Brunel University)
APQP	Advanced Product Quality Planning
ASME	American Society of Mechanical Engineers
ATM	Automated Teller Machine
BS	British Standard
BSI	British Standards Institution
BSOL	British Standards Online
CAE	Computer Aided Engineering
CE	Conformité Européenne
CFC	Chlorofluorocarbon
CPD	Continuing Professional Development
DEFRA	Department for Environment, Food and Rural Affairs
DeSReS	Design School Research Student Conference (Loughborough University)
DfA	Design for Assembly
DfD	Design for Disassembly
DfE	Design for the Environment
DfEoL	Design for End-of-Life
DfM	Design for Manufacture
DfMA	Design for Manufacture and Assembly
DfMADE	Design for Manufacture, Assembly, Disassembly and End-of-life processing
DfR	Design for Reprocessing or Recycling
DfS	Design for Sustainability
DfX	Design for X (collectively term)
DOI	Digital Object Identifier
DPC	Draft for Public Comment
DVD	Digital Video Disc
EC	European Commission
EEE	Electrical and Electronic Equipment
EIS	Engineering Integrity Society
ELV	End-of-Life Vehicle
EMAS	Eco Management and Audit Scheme
EMS	Environmental Management Systems
EN	Norme Européen (European Standard)
EoL	End-of-Life
EPA	Environmental Protection Act
EPR	Extended Producer Responsibility
ESD	Environmentally Sensitive Design
EU	European Union
EuP	Energy-using Products
FAME	Financial Analysis Made Easy

FEA	Finite Element Analysis
FMEA	Failure Modes Effects Analysis
FSC	Forest Stewardship Council
GD&T	Geometrical Dimensioning and Tolerancing
HAZOP	Hazard and Operability
HFC	Hydrofluorocarbons
HoQ	House of Quality
IED	Institution of Engineering Designers
IEEE	Institute of Electrical and Electronics Engineers
IfM	Institute for Manufacturing (University of Cambridge)
IMechE	Institution of Mechanical Engineers
IMS	Integrated Management System
IP	Ingress Protection or Intellectual property
IPP	Integrated Product Policy
ISIR	Initial Sampling and Inspection Report
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LRQA	Lloyds Register of Quality Assurance
MADE	Manufacture, Assembly, Disassembly and End-of-life processing
MAUDE	Manufacture, Assembly, Use, Disassembly and End-of-life processing
MJ/kg	Mega Joules per Kilogram
NPD	New Product Development
NSB	National Standards Body
NUD.IST	Non-numerical Unstructured Data Indexing, Searching and Theorizing
NVivo	A qualitative research software package from QSR
OEM	Original Equipment Manufacturer
OHSAS	Occupational Health and Safety
ONS	Office for National Statistics
PCB	Printed Circuit Board
PD	Published Document
PDS	Product Design Specification
PLC	Programmable Logic and Controller
POEMS	Product-Oriented Environmental Management System
PPAP	Production Part Approval Process
PSS	Product Service System
PVC	Polyvinyl Chloride
QA	Quality Assessed
QFD	Quality Function Deployment
QMS	Quality Management Systems
QSR	Qualitative Solutions and Research
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation & restriction of CHemicals
ReSCon	Research Student Conference (Brunel University)

RFID	Radio-Frequency Identification
RoHS	Restriction of the use of certain Hazardous Substances
SA	Social Accountability
SAP	Standard Assessment Procedure (for energy rating of dwellings)
SDN	Sustainable Design Network (Loughborough University)
SIC	Standard Industrial Classification
SMA	Shape Memory Alloy
SMC	Sheet Moulding Compound
SME	Small and Medium sized Enterprises
SMP	Shape Memory Polymer
SPC	Statistical Process Control
SPD	Sustainable Product Development
TC	Technical Committee
TPD	Technical Product Development
TPR	Technical Product Realization
TPS	Technical Product Specification
TRIZ	Theory of Inventive Problem Solving
TS	Technical Specification
TSO	The Stationery Office
UKAS	United Kingdom Accreditation Service
UN	United Nations
UNEP	United Nations Environment Programme
VA	Value Analysis
VCR	Video Cassette Recorder
VE	Value Engineering
WCED	World Commission on Environment and Development
WEEE	Waste Electrical and Electronic Equipment

CHAPTER 1 Introduction

Journal and conference papers and presentations prepared during the Ph.D. research process have been used as the basis for this thesis. Some of the key publications and presentations are referenced in *Figure 1.1: Research Process Map*. This shows the general structure of the thesis and illustrates how the papers relate to each other.

Phase	Purpose	Method	Output
Project Proposal	Outline the research topic, scope, background, influences, objectives, structure, focus and expected outcomes.	Review of previous Ph.D. theses and research papers. Mind-mapping and project planning Gantt charts.	Plant, A. V. C., Harrison, D. J. and Griffiths, B. J. (2008) 'Environmentally Sensitive Design Research Project Structure', Advanced Manufacturing and Enterprise Engineering (AMEE) and Design – Joint Research Seminar, Brunel University, Uxbridge, 26th November. Plant, A. V. C., Harrison, D. J. and Griffiths, B. J. (2008) 'Environmentally Sensitive Design Research Project Structure', TDW/4/7 Technical Product Realization, British Standards Institution, BSI House, Chiswick, 5th December.
Literature Review	Establish research context and find previous related works. Identify the gap in knowledge to be investigated.	Review relevant academic papers, articles, textbooks and web resources. Process data with NVivo software.	Plant, A. V. C., Harrison, D. J. and Griffiths, B. J. (2011) 'Raising the standard: A Review of Standards and Legislation in Sustainable Product Design', *The Journal of the Institution of Engineering Designers*, January/February. Discuss background to BS 8887 is along with other standards and legislation relevant to sustainable design. Propose research questions.
Methods Review	Evaluate and select research methods to investigate the use of BS 8887-1.	Match research methods to objectives, purpose and limitations.	Methods review describes and evaluates methods considered for use in this research. It includes some discussion of quantitative research and focuses on qualitative methods drawn from the social sciences. The selection of methods is explained in terms relevant to the research objectives.
SIC Study	Characterise organizations that purchased or downloaded BS 8887-1. Seek patterns and trends in the data and suggest hypotheses and reasons for high or low uptake in various relevant industry sectors.	Identify the activities, size, and location of organizations that accessed BS 8887-1. Use graphical representations of data to make trends visible. Consider charts with reference to external influences.	Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2009) 'An Analysis of organizations that have Purchased BS 8887-1', *Research Student Conference (ReSCon)*, Brunel University, 22-24 June pp. 160-162. Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2009) 'An Analysis of organizations that Purchased BS 8887-1', TDW/4/7 Technical Product Realization, British Standards Institution, BSI House, Chiswick, 14th December. Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2010) 'Design Standards for Product End-of-Life Processing', *International Journal of Sustainable Engineering*, 3 (3), pp. 159-169.
Pilot Study	Gather and analyse data in a single industry i.e. electronics. Practice research technique and seek emergent themes in the data.	Open-ended questions prepared, semi-structured interviews conducted, transcribed and data processed in NVivo.	Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2009) 'An Investigation into Standards in Sustainable Design and Manufacture', *Sustainable Innovation: Towards a Low Carbon Innovation Revolution*, Farnham Castle, 26-27 October pp.163-168 Available at: http://bura.brunel.ac.uk/bitstream/2438/3931/4/SI09%20Paper%20Alex%20Plant%20(3).pdf The version presented in this thesis has been expanded with additional data from later in the research process. The focus is the use of BS 8887-1 in the electronics industry.
Main Study	Explore, describe, and interpret the reaction to, and use of, BS 8887-1 by design and manufacturing companies, industry practitioners and design academics. Investigate the motives behind its use and the methods by which it has been integrated into the design process. As well as collating comment on, and criticism of, the standard. Disseminate examples of the use and benefits of BS 8887-1 in best practice product development. Investigate current issues in sustainable design as practiced in industry.	Contributions from users of BS 8887-1 were invited from all organizations and individuals known to have acquired it. This was based on the same data-sets as the SIC analysis. Semi-structured interviews arranged and conducted. Recordings and notes were subsequently transcribed. The resulting documents and other communications were processed with QSR's NVivo qualitative data analysis software. A new design process model was developed based on the evidence gathered throughout the study.	Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2010) 'Sustainable Design Standards: Industrial Acceptance and Implementation', *Design School Research Student Conference' (DeSReS),* Loughborough University, 21 April. Available at: http://www-staff.lboro.ac.uk/~cvijg/desresconference/DeSReS%202010%20Proceedings%20Web.pdf. Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2010) 'Economic benefits of Sustainable Design Standards in Industry', *Research Student Conference (ReSCon)*, Brunel University, 21-23 June pp. 82-83. (<u>Prize Awarded for Oral Presentation</u>). Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and Lam, B. (2010) 'Economic Benefits of Sustainable Design Standards in Industry', TDW/4/7 Technical Product Realization, British Standards Institution, BSI House, Chiswick, 13 July. Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and De Coster, R. J. (2010) 'Design for Manufacture and Sustainability in New Product Development', *15th Cambridge International Manufacturing Symposium: Innovation in Global Manufacturing – New Models for Sustainable Value Capture*, Institute for Manufacturing, University of Cambridge, 23-24 September. Available at: http://www.ifm.eng.cam.ac.uk/cim/symposium2010/proceedings/17_plant.pdf. Plant, A. V. C., Harrison, D. J., Griffiths, B. J. and De Coster, R. J. (2011) 'Design for Life (and Beyond)' *The Journal of the Institution of Engineering Designers*, March/April pp. 16-21. Plant, A. V. C., Harrison, D. J. and Griffiths, B. J. (2011) 'Case Studies in the Application of Sustainable Design Standards', *16th Sustainable Design Network (SDN) Seminar: Sustainable Consumption*, Nottingham Trent University, 4 April. De Coster, R. J., Bateman, R. J. and Plant, A. V. C. (2012) 'Supply Chain Implications of Sustainable Design Strategies for Electronics Products', *International Journal of Advanced Logistics*, (Pending).
Contribution	Summarise original research output and its significance in the context of the needs of society.	Identify the new knowledge from the data and add commentary and interpretation.	The research findings are presented concisely. Original thinking and the contributions to knowledge made by these studies are detailed and the outcomes are discussed. Opportunities for further research and development relating to the BS 8887 series are outlined along with suggestions to further enhance the standard's use by designers.

Figure 1.1: Research Process Map

1.1 Statement of Thesis

This thesis reports on an investigation into the use of BS 8887-1 and presents original findings. Its main argument is that the life cycle planning approach to product design and management required by the standard should assist industry in achieving more efficient production and greater profitability as well as helping to prevent unnecessary depletion of natural capital and the accumulation of potentially harmful waste. The purpose of the research was to provide feedback to BSI's TDW4/7 Committee developing the BS 8887 series.

Designing to meet the requirements of BS 8887-1 can support closed-loop production in which post-consumer products become the input materials for manufacture. This approach promotes the diversion of waste back into production, reduces the demand for virgin materials and retains some or all of the embodied energy within materials and components. BS 8887-1, together with the other BS 8887 standards in the series, authoritatively specifies the requirements necessary to facilitate efficient product recycling, remanufacturing, reconditioning and most recently, re-marketing. By making provision for product reprocessing during New Product Development (NPD), the economics of recycling and other related processes may be significantly improved.

Whilst this thesis argues that product life cycle planning supported by BS 8887 can constitute a financial advantage for manufacturers and the wider economy, the underlying argument is a moral one as well as practical one. It cannot be just to consume so voraciously as to impoverish future generations. Design for Disassembly (DfD) and Design for Reprocessing or Recycling (DfR) should help to assure the future availability of high quality materials thus achieving greater intergenerational equality. However, this idealist perspective would be of little interest to industry without sound financial justifications and a competitive advantage that can be realised by individual manufacturers within a relatively short time scale.

Evidence from the research has been used to support or add comment to the argument that there is a need in industry for standards on product life cycle planning to guide the development of more environmentally benign sustainable design. Novel aspects of this thesis include:

- Use of Standard Industrial Classification (SIC) to investigate the distribution of BS 8887-1 across industry sectors.
- Multilevel charts utilizing the hierarchical structure of the SIC system.
- Use of semi-structured research interview techniques to investigate the influence of BS 8887-1 among the people that use the standard in their professional work.
- Original combination of quantitative and qualitative research methods applied to the use of BS 8887-1
- Two original models of the design process:
    1. Combining NPD with the materials economy and product End-of-Life (EoL) roots.
    2. The use of standards in the design process based on the interview results.
- This is the first investigation into the distribution and use of BS 8887-1.

1.2 Background

Design and manufacture are centuries old activities, but the growth in consumer goods over the last 50 years has been phenomenal. The mineral wealth of our planet is extracted and used to manufacture products sold through vast retail networks. Additionally, the population increase over the last 200 years creates significant demand for more natural recourses. “In the UK it has been estimated that there are around two million computers, five million televisions and four million mobile phones sold each year" [Howarth, 2004 p.10] The wasteful disposal of products continues to accelerate as a result of both population growth and increasing standards of living [Herring, 2006 p. 8]. Industrialisation, the pace of technology change and poor production and consumption models are contributory factors in this environmentally damaging pattern.

Climate change is probably the most widely discussed and debated environmental issue of our day. When certain gases, especially carbon dioxide, nitrous oxide and methane are released, they form a barrier that reduces heat loss from our planet [Gore, 2007]. Recycling generally requires less input energy than the production of virgin materials and therefore results in lower volumes of emissions. “One way to measure the eco-efficiency of materials is to consider the embodied energy. This energy relates to the energy required to extract the raw resources, transport them to a factory and process them into refined materials. One tonne of aluminium, for example, takes more than 100 times more energy to produce than one tonne of sawn timber. In general, materials extracted from nature and requiring little processing tend to be low embodied energy materials (typically 2-12MJ/kg), while man-made materials tend to have medium or high embodied energies (typically 10MJ/kg to over 1000MJ/kg)” [Fuad-Luke 2008 p. 23].

Human industrial activity is having a significant and detrimental impact on the Earth. “The changing environment of our fragile planet is a result of the things that we do and the tools that we use. Now the changes that we have brought about are so major and so threatening it is imperative that the designers and architects play their part in helping to find solutions"

[Papanek, 1995 p. 8]. Over the past few decades environmental issues including the damage caused by certain industrial activities, have increasingly become a source of public concern. As a result there has been a proliferation of products about which various green claims have been made. Despite considerable advances in this field, it is difficult to think of many industrially manufactured products that do not have a negative impact on the environment. “Most are detrimental in terms of resource depletion, toxic metals and energy consumption” [Holdway and Walker, 2004 p. 9]. The impact of design and management decisions and their damaging effects can be seen downstream in the toxic waste filling the world's landfill sites [Holdway and Walker, 2004 p. 7]. However, environmentally conscious design can help to minimise negative impacts.

Business models incorporating service life extension or reprocessing strategies are of growing interest because of their potential to increase profits and reduce negative environmental impact. More sustainable industry and reduced CO_2 emissions may be achieved, at least in part, by “promoting increased levels of recycling and remanufacturing to recover the energy invested through virgin material processing and reducing the embedded energy content of materials” [ASME, 2009 p. iii]. However, for powered products that use energy to function, other strategies for life cycle emissions reduction may be more appropriate e.g. the use of high efficiency motors and light bulbs or lightweight materials in vehicles.

The necessity of finding ways to use finite resources more efficiently was one of the themes of the 1992 Rio Earth Summit policy document ‘Agenda 21’: “the major cause of the continued deterioration of the global environment is the unsustainable pattern of consumption and production, particularly in industrialized countries, which is a matter of grave concern, aggravating poverty and imbalances" [UNEP, 1992]. We can help to improve this situation by making the use of materials cyclical rather than linear i.e. reusing and recycling rather than dumping or incinerating them. To do this we must eliminate the disposal stage and replace it with other more sustainable options.

Sustainable design recognizes that nothing exists in isolation, and thus requires designers to consider their work in relation to the wider system. The objective is to design products that will be profitable for business and enhance people's lives while minimizing damage to the natural environment. Sustainable design offers business opportunities that should act as a catalyst for innovation. Goods and services that efficiently meet people's needs at reduced negative social and environmental cost provide an opportunity for companies to gain a sustainable advantage [Greenwood, 2008 pp. 28-29]. "The end-of-life is one phase of the life cycle stages gaining increasing attention in the market. Countries and companies are establishing goals for achieving sustainable development and reducing resource consumption" [Rose *et al*., 2001 p. 182]. For individual companies, an important motivator for sustainable design and development is economic, particularly the avoidance of penalties, improvements in efficiency, and enhanced corporate image.

The United Nations (UN) World Commission on Environment and Development (WCED) Brutland Report 'Our Common Future' published in 1987 defines 'Sustainable Development' as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [WCED, 1987 p. 8]. 'Sustainable' means to support or endure for an extended period of time. In this context it refers to the ability of the Earth to support advanced eco-systems and life-forms, particularly human civilization and its material and energy dependent economies. Sustainability goes beyond environmental aspects and encompasses financial and social issues. For sustainable industrial design, the objective must be the development of products, and Product Service Systems (PSS), that generate wealth and employment whilst preserving energy and materials. Additionally, the goals of sustainable development must include the minimization of pollution to land, air and water. "Sustainable development is the journey towards sustainability" [Howarth, 2004 p. 11]. The development of standards that may be used by designers and managers to help create more environmentally friendly products, that are suitable for reprocessing, is a step towards resolving some of these issues.

For production, the focus for industrial designers was traditionally on Design for Manufacture (DfM). This was later expanded to include Design for Assembly (DfA). The limitations of selected production processes, and the requirements for ease of assembly, influence the design decisions made. The objective of DfM is to optimise components to match their production processes. However, not all processes are relevant to all materials, parts or situations. Therefore it is necessary to have an understanding of the consequences of selecting a particular process before beginning to develop a new component or product. For example, to design a moulded plastic part, it is necessary to incorporate draft angles in the design so that it can be ejected easily from its mould. Failure to incorporate the appropriate draft angles could result in a higher cost or greater difficulty to manufacture.

Much has been written about DfM detailing the cost implications of materials use, part count and manufacturing processes, but similar details about the costs associated with EoL processing are less well established. There is a need for practical advice and information regarding the implications of design decisions and material choices in relation to EoL processing. If a product or part of a product has to go into landfill it has a negative value associated with it as someone will have to bear the cost of that disposal.

The environmental impact of manufactured goods can be reduced if designers plan for sustainability throughout the whole product life cycle. This requires consideration of the implications of materials selection, sourcing, product architecture, manufacturing processes and part fixing methods employed, as well as product energy efficiency and consumables used. Strategies to improve the efficiency with which post-consumer products may be reprocessed include planning for remanufacture, reconditioning, repair, repurposing, parts reuse, materials recovery and recycling or design for natural degradability. “Zero landfill cannot be achieved unless companies redesign their products to minimise life cycle impacts - particularly at the end-of-life” [Holdway and Walker, 2004 p. 7]. Planning for product reprocessing is an area of growing importance, as is emissions reduction from production. Design for reprocessing and disassembly are now frequently important aspects of design briefs [Howarth, 2004 p. 12].

The necessity to reduce the negative environmental impact of manufactured goods has led governments to pass legislation that forces more benign materials selection and product life cycle planning. Changes within the law, to protect our environment, cause companies to take action as they begin to affect profitability. Legislative pressures are increasing and consumers are becoming ever more aware of, and concerned about, environmental issues. The combination of these pressures is driving businesses to develop Sustainable Product Development (SPD) strategies [Jones, 2001 p. 27].

There is a strong financial incentive for product life cycle planning as well as an environmental one. By designing and planning for product reprocessing much of the production investment and embodied energy, i.e. the energy that is required to refine raw materials and then manufacture components and products, can be retained after the consumer no longer requires the original item. DfD makes efficient deconstruction possible. The design and configuration of a product plays a significant role in the ease of recycling at the EoL stage [Kobayashi *et al.*, 1999]. DfD is also important for product repair, maintenance and remanufacture and can improve the economics of recycling by enabling materials to be separated and reprocessed with minimal loss of purity thus maximising their value. EoL products should therefore become assets rather than liabilities. The four properties decisive in determining the efficiency with which a product can be disassembled and reprocessed are: ease of identification, accessibility, separation and handling of components and materials [Johansson 2008, p. 35].

EoL planning should be considered at the beginning of the design process. "The product design and development phase influences more than 80% of the economic cost connected with a product, as well as 80% of the environmental and social impacts of a product, incurred throughout its whole life cycle" [Charter and Tischner, 2001, p. 120]. It is therefore most cost effective when Design for Environment (DfE) and DfR are addressed at the *ab-initio* or early stages in the product development process. "Environment, especially end-of-life, concerns must be addressed early in the design stage, when alterations are still possible" [Rose *et al*., 2001 p. 193]. "Design for environment refers to the systematic incorporation of environmental factors into product design and development" [Tukker *et al*., 2001 p. 148].

There is even evidence that environmentally friendly design does not necessarily increase production costs and can "lead to reductions in costs of development, assembly, packaging, service and disposal of up to 50%" [Bullinger and Bopp, 1998, cited in O'Shea, 2002, p. 11]. A strong business case for sustainable design can be made as increasingly companies see the creation of positive environmental aspects to their products as a way of improving their market position [Rose *et al*., 2001 p. 182]. “Sustainable design can be portrayed as a competitive advantage in the market place ... because money saved from efficiency can put businesses ahead financially” [Thorpe, 2007 pp. 92-93].

1.3 Research Objectives

Although this research was primarily supervised by Professor David J. Harrison, whose research interests include sustainable design and printed electronics, the project was proposed by the Reverend Dr. Brian J. Griffiths, chairman of the BSI committee responsible for the BS 8887 series. BSI has also supported this work and results have been periodically presented to them during addresses made at committee meetings. The resulting publications have also been circulated among the committee members authoring the BS 8887 series.

The purpose of the research was to discover if, why and how BS 8887-1 is used, to gauge industry’s reaction to it, to gather criticisms of it and to seek opportunities for further development of the standard. The majority of the research takes the form of a survey, the results of which are used to ascertain the situation with regard to the use of BS 8887-1 in practice.

The positive findings of this study have helped to justify the continuing development of the BS 8887 series while the criticisms of the standard have been noted. This research has been rigorously conducted and therefore it is a significant source of feedback about BS 8887 that will continue to inform its development.

1.4 Summary of Chapters

1.4.1 CHAPTER 1: Introduction

This is an initial overview of the content and argument of the thesis detailing its structure and layout.

1.4.2 CHAPTER 2: Literature Review

The focus of this review is the relationship between standards and environmental legislation that influences Design for Sustainability (DfS). These are discussed with reference to authoritative published sources. Most of the available information relating to BS 8887-1 has been cited. Significantly, very little has been written about the standard other than the papers originating from this research and from Rev. Dr. Brian J. Griffiths. The literature review shows this to be original research and shows that no other studies into the implementation of this economically and environmentally beneficial British Standard have been conducted.

1.4.3 CHAPTER 3: Methods Review

The majority of the review is concerned with various qualitative research methods. These are evaluated in relation to the needs of the study. The emphasis on qualitative methods reflects the focus of this thesis. Some of the section headings in the review are based on the equivalent chapter in 'Industrial Application of Environmentally Conscious Design' [McAloone, 2000].

1.4.4 CHAPTER 4: Distribution of BS 8887-1

The market for BS 8887 is described according to the principal activities of companies and organizations that purchased or downloaded the standard since its publication in October 2006 and up until August 2009. The age, size and location of BS 8887-1 customers are investigated. Results are considered in relation to the possible influence of product-related environmental legislation. The proportion of these customers with an accredited International Organization for Standardization (ISO) Quality Management Systems (QMS) and/or Environmental Management Systems (EMS) is established. Additionally, the uptake of the standard by academic institutions is discussed.

1.4.5 CHAPTER 5: Quantitative Analysis of Interview Results

Information resulting from the qualitative research was reviewed and quantifiable results were extracted from the transcripts. Pie charts were produced to show organizations' use of BS 8887-1 and the motives and influences that caused them to consider environmental sustainability in relation to their business operations and product design.

NVivo-processed qualitative information is presented graphically with interpretation and discussion.

1.4.6 CHAPTER 6: Pilot Study – The Use of BS 8887-1 in the Electronics Industry

The SIC Study found a large proportion of the BS 8887-1 customer base consisted of companies engaged in the manufacture of Electrical and Electronic Equipment (EEE). These companies were contacted and interviews were arranged with appropriate members of design and engineering staff. By selecting firms with similar business interests it was anticipated that common themes would become apparent. The responses gathered formed the basis of the pilot study.

1.4.7 CHAPTER 7: Main Study (Part 1) Design for Manufacture and Sustainability in New Product Development

Following the pilot study, the research was broadened to include all organizations known to have accessed BS 8887-1. Throughout the information-gathering process, multiple aspects of design practice were investigated. This chapter focuses on the experiences of industry practitioners applying the standard and emphasises its influence on profitability, sustainability and its application in the design process. Comments from users are evaluated with reference to design process requirements detailed in BS 8887-1.

1.4.8 CHAPTER 8: Main Study (Part 2) Integrating Life Cycle Design Standards in New Product Development

The case studies show that BS 8887-1 is being used, or has been proposed for use, in combination with a number of existing systems and tools during commercial Technical Product Development (TPD). These include Advanced Product Quality Planning (APQP), EMS, Theory of Inventive Problem Solving (TRIZ) and House of Quality (HoQ) which is part of Quality Function Deployment (QFD).

The findings are significant because they demonstrate that BS 8887-1 is used in commercial design practice and the application of requirements specified by the standard has been shown to have a cost benefit. Additionally, the standard has proven to be useful in design education. It can therefore be anticipated that BS 8887-1 will continue to be used and continue to contribute to incremental product design improvements and environmental impact reduction.

1.4.9 CHAPTER 9: Discussion and Conclusions

The original research findings in this thesis are presented concisely. The significance of the results is discussed in the context of the need for sustainable design and production. Finally, suggestions and recommendations for the further development and use of BS 8887 are made.

1.5 Project Plan

A project plan was developed at the start of this research, and used in early presentations at both Brunel University and BSI. As the research progressed this was updated to illustrate how the research had developed, future objectives and the steps necessary for completion. This proved a useful reference during annual progress monitoring. The version presented here in *Figure 1.2: Project Planning Gantt Chart* has been finalized to retrospectively show when various tasks commenced and were accomplished, as well as the months in which conference addresses were delivered and when journal papers were published.

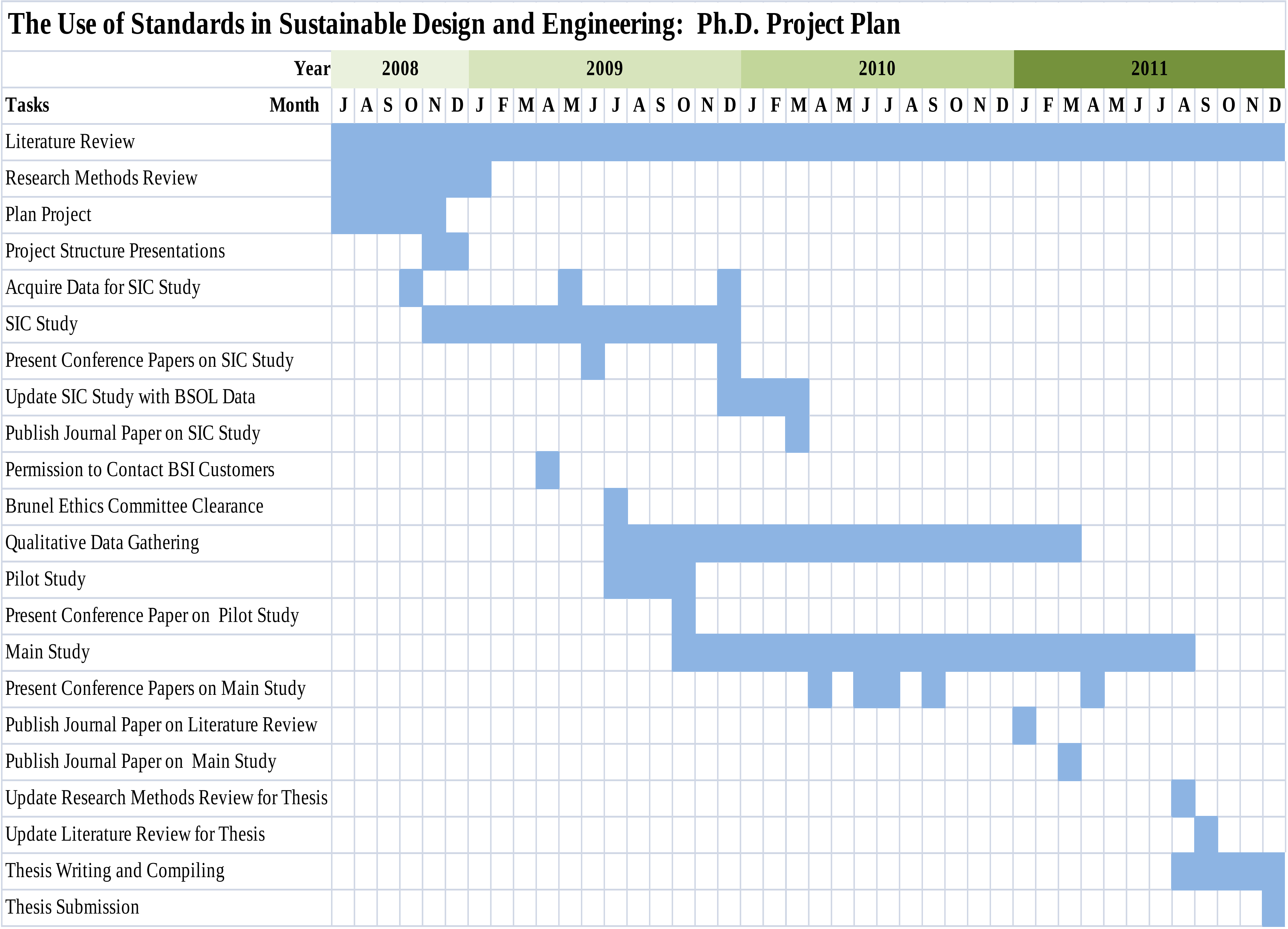

Figure 1.2: Project Planning Gantt Chart

CHAPTER 2 Literature Review

Themes for this review and the subsequent research were initially explored using mind maps [see Buzan, 1988]. An updated version of the mind map developed for this project is presented in *Figure 2.1: Research Themes.*

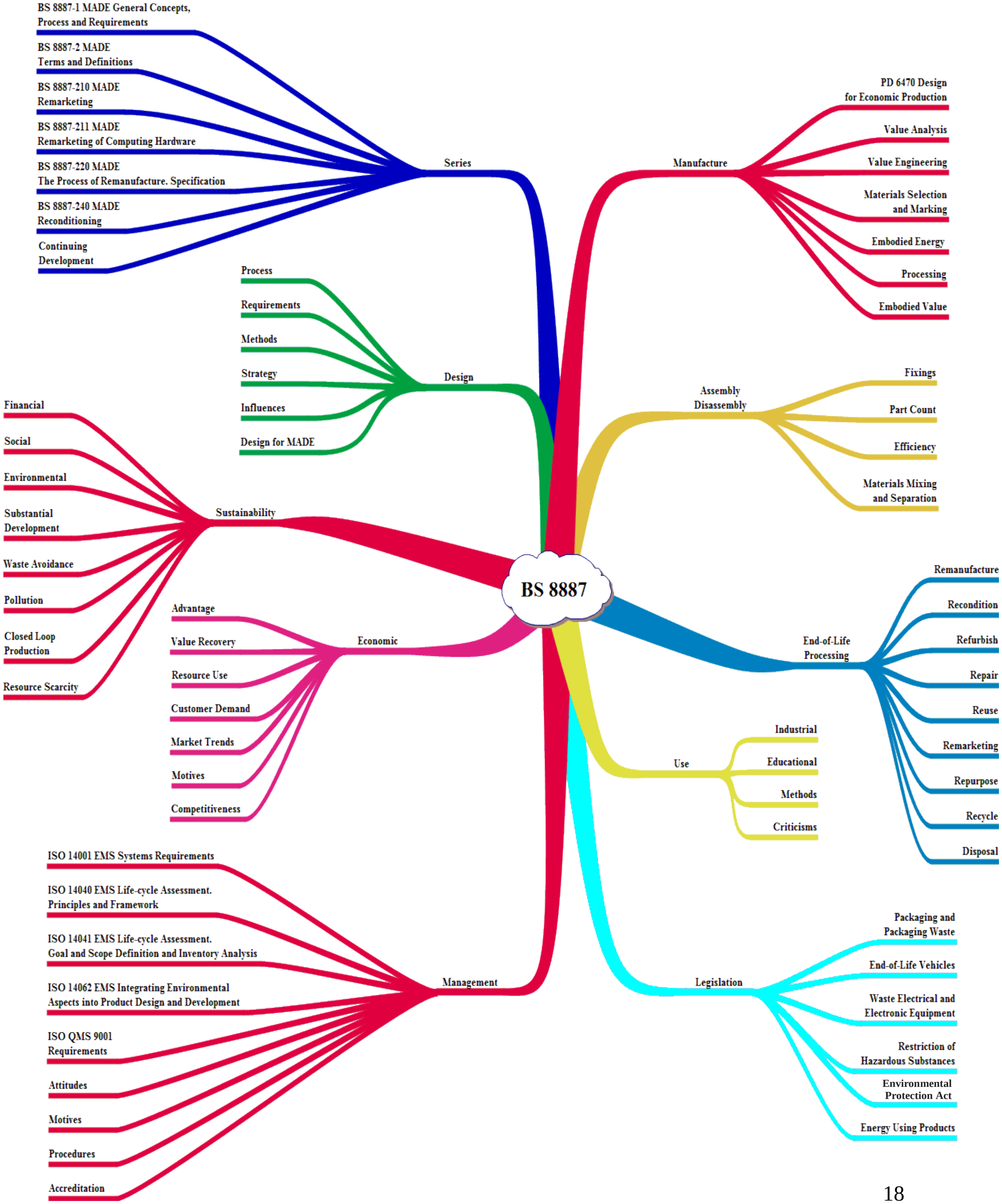

Figure 2.1: Research Themes

Each of the topics identified in *Figure 2.1* has had some influence on this thesis. The focus of the research is the relationship between Environmentally Sensitive Design (ESD), the use of standards, particularly BS 8887, and Extended Producer Responsibility (EPR) legislation. This is illustrated in the Venn diagram in *Figure 2.2: Research Focus.*

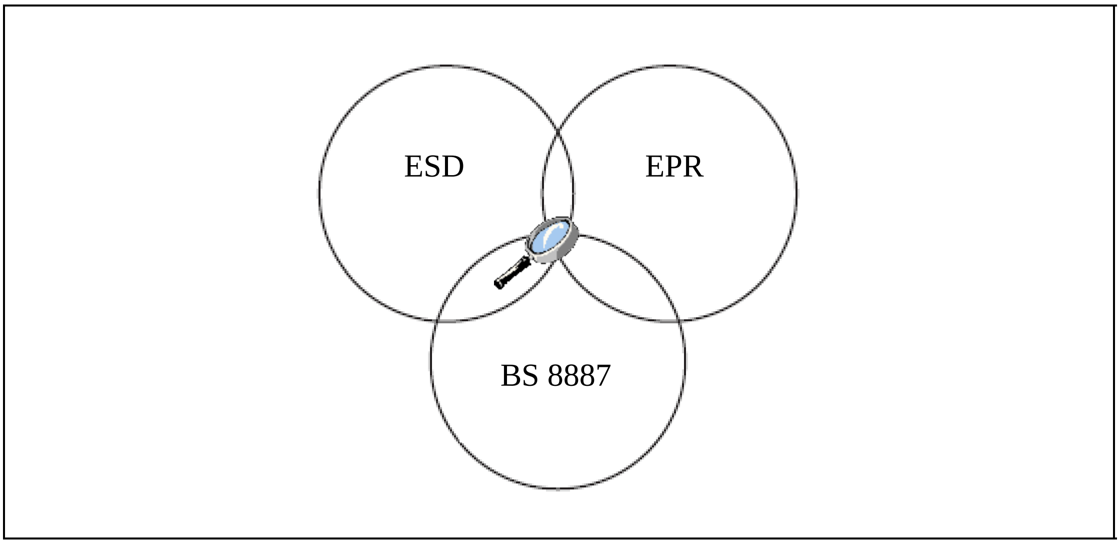

Figure 2.2: Research Focus

2.1 Product Design and the Environment

On average, ten tonnes of resources are used for every one tonne of products made and, for consumer products, 60% of them will no longer be in use after just six months [Humphries-Smith, 2010 p. 11; Howarth, 2004 p. 13]. "Product life spans are reducing rapidly" [Pugh, 1991 p. 56]. There are four principal reasons why products are retired from service, these are: technical cycle - a significant technological advance may make obsolete an old but functional product; wear out cycle – product deterioration through use; redesign reason – iterative improvement e.g. stylistic changes and function integration level - new features added. The reason for a product being retired is likely to have an influence on the EoL reprocessing strategy adopted [Xing *et al*., 2003 pp. 153-154].

Historically industrial designers and engineers have given little consideration to the wider areas of resource depletion, energy consumption, pollution from landfill sites and materials toxicity. Therefore, design is in part responsible for the condition of the planet, which becomes ever more critical [Holdway and Walker, 2004 p. 9]. The environmental impact of products may have been less of a concern in the past because natural resources were more abundant and rates of consumption lower owing to a less extravagant culture and smaller population. Today designers must not only achieve the required functionality, cost and value, but also consider environmental impacts. Social and regulatory responses to environmental issues are forcing companies and other organizations to reduce the burdens that they place on the systems of the natural world [Ellram *et al.*, 2008 p. 1620]. "International law is pushing companies towards increased recovery and recycling of all materials" [Holdway and Walker, 2004 p. 7].

2.2 Standards

BSI was the world's first National Standards Body (NSB) [BSI, 2009a] originating at the beginning of the 1900s [Woodward, 1972 p. i] It had been realised that the unnecessary diversity of components and parts produced by various manufacturers resulted in a lack of interchangeability. Standardization helps prevent problems in production, repair and maintenance of products. It fosters international trade thanks to the elimination of technical barriers [Casadesús *et al.*, 2008 p. 1741]. Today, standards facilitate the design and manufacturing process by "establishing safety criteria, promoting quality with economy, assisting communication and trade, and inspiring confidence in manufacturer and user" [Simmons *et al.*, 2009, p. 295].

BSI defines a standard as a: "document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context" [BSI, 2009b]. Standardization benefits both the customer and the manufacturer by ensuring that everyone works to an agreed and consistent model. "The consumer needs uniform and readily comprehensible standards that will be respected and policed" [Packard, 1960 p. 252]. Today, BSI is so well known and respected that it is recognized as a UK Business Superbrand [BSI, 2011a].

ISO is a federation of NSBs from industrialised countries. It was formed at the end of World War II and now represents over 150 nations. Since ISO began, BSI has been an important member [Macleod, 2007 p. 26]. The name ISO is derived from the Greek *isos*, meaning equal. It is referred to by the same name in every language [ISO, 2010].

Standards are developed in response to the needs of industry. Today they encompass specifications, codes of practice, management systems, testing, measurement, sampling, guides and glossaries. Increasingly they are referred to in contracts and legislation as well as being used in management, product certification, purchasing and marketing. They are indispensable for industry as they impact upon every aspect of product design and are essential for competitive, cost effective production as they specify the requirements to be met by materials, products and procedures. Standards are both unambiguous and authoritative [Simmons *et al*., 2009 p. 295].

Standards are written by committees of volunteers. Members that draft them represent manufacturers, trade and research associations, professional bodies, governments, academic institutions and consumers [Simmons *et al*., 2009 p. 296]. Standards epitomise best practice and should therefore be used as an 'expert knowledge base'. Writing them is a rigorous process and each standard must be made available as a Draft for Public Comment (DPC) prior to publication [Hollins, 2008 pp. 17-18]. The development of standards tends to be laborious, even when all those involved appreciate the advantages of standardization [Norman, 2002 p. 232].

Despite their rigorous development process there are still some concerns with standards. For instance, because industry contributes to writing them, there is a tendency to define requirements at a level that has a low economic impact [Birkeland, 2002 p. 212]. Also, standards usually reflect a technology, industry and agreed judgement at a particular time. They must not be permitted to stifle innovation [Pugh, 1991 p. 56]. This is unlikely as the use of standards is voluntary (except for those required by law), although in the case of environmental standards companies can rarely afford to ignore them [Fiksel, 1996 p. 27]. "Any company that is already marketing a product that meets the proposed standard will have a huge economic advantage" [Norman, 2002 p. 232].

In the context of sustainable design, standardization necessitates the incorporation of a set of principles in NPD intended to minimise the environmental impact of industrially produced goods. This approach applies to the whole product life cycle, including materials selection, extraction, manufacturing processes and consideration of the optimal working lifetime of the product as well as designing for reprocessing.

2.2.1 Standards and Sustainability

The three pillars of sustainability are: economic, social and environmental [Adams, 2006]. Standards contribute £2.5bn to the UK economy [BSI, 2009a], and during the last two decades there has been an increase in the number of standards issued concerned with the economic field. This is likely to be a result of increased globalization [Casadesús *et al*., 2008

p. 1741].

Social aspects of sustainability are supported by ISO 26000 *Guidance on Social Responsibility* and the SA 8000 *Social Accountability Standard.* Leipziger (2009) investigated case studies in the use of the latter standard. Environmental sustainability is supported by standards including the ISO 14000 *Environmental Management* series, BS 16001 *Energy Management*, and latterly for products BS 8887 *Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE).* "Neither ISO 14000 or SA 8000 is a product certification or product guarantee. Both refer to the activities on site. That is why the two standards may be suitable for corporate communications, but less so for product communications. Consumers are usually unaware whether a company is certified according to ISO 14000 and/or SA 8000. Nevertheless, there is an indirect effect that consumers profit from: some retailers request such standards from their suppliers. In these cases they become a pre-requisite for doing business" [Belz and Peattie, 2009 p. 156].

2.2.2 Technical Product Realization

BS 8887 is part of the Technical Product Realization (TPR) triumvirate of standards which includes BS 8888 *Technical Product Specification* (TPS) and the forthcoming BS 8889 Technical Product Verification. The relationship between these standards is represented by the Venn diagram in *Figure 2.3: Coverage between the Technical Product Realization Standards.*

None of the standards in the triumvirate should be taken in isolation, as together they support each other and there is some overlap in their content. TPR is defined as a "system facilitating cooperation between engineering disciplines to effect conversion of a concept into correctly functioning work pieces or product, to time, to budget and with minimal rework/reject requirement" [Griffiths, 2008 p. 22].

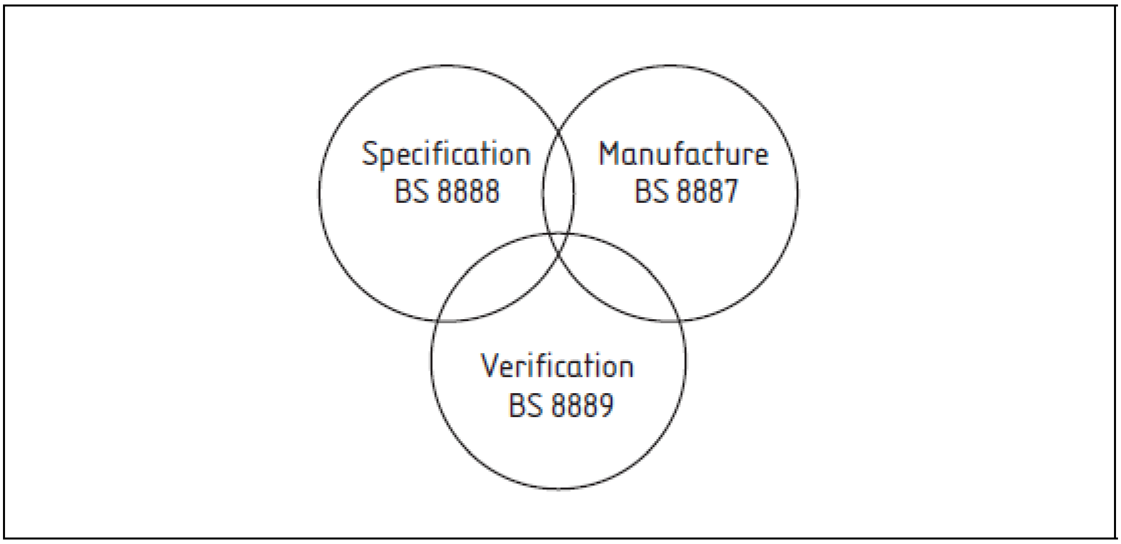

Figure 2.3: Coverage between the Technical Product Realization Standards [BS 8887-1, 2006 p. 39]

Since the withdrawal of BS 308 *Engineering Drawing Practice*, its replacement BS 8888 has been the definitive standard for TPS and engineering drawing [Macleod, 2007 p. 26]. Developing a design concept into a functioning product requires the coordination of a sequence of disciplines including specification, manufacture and verification. This should be achieved through the development of an unambiguous, correctly formatted, TPS [Griffiths, 2008 p. 22]. BS 8888 specification will "facilitate outsourcing, reduce time to market, improve material utilisation through better surface definition, increase the utilisation of technologically advanced equipment, improve market credibility and assist challenges to product quality" [Simmons, 2006 p. 18]. BS 8889 will provide the requirements for verifying that parts and products fulfil the necessary requirements specified. BS 8887 specifies design requirements relevant to each stage of the product life cycle and informs the design process.

2.2.3 BS 8887-1 Development

The BSI subcommittee concerned with TPR is designated TDW/4/7. BS 8887 is a progression from PD 6470 (1975) *The Management of Design for Economic Production.* This earlier publication focused on the 'productionising' of designs and the importance of manufacturing economics. The emphasis was on the efficient manufacture of piece-parts [Griffiths, 2008a p. 22]. NB: A Published Document (PD) is a publication that is like a standard but with lesser status.

For the new manufacturing standard it was decided to take a holistic view. BS 8887 was given an equal emphasis on each stage of the product life cycle. New material on DfA was included with reference to the work of Boothroyd *et al*., (1994) and importantly, advice on how to enhance designs for EoL processing was added [Griffiths, 2008b].

In industry, the terms DfM, DfA or Design for Manufacture and Assembly (DfMA) are commonly used. For those concerned with the environmental performance of products and ensuring that products are suitable for reprocessing, the terms Design for Environment (DfE) and Design for Recycling or Reprocessing (DfR) are used. The objective of DfR is to select appropriate materials and configure products so that they will be suitable for reuse, remanufacture or recovery [Xing *et al*., 2003 p. 150]. These terms are referred to collectively as DfX. The BS 8887 term MADE, or DfMADE, is used with the distinction that it encompasses the whole product life cycle [Griffiths, 2008b].

The MADE acronym represents the four stages of piece part manufacture, assembling them together and how in some way at EoL they will be disassembled and processed in an appropriate manner. MADE has however been criticised by some at TDW/4/7 committee meetings for not placing enough emphasis on the use phase which can have a significant impact, especially with regard to energy consumption. The standard should arguably place an equal emphasis upon this phase as it does the others, implying MAUDE as a more appropriate term. Although the use phase is not expressly covered by the MADE acronym, BS 8887-1 does have some information on this in *Annex C Life Cycle Considerations* under *C.4 Product Use*.

The development of BS 8887 could have been limited to producing an updated manufacturing standard. Instead, it was decided to develop the MADE process with its broader scope and environmentally conscious approach to design. BS 8887-1 structures the design process for the conversion of concepts into functional products that can be efficiently manufactured and that have a value at EoL. The product development process detailed in BS 8887-1 is an iterative one as each stage, especially design improvement, may be revisited many times [Griffiths, 2008a p. 23]. Significantly, by including sustainability considerations early in the design process, the BS 8887 series of standards should help to reduce the damaging impact of products [EIS, 2009 p. 20]. Post-consumer products should retain more of the original value invested in their development and manufacture.

Using a diagram from Part 1 of the standard, the BS 8887 life cycle planning approach is represented schematically in *Figure 2.4: The Stages in the Life of a Product, Including the Three Routes of Part End-of-Life* . Following disassembly parts may be reused in their current form or, if necessary, they may be reworked to bring them back to the required condition. Alternatively, material recovery may be most appropriate. Another option, not specifically included in the diagram, is to use parts for a different use from their original purpose.

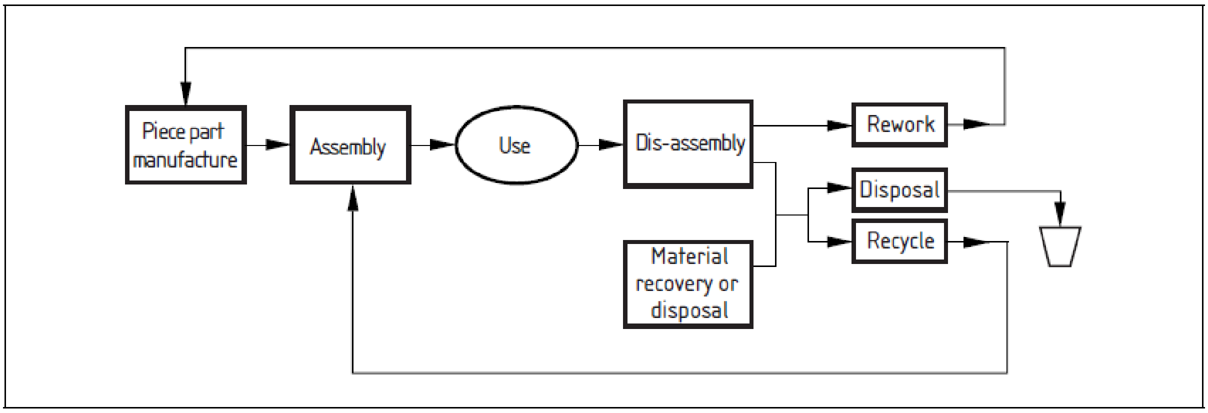

Figure 2.4: The Stages in the Life of a Product, Including the Three Routes of Part End-of-Life Processing [BS 8887-1, 2006 p. 14]

Approximately half of BS 8887-1 is concerned with conventional DfMA requirements; however, it is the DfD and EoL processing content that will be of particular interest to those developing SPD solutions.

2.2.4 The BS 8887 Series

The numerical structure of the BS 8887 series is defined in BS 8887-211 (p. 3) as follows:

- Part 1 to Part 99 are general MADE standards.
- Part 100 to Part 199 are related to DfMA.
- Part 200 to Part 299 are related to DfD and Design for End-of-Life (DfEoL).

BS 8887-1 (2006) is subtitled *General Concepts, Processes and Requirements* and is the first British Standard to address both design for efficient production and post-consumer product reprocessing, and is the entry standard to the BS 8887 series. It is therefore general in nature and applicable to a wide range of manufactured goods. Further parts of the standard continue to be developed to meet specific needs.

The second standard in the series, BS 8887-2 (2009) subtitled *Terms and Definitions* clarifies the differences between words such as reuse, repurpose, repair, refurbish, remanufacture, recycle, etc. For the 'MA' stages of MADE, the terms are well accepted and tend to be non-contentious. This is not the case for the 'DE' parts as these are developing areas and many of the terms are new [Griffiths, 2008a p. 24]. The advantage of agreed upon terms and definitions is reduced ambiguity and misinterpretation in communication between design practitioners and others in industry, business and commerce [Hollins, 2007 p. 29].

BS 8887-220 (2010) is subtitled *The Process of Remanufacture – Specification*. Remanufacture is defined as: "return a used product to at least its original performance with a warranty that is equivalent or better than that of the newly manufactured product" [BS 8887-2, 2009 p. 4]. This definition was developed from earlier Ph.D. research into the business and process of remanufacturing [Ijomah, 2002]. Remanufacturing enables lower cost, but high quality items to be supplied with reduced resource use and environmental impact [Walsh, 2009]. Of the possible EoL routes, remanufacture may be regarded as the most advanced option since the process brings used products back to as-new condition whilst retaining their embodied energy and geometrical form. However, remanufacture does necessitate additional planning effort [Doh and Lee, 2009 p. 159].

BS 8887-240 (2011) is subtitled *Reconditioning*. This term is synonymous with refurbishing and is defined as "returning a used product to a satisfactory working condition by rebuilding or repairing major components that are close to failure, even where there are no reported or apparent faults in those components" [BS 8887-240, 2011 p. 1]. As this Standard was adapted from the earlier remanufacturing standard BS 8887-220, it was it was relatively quick to develop.

BS 8887-211 subtitled *Remarketing of Computing Hardware* is currently a standard in development [BSI, 2011b] and, at the time of writing, is available as a Draft for Public Comment (DPC). This standard is being developed in response to a request from an Original Equipment Manufacturer (OEM) in the electronics industry. “Proposals for new and revised standards come from many sources but the largest proportion is from industry” [Simmons *et al.*, 2009, p. 296].

Remarketed products can include items that have been remanufactured, refurbished, repaired, unopened returns or upgraded equipment, as well as used but functioning items which may enter a second or third use-cycle. BS 8887-211 defines the terms for these various grades of remarketed computing equipment.

TDW/4/7 has planned the BS 8887 series to include a general remarketing standard applicable to a broad spectrum of products, not limited to just computing equipment. Numerically this will precede the *Remarketing of Computing Hardware* standard although it will be developed later. It will be designated BS 8887-210 and subtitled *Remarketing of Products*. “In many instances customers prefer re-used over new equipment because the price is lower while the quality is perceived as the same" [Donnelly *et al.,* 2004 p. 49].

A further new part to the BS 8887 series has been proposed to provide designers with a framework for selecting appropriate strategies for EoL processing. For example, heavy machinery may be well suited to remanufacture [e.g. Caterpillar Inc., 2009], whereas the plastic casings of post-consumer electronic products may be ideal for recycling as demonstrated by the ‘Reee Chair’ [Pli Design, 2009]. In some instances design for biodegradability could be the best option as has been suggested for certain types of packaging [Davis and Song, 2006]. This new part of BS 8887 is likely to take the form of a series of decision trees and flow charts based upon a product’s material composition and will provide route-maps through the DfMADE process [Griffiths, 2008 p. 24].

2.2.5 ISO 14000 – Environmental Management

The world's first QMS standard started as BS 5750 (1979) *Quality Systems. Specification for Design, Manufacture and Installation*. By 1987 it had been superseded by the ISO 9000 series it inspired. ISO 9001 *Quality Management Systems – Requirements*, specifies the stipulations and conditions against which companies can certify. Following this, the world's first EMS standard, BS 7750 (1992) *Specification for Environmental Management Systems,* was published. Subsequently, it was adopted internationally as ISO 14001 *Environmental Management Systems. Specification with Guidance for Use* [BSI, 2009c].

"Influenced by the UK experience, a host of other countries, including Canada, Ireland, France, the Netherlands and South Africa, have developed their own national standards for EMS which are very similar to BS 7750" [Fiksel, 1996 p. 30]. The main rationale for publishing ISO 14001 was to harmonise EMS standards and provide an internationally accepted system for pollution prevention and assurance [Delmas, 2002 p. 92].

The ISO 14000 series provides the framework necessary to develop an organization's EMS. From the findings of several studies it can be concluded that the coercive pressure of customers is a very important motivator in the implementation of EMS and QMS standards [Casadesús *et al*., 2008 p. 1742]. An EMS can be certified against the normative standard ISO 14001, which specifies the requirements to be met [González-Benito and González-Benito, 2005 p. 135]. Similarly, companies can certify against the ISO 9001 part of the ISO 9000 QMS series.

Compliance with the requirements of ISO 14001 has been found to have significant environmental benefits. Some companies also find the status helpful for marketing activities

[Charter and Tischner, 2001 p. 83]. Although, if ISO 14001 is only adopted for its marketing potential, it may not be the best investment [Sambasivan and Fei, 2008 pp. 1424-1425]. This may be owing to the cost of implementation, maintenance and auditing.

A company's opportunity to trade internationally is likely to be increased by the implementation of a certified QMS. So much so that in many instances ISO 9000 certification has now become a *sine qua non* or prerequisite for winning business. Industrial customers are reassured that their suppliers' quality practices are sufficient. Therefore, the need to audit them carefully is reduced [Fiksel, 1996 p. 27]. Similarly, companies are aware that consumers are interested in the interactions between businesses and the environment. As a result, ISO 14001 certification is now commercially beneficial [Sambasivan and Fei, 2007 p. 1424]. The implementation of a certified ISO 14001 EMS can result in improvements in processes, products and services as well as reduced costs and higher profits [Seiffert 2008 p1447].

EMSs develop best practice management through commitment to continual environmental improvement [Birkeland, 2002 p. 244]. This is the key concept of ISO 14001 [Brouwer and Van Koppen, 2006 p. 450]. It is defined as a "process of enhancing the environmental management system in order to achieve improvements in overall environmental performance consistent with the organization's environmental policy" [ISO 14001, 2004 p. 1] It is achieved through the Plan Do Check Review cycle [Donnelly *et al*., 2004 p. 44; Brouwer and Van Koppen, 2006 p. 451].

The EU's Eco Management and Audit Scheme (EMAS) can be used as an alternative to ISO 14000. Another option is for organizations to develop their own EMS. These usually have greater focus on enhancing performance in areas of specific concern, rather than the more procedural emphasis of ISO 14001 [Esty and Winston, 2009 p. 180]. Some organizations use their EMS to concentrate on ESD for their products [Charter and Tischner, 2001 p. 114].

The creation of international standards on environmental performance has led companies to address some of the negative impacts of their activities and the products that they manufacture [Fiksel, 1996 p. 27]. It has even been proposed that sustainable design should be integrated along with a total quality approach, so that environmental considerations are included with quality management. This view has been countered with the objection that quality issues are unwelcome, whereas environmental considerations are likely to add interest for those working on an engineering design project [McAloone, 2000 p. 97].

"Firms complying with the ISO 14000 series of standards are required to evaluate the environmental performance of their suppliers. In this way complying organizations pressure their suppliers to meet appropriate environmental standards, and these suppliers, in turn, pressure their suppliers to comply" [Charter and Tischner, 2001 pp. 284-5]. As a consequence, some smaller enterprises are compelled to implement an EMS that is more complex than they naturally would [Esty and Winston, 2009 p. 19]. But, there is an environmental advantage to this, in that the adoption of ISO 14001 by Small and Medium sized Enterprises (SMEs) is of significant value because of their large number and the variety of pollutants they produce [Seiffert, 2008 p. 1459]. SMEs are responsible for a significant environmental burden [Frijns and Vliet, 1999 p. 981]. It is estimated that SMEs are responsible for up to 70% of pollution from industry [Hillary, 2004 p 561]. Another criticism of EMS is "excessive bureaucracy, focusing on processes rather than actual performance and ignoring the broader issues of sustainable development" [Charter and Tischner, 2001 p. 83].

2.3 Environmental Legislation

The European Union (EU) has developed a series of environmental and product-related framework legislation for its member states. In the UK the EU Waste Framework Directive has been implemented in the form of the Environmental Protection Act (EPA) which is concerned with the regulation of waste management and pollution control. Product related legislation affecting producers has also been developed. For example, the Packaging and Packaging Waste Directive prevents the use of harmful materials in packaging and limits heavy metal content, as well as requiring that materials are recoverable, recycled and reused etc. The intention is to reduce the amount of material going into landfill, and that any waste should be non-hazardous [Howarth, 2004 p. 12]. When the process of developing BS 8887-1 began, legal requirements such as these, and the take-back legislation, and particularly the Waste Electrical and Electronic Equipment (WEEE) directive were significant influences causing changes in manufacturing design practice [Griffiths, 2003 p. 4].

Legislation is one of the primary motivators for environmental issues to be integrated into a company's philosophy [McAloone, 2000 p. 130]. Compliance is essential to avoid penalties and remain attractive within the market. Legislation is the 'blunt instrument' used by governments to move business in a required direction. The EU product directives encompass: WEEE; End-of-Life Vehicles - Producer Responsibility (ELV); Packaging and Packaging Waste; Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS); Eco-design Requirements for Energy-using Products (EuP); Waste Batteries and Accumulators Regulations; Registration, Evaluation, Authorisation and restriction of CHemicals (REACH); as well as ISO standards covering management, design, Life Cycle Assessment (LCA) and labelling [Humphries-Smith, 2010 p. 12].

The EPR approach puts pressure on firms by making them responsible for their products at EoL [Bereketli *et al.*, 2009 p. 214]. Thus EPR legislation is causing producers to plan their products with consideration for reducing negative environmental impact, designing for reprocessing and funding the treatment of volumes of waste equivalent to the amount of new product they place on the market. These legislative advances are necessary since a purely voluntary approach would probably fail to achieve broad implementation of eco-design [Tukker *et al.*, 2001 p. 160].

"The stick has worked well, but the stick is also getting bigger and heavier" [Fuad-Luke, 2008 p. 24]. Environmental regulations in Europe are expected to become steadily more demanding, thus making it necessary for firms to anticipate future legislation and plan EoL product processing strategies early in NPD [Gehin *et al.*, 2008 p. 567]. For instance, the EU Landfill Directive (1999) promotes the diversion of waste towards recycling. In particular, Article 5 restricts the amount of biodegradable material going into landfill and prohibits the dumping of some types of waste [Staikos and Rahimifard, 2007 p. 606]. In another example, the EU directive on Energy Labelling of Household Washing Machines, implemented from 1996 onwards, has led to significant efficiency improvements, to the extent that most currently available models are A-rated [Devoldere *et al.*, 2009 p. 269]. When these products, classified under WEEE as 'Large household appliances', reach the end of their useful working lives they will usually be recycled, but the householder will often have to pay a collection charge.

Both legislation and consumer pressure are influencing producers to develop product take-back systems. In some instances these can also be profitable [Rose *et al.*, 2001 p. 186]. SPD is now seen as so essential for society, that it is being supported by government, and legislation is forcing manufacturers to take responsibility for their products at the post-consumer stage [Griffiths, 2008b]. "The emphasis has shifted from a vague intention that products can be recycled to the obligation that it is recycled" [Holdway and Walker, 2004 p. 7].

The Integrated Product Policy (IPP) [European Commission, 2003] outlines the approach taken by the EU [Howarth 2004 p12]. This introduces measures to improve product environmental performance including: materials extraction, manufacture, transport, use and disposal. The IPP attempts to stimulate each of these stages, particularly those that will have the greatest positive effect. To achieve this, a variety of tools are used, including: substance bans; voluntary agreements; environmental labelling; and design guidelines [EC, 2008].

Whilst these developments are positive, it has been suggested that they may only result in incremental improvements, rather than step change innovations [Tukker *et al.*, 2001 p. 160], and that legal obligations only set the minimum performance level. To only just meet them is the equivalent of admitting that "if I could have made it worse I would have". It has been argued that by anticipating legislation and exceeding the legal minimum requirements, businesses have a strategic advantage that puts them ahead of the competition [Thorpe, 2007 p. 71]. Design education and training is of primary importance. Meeting legislative requirements in timely fashion can benefit companies first to market with compliant products. Legislative measures will require a shift in business philosophy, from merely aiming to sell 'more stuff', to an approach that embraces 'older values' of maintaining products and keeping them in service for as long as is practically possible [Humphries-Smith, 2010 p. 12].

It has been assumed that OEMs will produce more sustainable products if they are required to handle them at EoL. EU regulations have been developed based upon this premise, with the intention of reducing the build-up of toxic material in the environment. For example, the WEEE directive actively encourages designers to think about recycling and product reprocessing at the design stage [Gehin *et al.*, 2008 p. 567].

BS 8887-1 references the EuP, WEEE, RoHS, and, ELV legislation, each of which is discussed in the following subsections.

2.3.1 Eco-design of Energy Using Products (EuP) Directive

The EuP Directive is intended to improve the energy efficiency of manufactured goods [DEFRA, 2007]. It refers to aspects of the product life cycle including embodied energy, packaging, transport, distribution, use and energy for EoL processing [Fuad-Luke, 2008 p. 24]. The aims of the directive include: ensuring the free trade of EuPs between the member states; improving the environmental performance of these goods; reducing energy demand and enhancing the EU's economy whilst preserving the interests of industry and consumers [Bereketli *et al.*, 2009 p. 213].

2.3.2 Waste Electrical and Electronic Equipment (WEEE) Directive

Waste electronic products are particularly problematic in the environment as they typically contain multiple hazardous substances. These can leach into soil and drinking water from landfill sites, or pollute the air when incinerated. Toxins from electronics have been associated with cancers as well as reproductive, neurological and developmental disorders. Children are particularly vulnerable [Bereketli *et al*., 2009 p. 215]. Electronics is now the fastest growing type of waste, increasing at about 8% per year. To address this, the WEEE directive forces the recycling of EEE with producers covering the costs [Holdway and Walker, 2004 p. 7].

Under WEEE the term 'producers' includes importers, re-branders and manufacturers of products that use electricity for their main function [Harding, 2008 p. 26]. WEEE also promotes design that anticipates ecologically benign EoL processing and recovery [IED, 2006 p. 28]. It does this by encouraging both ESD and sophisticated recovery techniques. Products designed with recycling in mind generally have superior properties for EoL processing. However, more incentives are needed to reward this approach as, in its current form, the directive mainly serves to promote waste avoidance [Zuidwijk and Krikke, 2008 p. 1216]

Since the regulations came into force, thousands of companies have registered with compliance schemes, and they are making a significant contribution by financing the recycling of WEEE. To register with a scheme, a fee must be paid and the amount of EEE

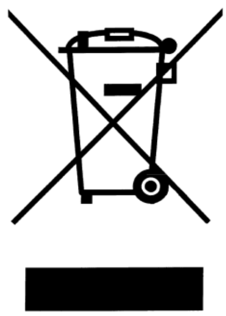

Figure 2.5: WEEE – Crossed Out Wheelie Bin Logo (Detailed in BS 50419)

placed on the market disclosed, along with whether it is for domestic or commercial use [Harding, 2008 pp. 26-28]. Noncompliant producers will not be permitted to sell their products in EU member states [Holdway and Walker, 2004 p. 7]. To show that they comply, all applicable products on the EU market must now carry the wheelie bin logo [IED, 2006 p. 27], as defined in BS 50419 *Marking of Electrical and Electronic Equipment*, and shown in *Figure 2.5: WEEE – Crossed Out Wheelie Bin Logo*

The purpose of the RoHS legislation is to reduce the use of toxic materials in products

[Holdway and Walker, 2004 p. 7]. The legislation restricts the use of six hazardous substances: Lead; Mercury; Cadmium; Hexavalent Chromium; Polybrominated Biphenyls and Polybrominated diphenyl ethers. As well as preventing pollution from electronic product waste, RoHS protects workers from the occupational hazards associated with these toxic chemicals in both manufacture and recycling [IED, 2006 p. 27].

Product types impacted by RoHS include household appliances, computers, consumer electronics, lighting, power tool, toys and dispensers e.g. vending and Automated Teller Machines (ATM). Exempt products include large stationary industrial tools, control and monitoring equipment, national security use and military equipment, medical devices, some light bulbs and batteries as well as replacement parts for equipment that was on the market before July 2006 [IED, 2006 pp. 28-29].

2.3.3 End-of-Life Vehicle (ELV) Directive

The ELV directive aims to increase recovery of vehicles at EoL and improve automotive environmental performance by promoting collection, reuse and recycling. The directive requires manufacturers and their suppliers to reduce the use of hazardous substances, as well as to design for disassembly, reuse, recovery and recycling. It also requires increased use of recycled materials and that components do not contain mercury, hexavalent chromium, cadmium or lead [Europa, 2010].

2.4 Literature Review Summary

Standards organizations are supporting industry in becoming more sustainable through establishing improved processes and procedures in design and management. BS 8887 specifies techniques and requirements to achieve better product design and product life cycle planning solutions. ISO 14001 promotes continuous improvement in environmental management practices.

Changes in the law and customer preference are forcing companies to act in more environmentally benign ways and to address sustainability in product design. The EU and the British Government have introduced EPR legislation designed to protect ecosystems, human health and long-term economic prosperity. BS 8887 has been planned, at least in part, to support design and manufacturing companies in complying with EPR legislation. Until now, the influence of this standard has not been researched.

2.5 Research Questions

This study seeks to answer the following research questions:

- What types of organizations are buying BS 8887-1?
- Are there examples of BS 8887-1 being used commercially?
- Can BS 8887-1 contribute to profit?
- What are the implications of BS 8887-1 regarding product disposal?
- How and why has BS 8887-1 been integrated into the design process?

Before attempting to answer these, it is necessary to chose appropriate research methods. In the next chapter, methods which could be used for this research are evaluated and the most appropriate selected.

2.6 Originality

Novel aspects of this research include:

- The first investigation into the distribution of BS 8887-1
- The first investigation into the use of BS 8887-1

- The first investigation into a national standard where the study has combined a quantitative SIC analysis of all known customers and an extensive qualitative field investigation with the same user group
- The development of new design process and product management models

CHAPTER 3 Methods Review

Prior to the commencement of the research phase of this project, a review of established methods was undertaken. The purpose of the review was to find and select the most suitable research methods that would yield the richest, most valuable and representative information possible given the subject of the investigation. This chapter explores the various research methods considered for use in support of the study. Concepts described are based on published sources, and the most relevant and practical methods for investigating the use of BS 8887-1 are identified.

3.1 Qualitative and Quantitative Research

Conventional scientific investigation uses quantitative methods to measure objective properties. Qualitative research is usually more exploratory and reflexive, relying upon subjective properties and drawing on the traditions of the social sciences. It is often argued that qualitative research opposes the positivism of quantitative research. Quantitative research is concerned with counting. Statistical analysis tells us how many, what percentage, and how valid the sample is in representing the whole. Whereas qualitative research allows flexibility and the option to adjust the research methods reactively rather than just following a rigid step-by-step predetermined sequence [Holliday, 2002 pp. 2-8]. These two approaches are described by Brett Davies (2007 p. 26) as follows:

> "**Quantitative** research requires imagination, patience and discipline at the planning and design stages; data collection may present technical problems and requires tenacity but is often straightforward; the tasks of data analysis and write-up are largely, although not entirely, determined by the way the project was set up."
>
> **"Qualitative** research requires careful thought at the outset; it demands mental

agility, flexibility and alertness during data collection; it calls for advanced skills in data management and text-driven creativity during the analysis and write-up."

For comparison, the Pocket Oxford Dictionary provides the following concise definitions:

"**Quantitative:** Concerned with, measured or measurable by, quantity."

"**Qualitative:** Concerned with or depending on quality."

Research design should be governed by fitness for purpose i.e. the purpose of the research should determine the methodology and research design. For this investigation the *Research Questions* listed in *Section 2.5* determined the selection of methods. This study uses both quantitative and qualitative techniques. The initial study into which industry sectors might be using BS 8887-1 required a quantitative method to enable an accurate assessment of the numbers of different types of organizations in the data-set. Whereas the study into how BS 8887 has been used in industry required a qualitative approach to explore the motivations and methods of users of the standard.

At the time when this investigation began, it was unknown whether or not BS 8887-1 had been used. As the standard covers a broad remit of industrial design and manufacturing issues, there are potentially many reasons why an organization might be interested in it. The exploratory qualitative research enabled a rich picture to emerge of the varied reasons why organizations use the standard.

3.2 Research Purpose

Prior to engaging in a research project it is necessary to determine the objectives of the work. Six purposes for research, suggested by Denscombe (2002 pp. 26-28), are summarized below in *Sections 3.2.1 - 3.2.6* and each is discussed in relation to this thesis.

3.2.1 Forecasting an Outcome

Scientific enquiry often uses the positivistic approach of forecasting an outcome. Predictions are made on the basis of existing knowledge and theories, with the purpose of arriving at useful conclusions. This was the underlying premise behind the study presented in *CHAPTER 4: Distribution of BS 8887*. It was hypothesized that product-related environmental legislation would stimulate orders for BS 8887-1 from the industry sectors most directly affected. This idea was subsequently tested through a numerical investigation.

3.2.2 Explaining Causes or Consequences

This is concerned with developing an understanding of why things happen as they do. The research presented here explains the causes or reasons that have led organizations to acquire BS 8887-1. Some of the consequences of developing product designs and businesses models that include concepts forwarded by the standard were also investigated.

3.2.3 Criticism or Evaluation

Most research projects have an element of criticism or evaluation. For some it will be the focus or *raison d'être*. The value of one thing or explanation will often be compared with another. *CHAPTER 7* discusses and evaluates the content of BS 8887-1 and contrasts it with the views and opinions of those that have used the standard or considered it for use. Some negative comments regarding BS 8887-1 and product reprocessing are dealt with in *Section 7.4: Criticisms of BS 8887 and Closed-loop Production*. The purpose of seeking criticism of the standard was to determine where there may be opportunities for future development and improvement.

3.2.4 Exploration and Description

The main purpose of a research investigation can be to discover new information by reporting on situations and events as they are, rather than how they will be or should be. Situations are evaluated without deliberately changing them.

The majority of this research is concerned with exploration and description. Both the quantitative and qualitative aspects of this thesis describe what has happened with BS 8887-1 since its publication. The influences that led people to the standard have been investigated. Asking design practitioners in companies about these has helped to explain why uptake in certain sectors has been relatively strong. A relationship therefore exists between the qualitative and quantitative elements, with the qualitative field research helping to explain the findings of the earlier quantitative desk based research.

3.2.5 Developing Best Practice

The development of best practice is a form of applied research that is particularly appropriate to finding good solutions to procedural problems. It is especially relevant to businesses and other types of organizations. Action research can be part of this approach when there is a requirement to improve a working environment, or the processes used within it. The need will then drive the research agenda.

Action research would not fulfil the purpose of this investigation as the objective was to describe the situation as it is, rather than to change it. Good practice in engineering and design is one of the major themes of this thesis.

3.2.6 Empowerment

Social research investigators conventionally refer to people as subjects. The empowerment approach is more collaborative with the intention of helping those involved and not just the researcher. Therefore the researcher no longer maintains neutrality and objectivity.

It is likely that as a result of being involved with this research project subjects, or participants as they are referred to here, will have read and considered the standard in greater depth than they otherwise would have done. Some participants stated that they would increase their use of it as a result. Whilst this was not the purpose of contacting them, it is an additional and positive outcome.

3.2.7 Research Purpose Summary

The main purpose of the initial SIC Study was to investigate the theory that uptake of BS 8887-1 will be highest in industry sectors targeted by EPR legislation.

For the qualitative research, the purpose was to explore and describe how and why BS 8887-1 has been used in industry and academia, to explain what causes have led organizations to acquire the standard, as well as to criticise and evaluate it based on comment from users.

The dissemination of information from these studies through conference and journal papers has stimulated interest in BS 8887. This is known from feedback received, particularly in relation to papers from this research published in *The Journal of the Institution of Engineering Designers.*

3.3 Research Methods

A research *method* is a technique for data collection or information gathering e.g. interviews and questionnaires, whereas *methodology* has a more philosophical meaning [Blaxter *et al.*, 1996 p. 59] originally from the Greek term *methodos* meaning the road towards knowledge. “Methodology is concerned with the logic of scientific enquiry; in particular with investigating the potentialities and limitations of particular techniques or procedures” [Grix, 2004 pp. 30-32].

3.3.1 Macro-Methods

The numerous research methods can be divided into broad categories of surveys, experiments, and case studies [Yin, 1989 p. 13].

3.3.1.1 Surveys

Surveying is a "method of collecting information by asking a set of pre-formulated questions in a predetermined sequence in a structured questionnaire to a sample of individuals, drawn so as to be representative of a defined population" [Hutton, 1990 p. 8]. Survey research does not necessarily have to be based on questionnaires. In-depth interviews, observation and content analysis can also be used. Surveys seek existing variation rather than creating it with interventions [de Vaus, 2002 p. 172].

Surveys can be quantitative or qualitative. Quantitative surveys are concerned with numerical data and the relationship between variables, whereas qualitative surveys ask open-ended questions requiring explanations from the respondent [Punch, 2003 pp. 1-2]. The use of a qualitative semi-structured interview survey technique was a more appropriate choice than a quantitative survey as the purpose was to explore in detail how and why BS 8887-1 had been used. The objectives were concerned with both description and explanation. Descriptive research aims to determine what is happening whereas explanatory surveys attempt to account for the phenomena they describe [de Vaus, 2002 p. 173]. This investigation features elements of both, in that evidence from the research describes a number of ways in which the standard has been used whilst also exploring the underlying reasons.

The participants interviewed for this survey share in common the fact that they were all known to have accessed BS 8887-1. The sample size was the maximum possible whilst limiting the research to UK organizations that had not objected to being contacted in connection with this work. Given that the standard has only been published since 2006, and that only a few hundred copies of it have been distributed, a random sampling method was not considered appropriate. Instead, the sample comprised a representative from every suitable organization where an appropriate person was willing to participate. This method raised the probability of finding interesting examples of the standard's use and generated a wealth of qualitative information.

3.3.1.2 Experiments

Experiments generally require a control against which to compare a test sample. The underlying concept is that observable differences between the control and the test subject can be attributed to the difference in treatment. "Independent variables are those that are systematically altered by the experimenter. Those items that are affected by the experimental treatment are the dependent variables" [Sommer and Sommer, 1991 p. 94].

Experiments in the application of BS 8887-1 and its influence on design have not featured in this research as the purpose was to examine the standard's actual use in industry, rather than to artificially create an experimental situation. This was a real world investigation.

3.3.1.3 Case Studies

The strength of the case study is its tight focus on a specific instance or situation enabling the identification of 'interactive processes' [Bell, 1999 pp. 10-11]. "In general, case studies are the preferred strategy when 'how' or 'why' questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context" [Yin, 2003 p. 1].

One of the characteristics of case study research is the use of multiple sources of information concerned with a single person, group, phenomenon or event. These sources of evidence can include, but are not limited to, documents, archival records, interviews, direct observation, participant observation and physical artefacts [Yin, 2003 p. 83]. The use of multiple sources of information, concerned with the subject of the research, enables the researcher to triangulate their findings.

The term *triangulate*, originally used to describe a method of finding one's position on a map, has been adopted into the vocabulary of social science researchers. Multiple different types of information relating to the same situation can be combined to create a more accurate picture. This is normally thought to increase the validity of the research by combining multiple perceptions of the same phenomenon [Stake, 1994 p. 241].

Building a more complete description of a particular phenomena in this way can be very helpful in interpreting information rather than just merely stating what happened or what was said [Holliday, 2002 p. 79]. Triangulation, in the social science meaning of the term, has been achieved in this work through the use of information from multiple participants and literature discussed in relation to the requirements of standards and legislation.

During the field research, case studies in the application of BS 8887-1 were developed. While these were largely investigated through interviews, there were instances where additional documentary evidence was helpful, see *Section 3.3.2.5: Documents.*

3.3.2 Micro-Methods

There are numerous methods and variations on methods tailored to the needs of specific types of research. Rather than attempting an exhaustive review, this section is limited to a discussion of the micro-methods used, or considered for use, in support of this research.

NB: Experiments can be considered as both macro-methods and micro-methods. They are discussed in *Section 3.3.1.2: Experiments.* Experimental methods would not have been appropriate for investigating the reality of the situation with regard to the use of a standard in industry. Therefore no further discussion of them is made.

3.3.2.1 Literature Review

A research contribution is normally set in the context of others' work in the relevant field [Grix, 2004 p. 39]. Conducting a literature review requires the investigation and the consideration of previous work in the same, or closely related, areas. The major part of this activity takes place early in the research process. It is also necessary to update the review as the research progresses [Brett Davies, 2007 pp. 38-39].

The literature review for this thesis was initially written as a set of notes that were later developed into a coherent piece of writing and published as a journal paper. The transition between being a set of notes and an organised review was assisted by use of use of the NVivo software. This software was primarily used for managing the interview transcripts; see *Section 3.5: Qualitative Research and Analysis Method*. The version presented here in *CHAPTER 2: Literature Review* is based on the published paper but has now been further updated.

The purpose of the review "is to locate the present study in relation to the relevant literature and to show how it contributes to that literature. It normally constitutes a separate chapter ... and also provides themes for the consideration and interpretation of the survey's findings" [Punch, 2003 pp. 75–76]. It identifies an opportunity to fill a gap in knowledge thereby justifying the contribution made by the research undertaken [Grix, 2004 p. 39]. The literature review material presented here places this study in the context of current environmental challenges, the associated legislative situation and others' work in the field. It also tells the story of the development of BS 8887 and highlights the lack of previous research into its use in practice.

The process of writing a literature review can be helpful in focussing a study. However, in qualitative research it may introduce bias into the researcher's thinking and reduce openness to emergent ideas [Patton, 1990 p. 163]. An additional danger is that the researcher will influence participants in light of knowledge and ideas gained from published works. Care was therefore taken to avoid leading participants during interview.

3.3.2.2 Grounded Theory

With this type of research, a theory is developed from evidence. Thus the theory is grounded in the data. The purpose is to develop theories rather than to test them. This is different from positivistic research where a hypothesis is proposed and evidence subsequently gathered which either supports or counters the hypothesis. Grounded research requires the researcher to approach a situation without preconceived ideas [Grix, 2004 p. 111].

Whilst the qualitative elements of this research are exploratory, the themes were decided in advance. Grounded theory would be more appropriate in an ethnographic study *Section 3.3.2.4: Ethnography*. As this research was based on semi-structured interviews, the questions were largely predetermined.

3.3.2.3 Observation

The techniques for observation research are either participatory or non-participatory. In participatory observation the researcher interacts with the subjects whereas in non-participatory research he takes a passive role. These techniques are commonly used in qualitative, ethnographic and anthropological studies. Gaining access to the relevant suitable subjects can be challenging. In non-participatory observation research, the researcher must be careful not to influence the actions of those that he observes. Notes taken by the researcher whilst observing a scene or reviewing a video recording of it provide the information for later analysis [Grix, 2004 pp. 129-130].

Observation techniques were considered unsuitable for this work as they may not necessarily explain the motive or purpose of a designer's actions or his methodological approach. Practical difficulties in having access to working designers for extended periods were anticipated. Therefore observation techniques were considered inappropriate.

3.3.2.4 Ethnography

"Ethnographic research is a form of participant observation in which the emphasis is on the recording of details about the object of study in its cultural setting" [Brett Davis, 2007 p. 30]. It is one of the core methods in social anthropology [Brett Davis, 2007 p. 168]. Ethnography is sometimes referred to as 'going native'.

The ethnographic approach commonly requires the researcher to spend extended periods of time with the community he is researching. During these periods he will endeavour to integrate himself into the community as an active member. This method may reasonably be criticised as the researcher is likely to influence the behaviour of those he is studying. He may also develop a personal involvement that could cloud his judgement so that it becomes difficult to maintain a dispassionate and objective stance on a situation.

An ethnographer can combine additional techniques including naturalistic and participant observation, document analysis and interviewing to acquire insight into the context of the situation being researched [Shaughnessy *et al.*, 2000 p. 100].

If an ethnographic method of investigation had been used, the information collected may have been deeper but would be limited to fewer organizations. The research questions might have needed to be adjusted from their focus on a single British Standard. Most of the direct research for the case studies here was conducted within single visits lasting a maximum of a couple of hours. Given the purpose of the investigation, ethnography was unsuitable.

3.3.2.5 Documents

Case studies can be based on the results of practical research or on documentary evidence. Documents can include letters, memoranda, communiqués, agendas, announcements, reports, proposals, studies and articles appearing in newspapers and magazines. The use of these has several advantages as they can be reviewed repeatedly, are not necessarily created for the case study and so are not influenced by it and can cover long periods [Yin, 2003 pp. 85-86]. However, gaining access to the required information, especially if it is of a particularly sensitive nature, can be a challenge with document based research.

Some of the e-mail communications with participants, or potential participants, were useful because they provided additional insight into why BS 8887-1 has been used or why it has been rejected for use. It was also a frequent occurrence to be given a variety of documents, mainly sales literature, by participants at the companies visited. These documents provided additional context and background to the case studies. All electronic documentation relating to the study was imported into NVivo and processed in the same way as the transcripts.

For *Section 8.2.2: MADE with Advanced Product Quality Planning* additional documentation was requested after the initial interview. Permission was granted to publish a portion of this in an anonymous form, see *Figure 8.1: Phase-3 Part of a Company's Design Freeze APQP Flowchart*. Unfortunately, this was not possible for *Section 8.2.4: MADE with House of Quality*.

3.3.2.6 Workshops and Focus Groups

With these techniques the researcher becomes a facilitator rather than an interviewer [Punch, 2000 p. 177]. An interviewer would ask questions directly whereas a facilitator's job is to guide a discussion or an activity of a selected group of people to focus on a specific topic [Grix, 2004 p. 128]. Group interviews can have the benefit that participants develop the discussion among themselves thus exploring the topic more deeply and in unexpected directions. "Although group interviews may sometimes be appropriate, there is a real danger that you will obtain less information and achieve less rapport when more than one person is included in the same interview" [Hickman and Longman, 1994 p. 56]. Managed well, group discussions and focus groups can be very time-efficient for the researcher as contributions from multiple individuals can be gathered in a relatively short time period. Another advantage of workshops or focus groups is that the participants will have been selected for their knowledge of or experience in the research topic and can form a panel of experts on the subject [Blumer, 1969 cited in Patton, 1990 pp. 75-76].

Focus groups were not appropriate for this research because of the geographic distances between the relevant organizations; see *Figure 4.4: Geographical Distribution in the British Isles*. To make up a suitable group, people that work in these organizations and use BS 8887-1 would be required. This geographic problem could arguably be overcome by the creation of an online forum. However face-to-face interviewing was considered most likely to achieve the required depth and focus.

There were several instances during meetings with industry practitioners, where two or even three people became involved and contributed to the discussion. This was invariably at the request of the principal participant who would call upon colleagues who he thought would be able to add further useful comments.

Workshops may be a suitable way of assessing the effectiveness of an intervention intended to improve the design process in some way. This method may be relevant to testing ideas outlined in *Section 9.5: Further Research*.

3.3.2.7 Quantitative Questionnaires

Questionnaires can be conducted face-to-face, over the telephone, through the post or e-mail or with purpose-made software accessible online. Benefits of quantitative questionnaires include reliability and repeatability. Responses to questions put to a community should be similar irrespective of who is asking them. Another advantage of this type of survey is that the method is suitable for asking the opinions of many people relatively quickly. For data collection, closed questions that generate a ‘Yes or No’, ‘On a scale of 1-5’ or ‘in which category A B or C ...’ type of response are likely to be an ideal format. Results can be processed statistically and represented graphically. However a disadvantage to this method is that “respondents must fit their experiences and feelings into the researcher’s categories.” [Hughes, 2002 p. 211].

3.3.2.8 Qualitative Questionnaires

A questionnaire can ask open-ended questions requiring descriptive answers. Responses can be spoken and noted by the researcher, recorded for later transcription or written by the participant. However, “the use of questionnaires is often best limited to eliciting detailed information that does not require explanation. Information that needs further explanation is better gathered during an interview, where there is the immediate opportunity to clarify it” [Hickman and Longman, 1994 p. 150].

For this research a questionnaire could have been used but would have lacked the benefit of flexibility to explore participant’s responses more deeply, therefore prescriptive questionnaires were not used. Also, it is unlikely that many working design professionals would be willing to find time to complete answers to a series of qualitative questions in a detailed text-based manner. It is much easier and faster for them if they can explain their experiences and ideas verbally.

3.3.2.9 Structured Interviews

Using this method, a set of questions is written and ordered in advance of the interview process. This approach has the advantage that the questions are delivered consistently and the wording can be carefully considered beforehand. Every participant will be asked the same set of questions in the same order, thus their responses can be directly compared. Nothing will be forgotten, so important topics will not be missed. But there is little flexibility to adapt to individual circumstances [Hughes, 2002 p. 211]. As with the semi-structured interview method used, participant responses can be captured with recording equipment or note taking for later processing and analysis.

3.3.2.10 Semi-structured Interviews

This was the selected method of investigation. Themes for discussions were prepared in advance, ensuring that the interviews were reasonably consistent and covered the relevant topics while allowing flexibility to explore issues more deeply. Additionally, questions could be re-phrased or clarified as required and, as interesting ideas were expressed by the participant further detail and elaboration could be sought. Participants were also able to influence the agenda and raise issues during discussion.

3.4 Data Analysis

3.4.1 Quantitative Data Analysis (Standard Industrial Classification Study)

The SIC system is used to classify businesses and other organizations according to their activities [ONS, 2008]. This makes it possible to analyse and display industry or sector specific data in a standardised format. For instance, economists can use SIC to investigate the contribution made to the wealth of a nation by each of its industries. SIC analysis has been used in this thesis to investigate the types of organizations that have bought BS 8887-1. SIC has made it possible to see where uptake of the standard has been high or low.

For the interpretation of the numerical data arising from the SIC study, a graphical approach was adopted. A combination of graphs, pie-charts, multi-level pie-charts, histograms and other graphics was used. Together these illustrate some of the quantifiable group characteristics of the organizations interested in BS 8887-1 during the first few years following its publication.

3.4.2 Qualitative Information Analysis (Pilot and Main Study)

During the extensive industry survey of companies and other organizations that bought BS 8887-1, a substantial body of information was created i.e. typed transcripts of meetings, notes on meetings and other correspondence. Managing and analysing this was assisted by the use of Qualitative Solutions and Research (QSR) NVivo software. This computer program was chosen because Brunel University supported it, provided training in its use and sold licences at a discounted rate. In addition to having the University's support, the software was also recommended in a review including other alternatives [McAloone, 2000 p. 46]. In this earlier review it was referred to under its former name Non-Numerical Unstructured Data Indexing Searching and Theorising (NUD.IST). The NVivo software is designed to assist in managing and querying information, and authoring reports using imported content.

3.5 Qualitative Research and Analysis Method

Having chosen a qualitative semi-structured interview based research method to investigate the use of BS 8887-1, organizations using it were contacted and invited to participate. With their customers' consent, BSI provided the contact details. The occupations of respondents included: design; quality management; engineering; production; drafting; management and teaching. The common link was that they all had design related jobs and had ordered, electronically downloaded or otherwise had access to BS 8887-1.

Initially the BSI committee manager responsible for the BS 8887 series e-mailed customers that had the standard, to request permission to allow a third party to contact them for research purposes. In total permission was given to contact 83 organizations. A decision to limit the research to the UK excluded three of these as they were overseas companies; a standard letter was then sent to relevant people at each organization; see *Appendix 1: Invitation to Participate*.

The pilot study interviews took place from March to August 2009. The main study ran from November 2009 to June 2010. Where possible the interviews comprised face-to-face meetings. Generally these yielded more in-depth information than telephone discussions. In many instances, the order for BS 8887-1 had originated from the person interviewed. A series of open-ended questions was written for use as prompts. For the main study, the number of questions was reduced following experience gained during pilot study.

Before each meeting commenced, permission was requested to allow the use of a digital voice recorder. Where recording was prohibited, extensive hand-written notes were taken instead.

Edited transcripts meetings were subsequently typed and forwarded to those concerned, to make sure that they were accurate. In several instances, commercially sensitive content was removed at this stage. The information collection and analysis method is illustrated in *Figure 3.1: Qualitative Research Process*. Example edited transcripts are given in *Appendix 4 and 5.*

Use of the NVivo qualitative data analysis software simplified searching multiple documents for information relating to each topic. It was also helpful in clustering related information from each of the participants.

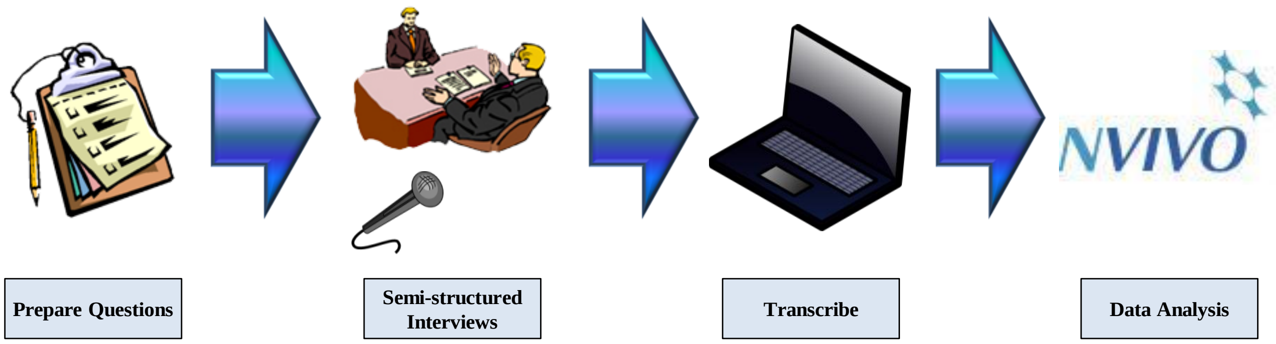

Figure 3.1: Qualitative Research Process

The information generated from the research was coded at appropriately named nodes. A sentence or paragraph that was relevant to more than one subject would be coded at multiple nodes. This concept is illustrated in *Figure 3.2: Coding Qualitative Information at Nodes*. Information, once arranged thematically can be used to support the argument of a study [Holliday, 2002 p. 98].

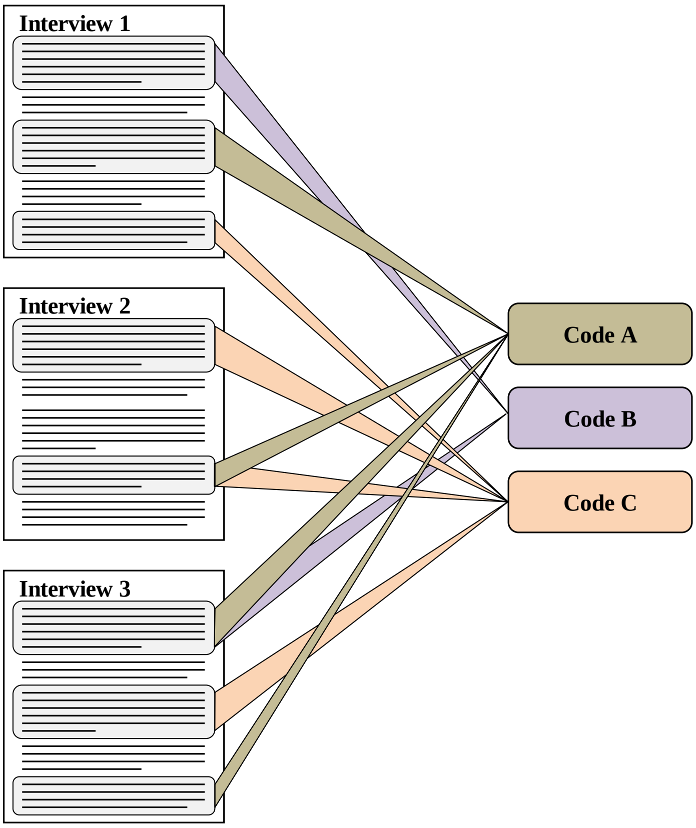

Figure 3.2: Coding Qualitative Information at Nodes

Having completed the coding task, by opening a node it was possible to view everything that had been said about each subject. This broke the continuity of the transcripts but produced a thematic arrangement of information that enabled the efficient comparison of related statements from multiple sources. A danger of arranging text from verbatim transcripts thematically is that statements can be taken out of context, preceding or subsequent sentences that might present a fuller picture could be edited out in order to support or counter an argument. In this thesis, care has been taken to not to change the meaning or emphasis of statements through the editing process.

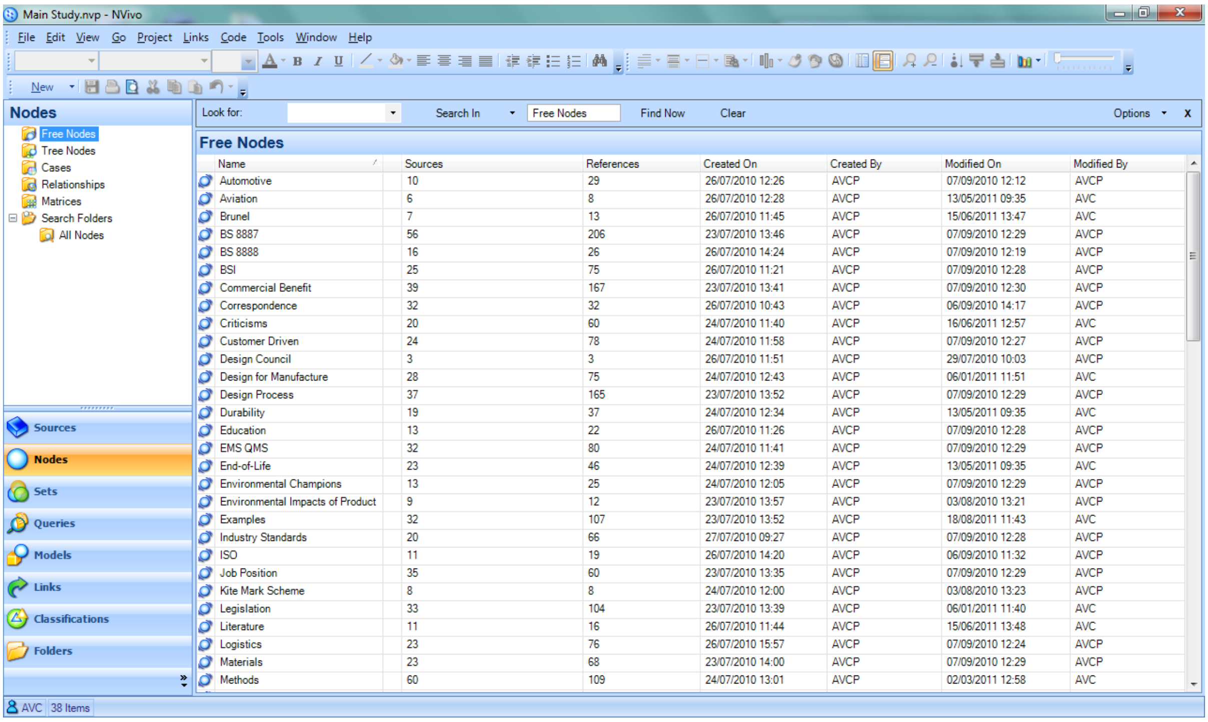

Figure 3.3: NVivo Screenshot of Project Nodes

Figure 3.3: NVivo Screenshot of Project Nodes illustrates the breadth of the topics covered. Once a quotation or idea from the interviews had appeared in published work, it was coded at the node ‘Used’ and un-coded at all other nodes, thus preventing it from being included in future papers. To ensure rigour, some of the statements made and opinions expressed have been cross-referenced with published sources.

3.5.1 Limitations

Despite the benefits of the semi-structured interview method and its appropriateness for the research topic, there were some disadvantages. The most labour-intensive part of the process was transcribing hours of audio recording. Most of this transcribed text has not been used; therefore the technique is arguably inefficient.

Academic criticisms of the method include the potential for the interviewer to lead or influence the participant to answer in a particular way resulting in biased responses. Care was taken to avoid this. There is also the difficulty of comparing comments made during different interviews where the context of the discussion may not have been the same. Other disadvantages of semi-structured interviews include excessive reliance on the quality of the participants’ responses, knowledge and experience. This was minimised through good research design, particularly the selection of appropriate personnel for interview and the use of authoritative published sources to check facts.

3.6 Research Ethics

Prior to the commencement of the investigation, it was a necessary regulatory requirement to obtain approval from Brunel University’s School of Engineering and Design Ethics Committee. In January 2009 it was confirmed that the project could proceed without any revisions to the proposed research method.

3.6.1 The Principle of Informed Consent

Individuals being interviewed for the industrial survey were given a *Participant Information Sheet* and were asked to sign an *Informed Consent Form*. Examples of these documents are given in *Appendix 2*: and *Appendix 3*: respectively. The participant's right to withdraw from the study at any time was made clear. Institutional affiliations were indicated by the use of the Brunel University and BSI logos on the paperwork.

3.6.2 Participant Anonymity

It was anticipated that if participants knew they could talk candidly about their views and experiences with neither themselves nor their organizations being named, this would be an advantage for the research, as well as being an ethical obligation. When participants were asked about this, without exception they preferred to remain anonymous. It was also stressed by BSI, and a condition of having sight of their BS 8887-1 distribution data, that the names of their customers must not be identified in research publications. Additionally, the participants were not necessarily authorised spokespersons for their employers.

CHAPTER 4 Distribution of BS 8887-1

4.1 Rationale

To evaluate the justification for the continuing development of the BS 8887 series it is important to examine market acceptance of Part 1. This is necessary to develop an understanding of the demand for the standard, types of organizations that may be using it and factors that may have influenced them.

4.2 Hypotheses

Prior to commencement of this research, hypotheses were proposed for investigation. These have been summarised below:

- The recent introduction of product-related environmental legislation may have stimulated sales of BS 8887-1.
- As BSI is the UK's National Standards Body (NSB), the distribution of BS 8887-1 may be strongest in its home country.
- Age and size may not be a major factor in determining the types of companies that access BS 8887-1 as they will all be influenced by current legislation and market demand.
- Design and manufacturing companies that have an accredited ISO EMS may be more likely to use BS 8887-1 as they have shown commitment to both standards compliance and the environment.

This investigation into these hypotheses is part of the novelty and contribution of this thesis.

Recent legislation planned to reduce the impact of electronic products includes EuP, WEEE and RoHS, all of which are referenced in BS 8887-1. EPR legislation is now forcing producers to take legal and financial responsibility for reprocessing the products they make

[Abu Bakar and Rahimifard, 2007 p. 1369].

Corporate environmental concern usually starts with regulatory compliance [Gehin *et al*., 2008 p. 569]. The WEEE directive promotes reuse and recycling of waste consumer products with high targets of 75–85% [Howarth, 2004 p. 12]. BS 8887-1 specifies the design requirements necessary to facilitate efficient reprocessing of post-consumer goods. It is possible that the WEEE directive may have prompted some electronics producers to purchase or access the standard. If this is the case, then its influence may be apparent in the sales and online download data.

4.3 Method

BSI has supported this study by providing data on BS 8887-1 which contained sales figures for the standard from its publication at the end of October 2006 until July 2008. It showed that 117 copies had been distributed. Of these, 114 had been sold and three provided free of charge. BSI also used 14 copies internally; these have been removed from further analyses.

Upon receiving the data, the first study made was the distribution of sales over time. The orders were grouped according to the months in which they were sold. The number of sales occurring in each month was calculated and the results were plotted as a graph, as shown in *Figure 4.1: Sales Graph*.

The second data-set from BSI showed sales until March 2009. This listed a further four new entries; however, they were undated and so are not represented in *Figure 4.1*. A third list with contact details for organizations that had agreed to participate in the next phase of this research showed two more orders for purchase of the standard. New entries from these subsequent lists were included in the SIC code analysis. The time intervals and numbers of fresh orders suggest a continuation of the sales trend.

In addition to selling standards in hard copy, BSI offers a download service called British Standards Online (BSOL). When this study commenced, data relating to BS 8887-1 downloads was unavailable. The BSOL system has since been improved so that download data is now logged for all BSI publications. Data relating to BS 8887-1 downloads from BSOL between August 2008 and August 2009 has been included here, and merged with the information on hard copy sales. The lists were combined and repeat orders and downloads were eliminated leaving 192 unique entries. This data was processed as a spreadsheet.

4.3.1 Adding to the data-set

Having established a list of BS 8887-1 customer organizations, additional information about each of them was incorporated from a variety of sources so that patterns might be more easily identifiable. Sources of data included individual company websites, the Companies House website and the FAME financial analysis database.

4.3.2 Standard Industrial Classification

The SIC code is a hierarchical system used to categorise the activities of organizations. It classifies by Section, Division, Group, Class and Subclass. Section is represented by a capital letter and Division by the first two digits of the code. An optional point mark separates these from digits representing Group and Class respectively. The Subclass code may be appended, but has not been used in this study.

4.3.3 Mapping BS 8887-1 Distribution

For some entries, the BSI data included the address to which the standard had been sent. Where this was unavailable, the customer's head office address was added. These locations were plotted on the map shown in *Figure 4.4: Geographical Distribution in the British Isles.*

4.3.4 Company Age

The ages of companies that accessed BS 8887-1 were calculated from their year of incorporation. The results were plotted in *Figure 4.5: Age Distribution Graph*.

4.3.5 Company Size

EU standard terms were used to identify the size of organizations based on employee numbers. A small enterprise is defined "as one with fewer than 50 employees (with micro-enterprises having fewer than 10 employees). A medium enterprise is defined as one with 50 or more employees, but fewer than 250, and a large enterprise as one having 250 or more employees" [ONS, 2008]. Applying these thresholds enabled results to be evaluated against UK data from the Office for National Statistics (ONS). Comparative pie-charts were used to illustrate this in *Figure 4.6.*

4.3.6 ISO 9001 and ISO 14001 Compliance

Evidence of ISO 9001 and ISO 14001 certifications was sought for each company on the BS 8887-1 customer list, by checking each company name against the UK Register of Quality Assessed Companies (QA Register) maintained by The Stationery Office (TSO). The websites belonging to each company were also individually searched for references to ISO 9001 and ISO 14001, using the Google's search in site function. The images in each site were also checked for compliance accreditation logos. Companies that merely claimed to operate in accordance with principles of ISO 9001 or ISO 14001 but which did not have certification, were recorded as negative.

The results from the QA Register and the data from the corporate websites were merged prior to calculating the percentages of ISO 9001 and ISO 14001 certified companies among the BS 8887-1 customer firms. If either the QA Register or corporate website searches produced a positive result, then the company was recorded as compliant with the relevant standard. The results of the two searches largely served to confirm each other, although there were some minor differences. By merging the results, the combined totals were slightly higher than if just one method had been employed, since sometimes one search would reveal a positive result that was missing from another.

4.3.7 Limitations

For some organizations interested in BS 8887-1, especially in the non-commercial sectors, SIC codes could not be found from published sources. In these cases, a suitable code was selected based on the activities described on their websites. Larger companies frequently had multiple SIC codes as they compete in various markets. For consistency, analysis has been limited to the primary SIC code for each.

Of the 192 unique orders and downloads included in the SIC code analysis, 123 were used to find the percentage with ISO 9001 and ISO 14001 accreditation. The same subset was used to determine the ages of companies that might be using BS 8887-1 and their sizes. The focus for these studies was UK businesses. The excluded organizations comprised: 47 from education, three of which were non-UK; 10 other non-UK organizations; seven libraries; two government-run defence-related sites; two state-funded engineering research organizations and one chamber of commerce. For the business size analysis, micro-enterprises were grouped with small firms, as the exact number of employees was often unavailable.

In gathering data to determine the percentage of ISO 9001 and ISO 14001 certified companies, a number of factors will have affected the accuracy of the final figures. It is possible that there may be a time delay between changes in the status of company compliance certification, and updates being applied to websites. Additionally, the QA Register is dependent upon current information being forwarded by accreditation bodies.

4.4 Results and Analysis

The data collected in this study is presented graphically to provide clarity, and to assist in the visualisation of emergent trends. SIC data colour coding has been kept consistent for all diagrams.

4.4.1 Sales

Immediately after the initial publication of BS 8887-1 sales were strong with a surge in orders in January 2007. New orders then settled to a steady rate of one or two per month. This pattern is shown in *Figure 4.1: Sales Graph*.

Figure 4.1: Sales Graph

The shape of the graph is typical of the sales pattern expected for a newly introduced standard. The release of new standards is publicised in BSI's 'Update Standards' and 'Business Standards' magazines. Several articles in the engineering trade journals have also been published about BS 8887-1 and the TPR triumvirate. These may have encouraged some of the initial orders for the standard. The pattern of sales does not appear to show a correlation with the timings of product-related environmental legislation coming into force.

4.4.2 Management Accreditation

Of the 123 UK commercial firms that ordered or downloaded BS 8887-1, 86% had ISO 9001 certification and 46% had ISO 14001 certification. These high levels suggest commitment to standards, quality and environmental responsibility among the companies interested in BS 8887-1.

The results may also be an indication of the relative importance of the management system standards in industry. Almost all of the ISO 14001 certified firms also had ISO 9001. Perhaps ISO 9001 is seen as essential while ISO 14001 is highly desirable.

4.4.3 SIC Analysis of BS 8887-1 Customers

4.4.3.1 General SIC Analysis

The industry sectors to which organizations that have purchased BS 8887-1 belong are represented in *Figure 4.2: SIC Section and Division of Manufacturing*. The pie-chart indicates high uptake in Section-D 'Manufacturing' with 97 orders or nearly 51%. The bar-of-pie shows that Division-31 'Manufacture of Electrical Machinery' is the largest subset of manufacturing with 19 orders. Division-32 'Manufacture of Radio, Television and Communication Equipment' has a further four firms engaged in similar activities. Therefore, at least 23 of the 192 orders, or nearly 12%, are from companies that manufacture electrical goods. This figure excludes design consultancies, some of which assist in the development of these types of products. The high uptake of BS 8887-1 by electronics companies may have been motivated by increasingly stringent legislative requirements imposed on this industry by both the EU and the UK Government.

General engineering companies were well represented with 17 from Division-29 'Manufacture of Machinery and Equipment Not Elsewhere Classified'. A further 15 firms concerned with similar business in Division-28 ‘Manufacture of Fabricated Metal Products, Except Machinery and Equipment’ brings the number of engineering production companies to at least 32 out of 192 or 17%. By considering the data in these combinations, it can be seen that there are more general engineering than electrical manufacturers ordering BS 8887-1. The standard may be of interest to these companies because of the detailed design requirements it lays out for efficient manufacture and assembly, as well as EoL value recovery processes.

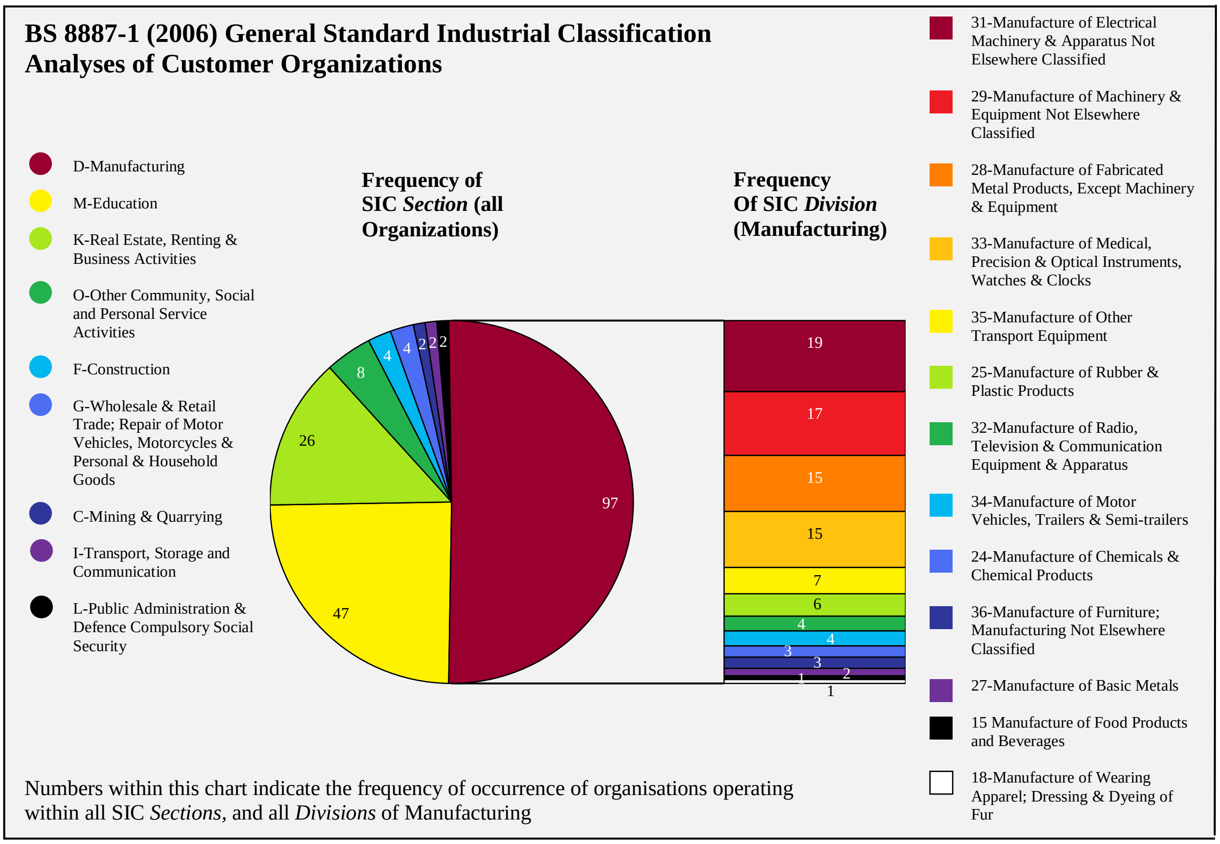

Figure 4.2: SIC Section and Division of Manufacturing

Six orders were from businesses operating in Division-25 ‘Manufacture of Rubber and Plastic Products’. The use of BS 8887-1 could help with the development of product designs that enable efficient post-consumer recovery and recycling. It has been argued that plastic should be treated as having a higher value. Perhaps as the global supply of crude oil declines, plastics will take on a monetary value that better represents their true value and recycling will become more economically worthwhile [Hornbuckle, 2008 p. 168].

The data shows only four companies from Division-34 ‘Manufacture of Motor Vehicles, Trailers and Semi-trailers’. This is disappointing given the high-potential end-of-life environmental impact of cars and trucks etc. [e.g. Jones, 2003]. The standard is particularly relevant to this sector following the introduction of the ELV regulations. Of the companies in this division, only two were manufacturers of complete vehicles and only one of those was a high-volume producer.

It is possible that economic factors have had an impact on the automotive industry’s demand for British Standards. “Car-making is moving eastwards, to Eastern Europe and Asia, and its support industries are going too” [Hennock, 2005]. Interestingly, the high-volume car maker was from one of the rapidly developing Asian economies.

Section-M ‘Education’ is the second largest group of standards users that have accessed BS 8887-1, as seen in *Figure 4.2* with 47 institutions represented. These include schools and colleges but mainly universities, as shown in *Figure 4.3: SIC Section, Division and Group*. This is a very positive finding as: “what is really needed is an ethos in educational establishments that supports and promotes sustainability in all activities and in all courses at every level” [Rahimifard and Clegg, 2008 p. 2].

The education provided by institutions accessing, and hopefully using, BS 8887-1 may influence designers for the duration of their careers. Sustainable design knowledge will thus be taken to the companies they start, or for whom they work.

The majority of education-related entries were from BSOL. Several of the universities downloaded the standard between 5 and 12 times. Multiple downloads were reduced to single entries for this analysis, however high levels of interest were evident at certain institutions. It is likely that design and engineering lecturers have been referencing the standard during their teaching and that their students have taken the initiative to download the standard for use in their project work. Education is a particularly important sector that should be further encouraged to promote ESD and to use BS 8887-1 for teaching purposes.

The remaining smaller portions of the pie-charts are discussed in the following section along with SIC Division and Group.

4.4.3.2 Specific SIC analysis

Section-K 'Real estate, renting and business activities' is the third largest segment of the pie-chart in *Figure 4.2*. Only a few firms appearing under this classification were concerned with property as their principal activity. Of the 26 orders in this Section, 17 actually fell into Division-74 'Other Business Activities' and seven of the remaining nine were Division-73 'Research and Development' organizations.

Division-74 'Other Business Activities' subdivides into 13 entries in Group-74.8 'Miscellaneous Business Activities', and three in Group-74.2 'Architectural and Engineering Activities and related Technical Consultancy'. This additional detail is not shown in *Figure 4.2*, but is illustrated by the labelled segments of multi-level diagram shown in *Figure 4.3: SIC Section, Division and Group*.

Public libraries with a BSOL subscription afford access to standards for local small businesses and other interested parties. The data shows the standard being downloaded at seven different UK libraries. These are represented in Section-O 'Other Community, Social and Personal Service Activities'. Their full SIC code would be 92.51 'Library and Archives Activities' (SIC Class has not been shown in *Figure 4.3* to avoid over complication.

Division-33 'Manufacture of Medical, Precision and Optical Instruments, Watches and Clocks' shows 15 orders. Over half of these were companies in the medical sector. This type of business has a tradition of being highly innovative.

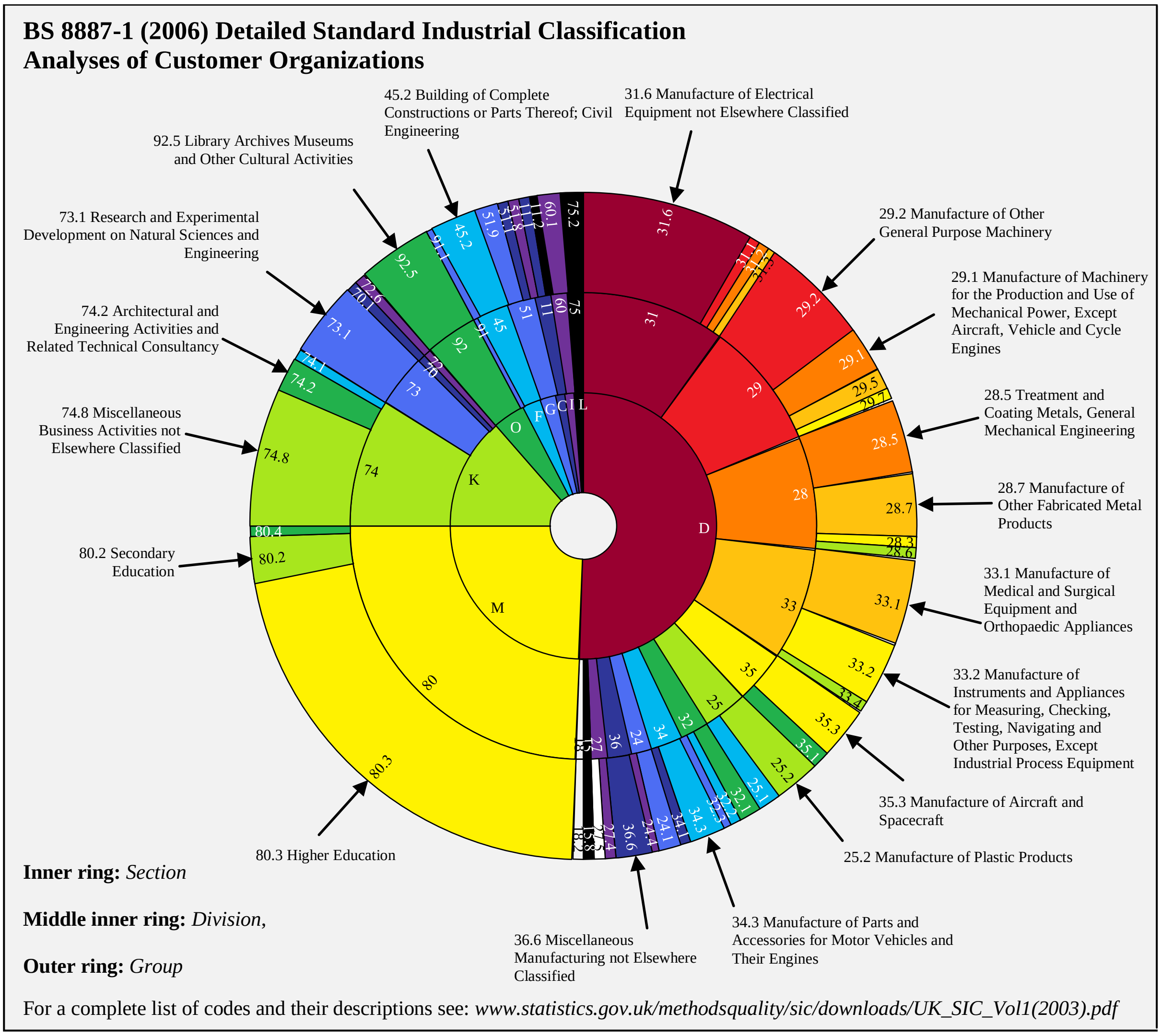

Figure 4.3: SIC Section, Division and Group

DfD and maintenance are especially important in the defence industry as non-consumable military equipment often has an exceptionally long service life. At least six of the commercial firms that ordered BS 8887-1 are involved in the development and manufacture of defence products. As an example, battle tanks have much structurally in common with heavy earth-moving equipment. They may be ideal candidates for remanufacture and design for upgradeability.

The rings of the doughnut diagram in *Figure 4.3*, from the inside to the outside, represent SIC Section, Division and Group, respectively. These are indicated by the letters on the inner ring and progressively longer codes on the outer rings. The diagram is a graphical representation of the parts of the SIC code system covering the principal activities of BS 8887-1 customers and their relative proportion of the total orders. Around the outside of the chart, SIC codes with three or more occurrences have been labelled with their descriptions. The definitions of all the codes can be found in 'UK Standard Industrial Classification of Economic Activities 2003' [ONS, 2003].

4.4.4 Geographical Distribution

The approximate locations of BS 8887-1 customers are shown on the map of the British Isles in *Figure 4.4: Geographical Distribution in the British Isles*. The colours of the markers are consistent with all of the diagrams relating to SIC code Section, and identify the type of organization at each site. The markers are clustered around the UK's major industrial centres of London, Birmingham and Manchester. The map also indicates considerable manufacturing activity along the south coast particularly between Southampton and Brighton.

Of the 192 organizations in the study, 13 are based outside the UK. Orders for BS 8887-1 have originated from: France, Hong Kong, Kuwait, Malta, Norway, Oman, Republic of Ireland, Slovenia, South Korea and the USA. To some extent the influence of this British Standard appears to be reaching an international audience. The corporate non UK orders were from manufacturers of aircraft parts, auto-electrical parts, pharmaceuticals, vehicles and industrial electrical equipment. It is possible that these companies sell their products into the UK and are therefore interested in certain British Standards.

The use of BS 8887-1 may have a global benefit as a result of international trade. By incorporating sustainable design principles into product specifications, some environmental benefits should result even in a global manufacturing context. For instance, if an item was designed in the UK but manufactured in Malaysia, the overseas producer would be expected to meet the specification. If '100% recycled or part-recycled material' was stipulated for a particular component, or that 'secondary finishing such as painting, coating or plating should not be used' [BS 8887-1, 2006 p. 36], then these specifications would have to be met, or at least negotiated.

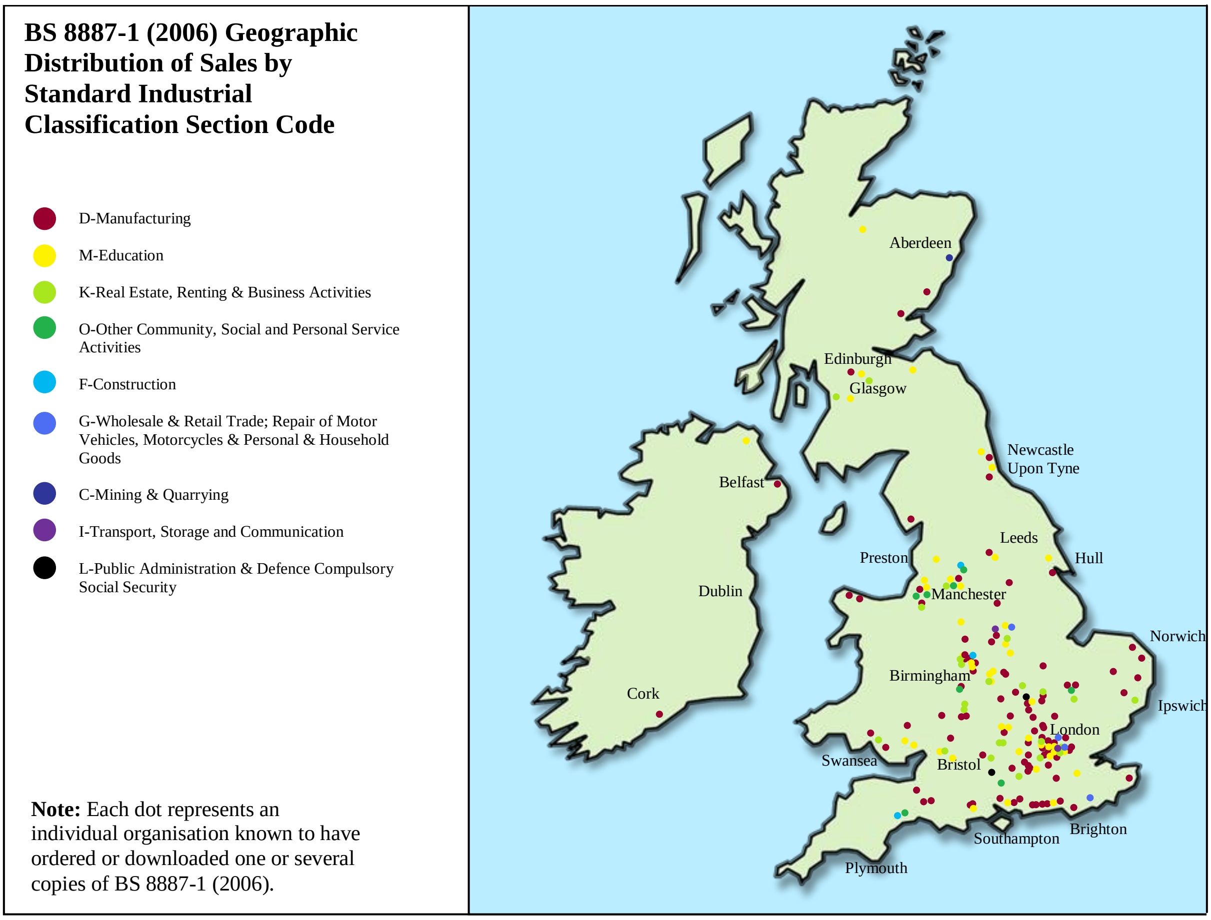

Figure 4.4: Geographical Distribution in the British Isles

4.4.5 Age of BS 8887-1 Customer Firms

The number of UK businesses in each of the given age ranges that have ordered BS 8887-1 is presented in *Figure 4.5: Age Distribution Graph*. The curve of the graph shows a kink over 11–20 years, possibly the result of the sample size and the groupings used. Significantly, the peak of the curve represents 21–50 year old companies, suggesting that BS 8887-1, and probably standards generally, are most frequently bought by well established companies. A considerable number of younger companies are also represented in the 6–10 and 11–20 year ranges.

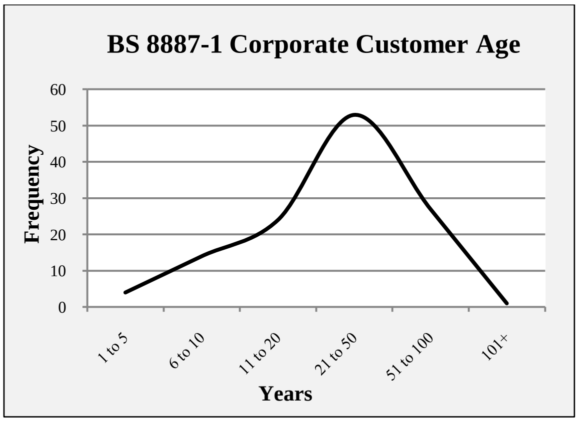

Figure 4.5: Age Distribution Graph

4.4.6 Size of BS 8887-1 Customer Firms

Most of the orders for BS 8887-1 from the commercial sector originated from medium or large firms. These comprise 45% and 42% of the total respectively, with 13% from small and micro-enterprises. The pie-chart in *Figure 4.6: (A) BS 8887-1 Customer Business Sizes* graphically represents these percentages so that they can be compared with UK national data [from ONS, 2000] shown in *Figure 4.6: (B) All UK Business Sizes*. The majority of UK businesses are either micro 83.5%, or small 13.6%. Micro-businesses are considered a subset of small businesses. This brings the total proportion of UK companies with fewer than 50 employees to 97.1%. Medium-sized businesses represent 2.2% of the UK total, while only 0.6% of firms qualify as large with 250 or more employees. When charts *(A)* and *(B)* are compared, it appears that the percentage of companies of each size in the BS 8887-1 customer base has no apparent relationship with the national data. There is no consistent percentage of businesses, in each size range buying the standard.

The percentage of turnover from UK businesses of each size is represented in *Figure 4.6: (C) All UK Business Turnover*. This shows that large companies generate 52.8% of UK turnover. Therefore, more than half of all UK commercial trade is generated by 0.6% of firms that qualify as large. The remaining national business turnover is divided fairly evenly between micro, small and medium-sized firms. When the three pie-charts are considered together, the BS 8887-1 data appears closer to the average, although small firms are arguably still under-represented. The activities of the UK businesses used for this comparison have not been accounted for.

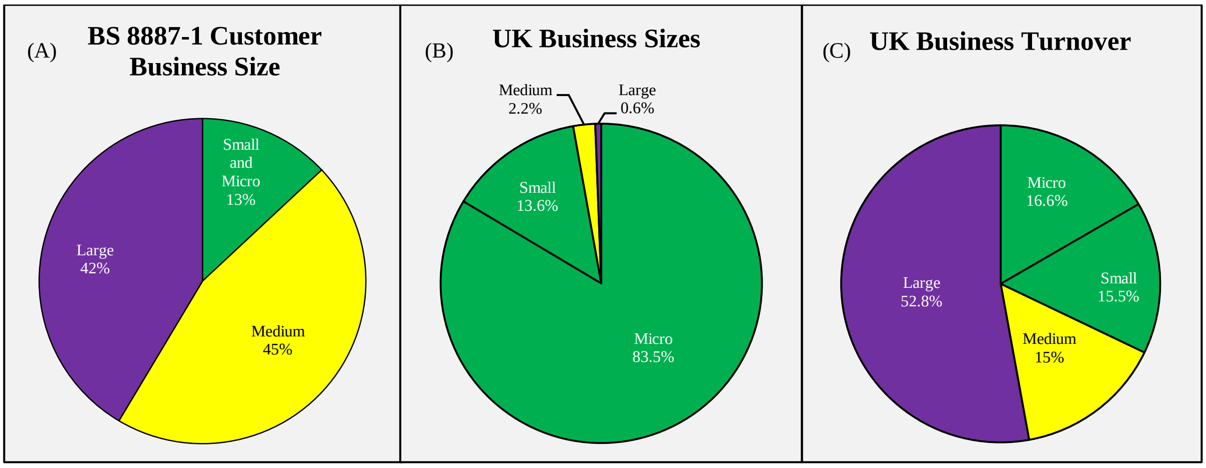

Figure 4.6: (A) BS 8887-1 Customer Business Sizes, (B) All UK Business Sizes (Data source: ONS, 2000), (C) All UK Business Turnover (Data source: ONS, 2000).

Data regarding company size, age and activity by SIC code Section has been combined in *Figure 4.7: Age, Size and Classification*. It can be seen that medium-sized companies aged 21–50 years in the manufacturing sector account for the highest frequency of orders. The chart also shows that the larger companies tend to be older. Several of the large younger companies were formed from pre-existing organizations that are now conglomerates or privatised national organizations.

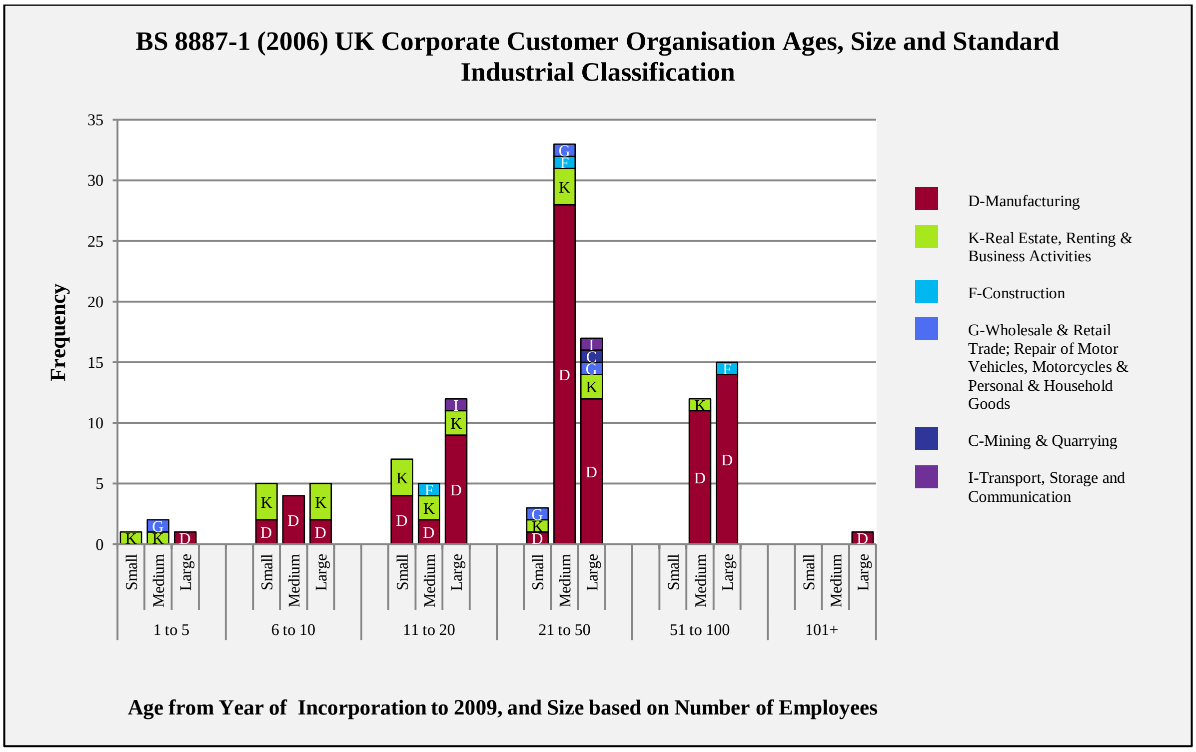

Figure 4.7: Age, Size and Classification

Conclusions from Standard Industrial Classification Study

Commercial businesses accounted for the bulk of orders, followed by educational institutions. The interest shown by education may suggest that more sustainable environmentally sensitive design will become increasingly common as new graduates enter the workplace and as our world situation demands.

Some international distribution of BS 8887-1 was evident, especially via online download. The BSI is the UK's NSB and its greatest influence is in its home country.

The BS 8887-1 commercial customer organization age distribution suggests that the standard may be of relevance to firms of all ages.

Having compared the sizes of BS 8887-1 customer firms with national averages, it appears that small and micro-enterprises may be under-represented. This is true for both the number of businesses nationally in these size categories, and the percentage of UK turnover that they represent.

Customers of BS 8887-1 show belief in the value of standards, with exceptional levels of ISO 9001 certification, and high rates of ISO 14001 certification.

Very few motor vehicle manufacturers have bought BS 8887-1, and producers of packaging are absent from the sales data. The standard is relevant to both of these industries, especially the automotive business given the complexity of assemblies, variety of materials used and the high potential for recycling, repair, reconditioning and remanufacturing.

The recent introduction of multiple pieces of environmental legislation relating to electrical and electronic product manufacture may have stimulated orders for BS 8887-1 as a high proportion of these businesses were evident in the customer data.

The SIC study identified where sales of BS 8887-1 have been strong and where they have been weak. This new knowledge could be used to underpin the decision making process in support of further marketing of BS 8887-1 and even the development of future parts of the BS 8887 series. For marketing, the value of this could be further increased if the results were compared with data regarding growth or contraction of each type of UK industry represented.

This could enable a highly targeted promotion, further assisting UK industry.

CHAPTER 5 Quantitative Analysis of Interview Results

5.1 Introduction

This investigation was made retrospectively to place the findings of the following qualitative studies in the context of the sample size and frequency with which certain similar responses to questions were given during the interview series.

5.2 Aim

The aim of this study was to provide information regarding the number of organizations that contributed to the case study evidence, specifically:

- How many people who accessed BS 8887-1 actually read it?
- How many people who read BS 8887-1 used it within their organizations?
- What was the main motive for acquiring BS 8887-1?
- What, if anything, has motivated the organizations to consider ESD and develop cleaner operations?
- What topics were of particular importance during the interviews?

5.3 Method

The interview transcripts and e-mail responses from the qualitative study were reviewed, and specific pieces of information from each organization were collected, typically from a single participant. Where multiple individuals from the same organization responded, the answers were combined.

To investigate the last research question in *Section 5.2: Aim,* a new version of the NVivo project was created. Text that had been previously included in research publications and this thesis was re-coded at the appropriate nodes, and then the ‘Used’ node, discussed in *Section 3.5: Qualitative Research and Analysis Method*, was deleted. The number of references and sources coded at each node were exported and represented graphically.

5.4 Limitations

A quantitative survey method as discussed in *Section 3.3.2.7: Quantitative Questionnaires,* may have been preferable for conducting the type of investigation presented in this chapter. As the decision to conduct a numerical analysis of the field data was made retrospectively in response to a reviewer’s suggestion, detailed explanations from participants have been interpreted, simplified and placed into categories so they can be counted. Had this part of the research been planned originally, the interviews could have been tailored towards producing quantitative results. However, the intention and purpose was to gather detailed evidence and information of greater depth than a numerically-focused questionnaire would have provided.

5.5 Results

Out of the 192 organizations that accessed BS 8887-1 included in the previous SIC study, 80 of them who had previously not objected to being contacted in relation to this research, were invited to participate. Responses, including rejections, were gathered from 60 of them. Two transcripts are included for illustrative purposes in *Appendix 4 and 5.*

5.5.1 Use of BS 8887-1

Within the sample group a subset of 24 individuals from different organizations were identified as having read BS 8887-1, and 9 of them had used it. This is represented in *Figure 5.1: Impact and Use of BS 8887-1.*

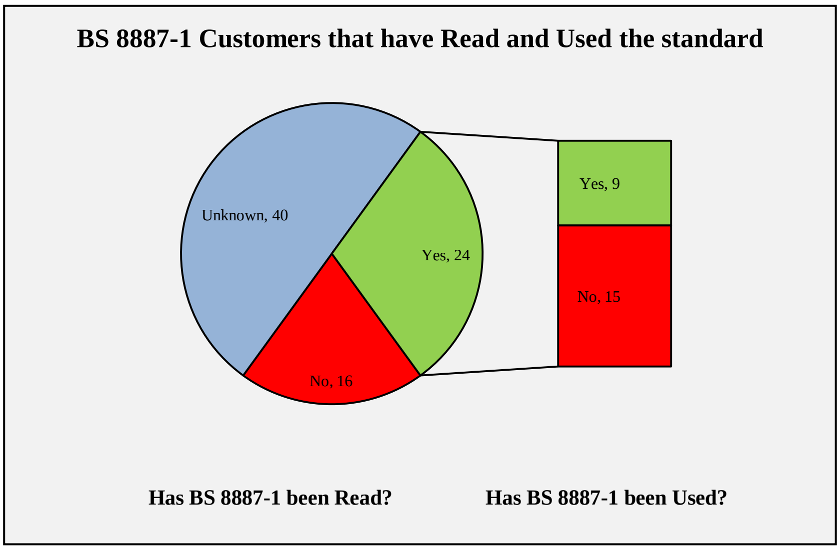

Figure 5.1: Impact and Use of BS 8887-1

The 40 organizations comprising the 'Unknown' section of the pie chart in *Figure 5.1* were mainly those that declined to be interviewed, or had no knowledge of the standard. Several of these organizations nevertheless provided useful information regarding their approaches towards ESD, DfM, compliance with EPR legislation and their use of standards in general.

The qualitative studies in the following chapters are based primarily on the organizations where BS 8887-1 had been used. They are supported with other relevant examples of DfM, DfA, DfD and DfE. The types of organizations found to have used the standard are summarized in *Table 5.1: Implementation of BS 8887-1*.

Quantity	Type of Organization	Extent of Implementation
1	Automotive electrical parts manufacturer	Referenced under APQP and used to specify techniques in the design process
1	Boiler systems manufacturer	Document and design process management
1	Construction products manufacturer	Reference source for reducing production costs through improved design, during a wide-ranging product review
1	Industrial refrigeration manufacturer	DfD, DfR and EoL product price negotiations
1	Niche car manufacturer	Used to support ISO 14001 EMS
2	Sixth Form College	Referenced in lectures, used to support ESD elements of design and engineering courses
2	University	Referenced in lectures, used to support ESD elements of design and engineering courses

Table 5.1: Implementation of BS 8887-1

Internet searches also revealed the use of BS 8887-1 within Bachelors and Masters Degree courses in engineering and design at a third university, as described in *Section 8.3: MADE in Education.*

5.5.2 Motivation to Acquire BS 8887-1

Within the group of 24 participants who had read the standard, 11 identified ESD as their primary interest in BS 8887-1 and the reason had they acquired it. For 5 of these 24 participants, the relevance of the standard mainly surrounded design for production. This included those who reviewed the standard with consideration for DfMA as well as those whose primary interest in BS 8887-1 originated from it being part of the TPR triumvirate along with BS 8888. One of the most frequently cited reasons to acquire BS 8887-1 was simply to have it available as a reference source for future projects.

5.5.3 Motivation for Environmentally Sensitive Design among BS 8887-1 Customers

The main reasons that commercial businesses consider ESD were found to be customer demand, EPR legislation and employees who champion environmental causes, as represented in *Figure 5.2: Motive for Environmentally Sensitive Design*. The pie chart includes data

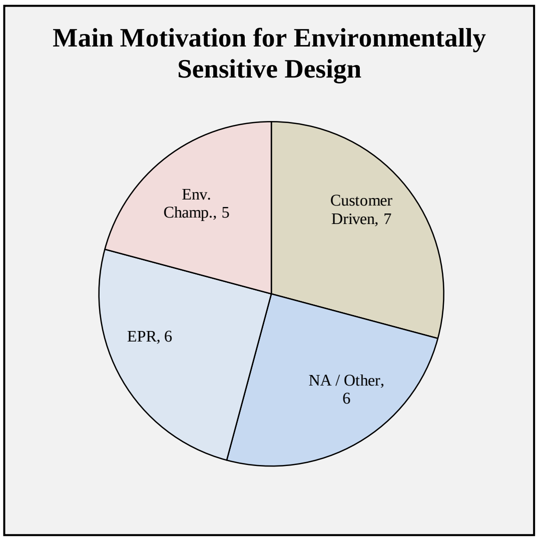

Figure 5.2: Motive for Environmentally Sensitive Design

from the four academic institutions listed in *Table 5.1*. At the two universities, ESD was primarily driven by lecturers keen to promote consideration of the environment in students' design work. These universities were included in the 'Environmental Champions' category of *Figure 5.2*.

The organizations represented in *Figure 5.2* are limited to the 24 where the participant had read BS 8887-1. From the remaining 56 organizations contacted, 8 reported EPR legislation as their primary interest in ESD and 4 cited pressure from customers as the main reason to minimise the environmental impact of their operations.

5.5.4 BS 8887-1 and ISO 14001

One of the interview themes was concerned with reducing product-related environmental impact through ESD under ISO 14001. Of the 24 main participants, nine worked in design and management related roles for companies that had ISO 14001 accreditation. Three of these participants, and one independent consultant whose work was concerned with EMS/QMS implementation, broadly agreed that there could be, a supporting relationship between the use of BS 8887-1 and ISO 14001 with the latter provider greater opportunity to promote ESD principles.

One company identified product design decisions as having the greatest influence upon the organization's environmental impact, and had planned to apply ESD for use as evidence supporting their ISO 14001 accreditation. Their EMS auditor advised that DFE was not relevant to ISO 14001 since environmental impacts attributable to design are difficult to quantify. However, two companies purchased BS 8887-1 following more positive comments in this regard from their EMS auditors. Others argued that it was already challenging enough to meet the requirements of ISO 14001 without adding to them.

5.5.5 Quantitative Analysis of NVivo Processed Transcripts

During the final stages of this research project, the 'Used' node in NVivo showed that over 150 quotations from 40 transcripts and other original documents from the research had been considered in this Ph.D. thesis and associated papers. A report was generated to show the most prominent topics arising during the interviews. This data is presented in *Figure 5.3: Transcript References and Sources Coded at Nodes.*

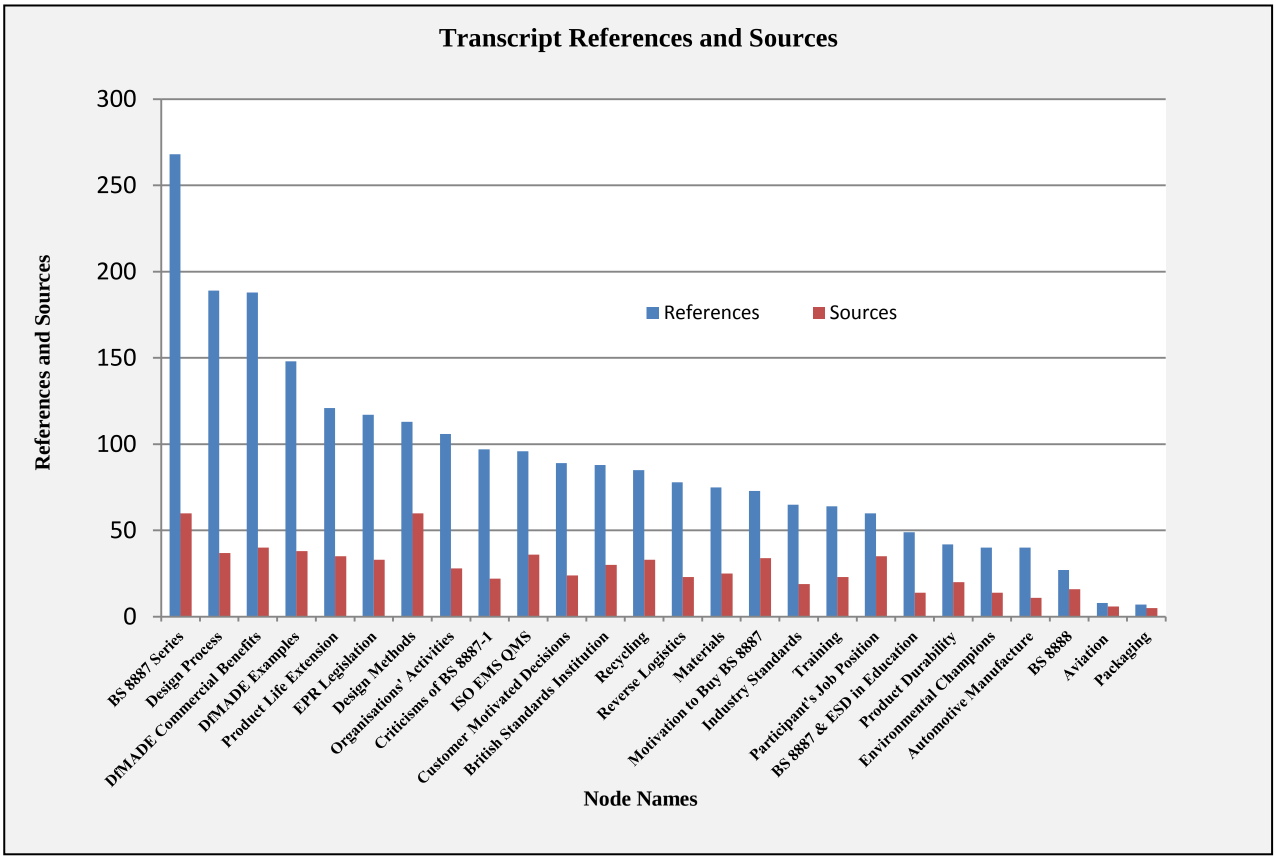

Figure 5.3: Transcript References and Sources Coded at Nodes

5.6 Discussion

The results shown in *Figure 5.1* indicate that although organizations purchase standards, and specifically BS 8887-1, they may not always be given proper consideration. An opportunity therefore arises to improve engagement. This could be realized by supplementing the standard with additional material presented in suitable format.

Arguably the two strongest commercial examples of the use of BS 8887-1 were from an industrial refrigeration company and an automotive electrical parts manufacturer. The former developed their most recent products based on the BS 8887-1 specification with the purpose of keeping the cost of disposal to a minimum, and the latter referenced the standard in one of their APQP procedures for use with every new product they designed.

The positive influence of environmentally conscious customers can be seen in *Figure 5.2* where the largest portion of the pie chart comprises those organizations where participants cited customer demand or market preference as their primary reason to consider ESD. EPR legislation was also a major motivator of ESD. Within the interview series as a whole, 12 participants said EPR was a major reason to make changes to their designs and reduce the environmental impact of their products.

Large organizations including businesses and public sector bodies often have a preference for dealing with companies with a certified ISO 14001 EMS, thereby creating a strong incentive for suppliers to achieve certification. ISO 14001 lists some areas that are relevant to ESD under *Annex A.3.1 Environmental Aspects*:

> *"Consideration should be given to aspects related to the organization's activities, products and services, such as:*
>
> - *Design and development*
> - *Manufacturing processes*
> - Packaging and transportation
> - Environmental performance and practices of contractors and suppliers
> - Waste management
> - *Extraction and distribution of raw materials and natural resources*
> - *Distribution, use and end-of-life of products*
> - *Wildlife and biodiversity"* [ISO 14001, 2004 p. 12]

BS 8887-1 provides further details and should constitute a relevant and useful reference source for addressing some of these considerations in design practice. It may be possible to overcome the difficulties of quantifying product-related environmental impact through the use of LCA and eco-footprinting.

In *Figure 5.3* the node names are arranged in descending order, based on the number of times their particular topic appeared in the transcripts. The frequency with which they arose was influenced by a combination of the prepared themes and the participants' interests. References are indicated in blue on the graph, and sources in red. One striking feature is the relatively low variance in the number of sources coded at each node, a product of the semi-structured interview technique.

The topics appearing most frequently after BS 8887, concerned the design process and the commercial benefits of using the standard. Examples of the use of the standard were specifically sought, as is evident from high rates of reference to the design process and DfMADE examples.

Management systems occupied a position within the top 10 discussion topics, and participants frequently had experience with the ISO management standards. Product-related environmental legislation was also a subject of particular interest to participants as they tended to be the people responsible for achieving compliance.

5.7 Conclusion

The findings demonstrate some interest in BS 8887-1 and ESD from both industry and academia, but there are only a few strong commercial examples of the standard's use in practice. This could perhaps be attributed to the economy presently being in recession, thus leading to reduced levels of product development. An opportunity must surely exist to further the use of BS 8887-1 and the other standards in the series.

CHAPTER 6 Pilot Study – The Use of BS 8887-1 in the Electronics Industry

6.1 Aims and Objectives

The goal for the pilot study was to learn about the motives and challenges for designers and manufacturers that use BS 8887-1 and to practice the techniques that would be used for the main study. The data gathering and handling procedure is detailed in *Section 3.5: Qualitative Research and Analysis Method.*

By limiting the pilot study to companies engaged in similar commercial activities, it was anticipated that common trends and themes would emerge in the resulting information. The focus of the pilot study is on manufacturers and designers of EEE. This sector was chosen because there was a high uptake of BS 8887-1 from EEE producers, as illustrated in *Figure 4.2: SIC Section and Division of Manufacturing*.

Of the 23 companies identified as being part of the EEE industry and known to have ordered or downloaded the standard, 10 were among the 80 UK organizations that had not objected to being contacted in relation to this research. Contributions were successfully gathered from eight of these. Interviews with participants at these companies provided the information that this chapter is based on. Some additional relevant comment regarding the production of electronics, gathered later in the study, has also been included.

6.2 Introduction

It has been necessary to develop waste disposal legislation specifically targeting the EEE sector. Beyond achieving compliance with relevant legislation, the development of electronic products may not necessarily take account of design considerations that can have an environmental impact. Certain features can hinder or even prevent maintenance or the separation of materials at EoL [Platcheck *et al.*, 2007 p. 76]. EoL has been defined as: "the point in time when the product no longer satisfies the initial purchaser or first owner"[Rose *et al.,* 2001 p. 183] “The key issue for a successful eco-design product is not only to meet environmental objectives such as resource and energy conservation and environmental burden reduction, but also to take into account cost effectiveness, market demand, and multi-functionality requirements. The main environmental concerns in the EEE sector stem from soil and water contamination, resource depletion, energy use and waste” [Bereketli *et al*., 2009 p. 214].

Solutions to the EoL reprocessing of electronic products must address the issues of “reducing land-filled material, maximising recycling and controlling hazardous substances” [Rose *et al*., 2001 p. 182]. Additional goals might include the retention of embodied energy, minimisation of the potential pollution caused by disposal, maintenance of the purity and value of materials for recycling through DfD and minimising the necessity for the extraction of virgin materials from the Earth. “Technical challenges include issues such as the type of products received in the EoL collection, treatment procedure, and product characteristics. The non-technical challenges include concerns to make the EoL treatment system economically feasible, develop business goals and metrics to quantify the success of the programme, and appropriately organise the value chain” [Rose *et al*., 2001 p. 182].

BS 8887 may be of help to those seeking solutions to some of the technical challenges, especially for product characteristics that may influence the viability of reprocessing:

> *“It is a complex and confusing field but you can be confident that a British Standard is good practice and actually works and makes a difference.”*

The participant quoted above recognised that British Standards are highly authoritative and that BS 8887-1 can help with planning for sustainability. Commercial interest in BS 8887-1 may be influenced by other potentially significant factors including compulsory regulatory requirements, customer preference, employees who take on the role of environmental champion and the competitive advantage achieved through a positive environmentally responsible corporate identity.

A study conducted by Gallup found that 52% of people surveyed stopped buying products from companies with a poor environmental image [Haklik, 1997 cited in Sambasivan and Fei, 2007 p. 1428]. The growing market trend of customers preferring to deal with environmentally responsible companies was most apparent with regard to the need for ISO 14001 accreditation. This mainly applied to commercial customers and is discussed in *Section 6.6: Management Systems and MADE.*

6.3 Motivation for Sustainable Design

Customer preference for more eco-friendly goods can motivate industrial designers and manufacturers to develop more sustainable products. The objective is to develop products that will be profitable for business and enhance people's lives without damaging the environment [Greenwood, 2008 p. 28]. The following quotations are from a producer of traffic light systems and an electronics design consultant:

> *"It's a good sales tactic for us to be able to say that our products are completely recyclable at the end-of-life and that the end-of-life is a long way off."*

> *"The purchase of BS 8887-1 was driven by the knowledge of its existence*

and its value in terms of how we advise customers or clients. We had an appreciation of the necessity to be aware of and focussed on the BS 8887-1 standard... Older products were designed with less consideration for the environment than the newer designs. Customer requirements have influenced this."

The DfD and EoL processing content of BS 8887-1 was significant for some of its users, as illustrated in the following examples from a manufacturer of motion control systems and another technology company:

"BS 8887-1 was reviewed with the possibility that end-of-life processing requirements might be incorporated into new product development. The standard was ordered to assist with the whole life cycle planning of our products."

"The disassembly part of the standard was of particular interest. Ideas on this are being asked for by customers occasionally."

The holistic nature of the standard, implied by its title and description, did attract designers concerned with environmental impact reduction:

"I have been interested in green design for a few years and wanted to know what was missing from our approach... I am trying to apply best practice by thinking about the whole life cycle of products… BS 8887-1 was ordered as a guide for manufacturing products that are sustainable and repairable."

"If designers and design managers are able to raise their own awareness of the issues surrounding sustainable product development, they can play an

important part in educating higher levels of management and, in the case of design consultancies, client companies."

In addition to the environmental argument in favour of DfD, servicing and product life extension, the approach can help manufacturers to differentiate themselves in a crowded market by making superior customer service and lower life cycle cost of ownership possible. This is demonstrated in the next example. The product being described is an electronic control panel for an assisted living device:

> *"For some of our competitors, their batteries are integrated into the handset. When the batteries fail it is necessary to replace all the mouldings and the electronics, whereas we have a competitive advantage in that it is possible to replace just the battery cells. One of our competitors sells a hand controller for over £50. With our product, if the batteries fail they can be changed for about £10. This gives us a competitive advantage."*

In another battery related example, a power pack was redesigned to facilitate service and prevent unnecessary waste:

> *"The design of the battery stick was changed in 2006. It was given a substantial review in order to make it more serviceable. The old and new pack can be compared to show how sustainability and serviceability have been applied. The design has been kept consistent in terms of aesthetics and functionality. The battery stick used to be made in two halves. The batteries were placed inside and the top half was then glued on. This worked well until the batteries required removal. This was not possible, so the whole battery stick had to be thrown away. The redesigned battery stick has four*

> *screws in an end-cap with a rubber moulding on the inside to keep the water out. The IP* [Ingress Protection] *rating of the equipment for water and dust has been maintained, but now the unit can be serviced. Sufficient cable has been soldered into the unit to allow the batteries to be changed 2-3 times. The customer only has to buy the cells because the casings are now being reused."*

A company that developed an emergency communication device for use by lone workers was forced to adopt a similar strategy by contractual obligations:

> *"I was involved with negotiations for the contract. Part of the stipulation for this was concerned with recycling and disposal of the product. There was a contractual requirement in supplying the product that a suitable method of disposal at end-of-life would be in place... This was one of the drivers in making the batteries easier to unclip and replace. Some of the design for end-of-life features were driven by the contract... At the product's end-of-life it will be returned to the producer. They will then see the benefit of the design modifications that make it easier to service or recycle."*

Some of these design improvements, like being able to change batteries, are modest design advances that may nonetheless yield significant environmental performance and cost improvements because of the high volumes of identical items produced to each design. Entrepreneurial designers may be able to make radical leaps and develop completely new ways of working whereas other journeymen designers may be able to make small improvements with each new work [Howarth, 2004 p. 11]. Arguably BS 8887-1 can support the journeymen designer in making small but valuable changes as well as improving product management over the entire life cycle, thereby improving the product's EoL processing properties.

Planning for, and offering customers product upgrades and service options provided some manufacturers with an additional revenue stream. In the following example, the participant is talking about sophisticated target acquisition systems for military use:

> *"About five years ago we made a range of electronic products. Over the years the software has been developed further. We are now happy to offer customers the facility to return older products to have the software updated and thus improve functionality. This would be at the customer's cost because we would be enhancing the product. Normally, while we have the customer's product, a quote would be given to re-spray it... We would also service it."*

All those interviewed agreed that sustainable design is becoming more important because of tightening regulations, consumer pressure and corporate responsibility. However at some of the companies visited, the rate at which new design projects were initiated had slowed owing to the economic decline. For some, sustainability concerns had taken a lower priority as a result of today's tougher market conditions.

6.4 New Product Development

There was general agreement that for the principles of BS 8887-1 to be of greatest value and least cost, they would have to be addressed as early as possible in NPD. Once a design goes into production it becomes expensive to make changes:

> *"In the initial design phase we are trying to use materials which are all*

recyclable and keeping the parts count down so that the device, at its end-of-life, is easily disassembled and can be broken down into its component parts."

"Our Technical Director agreed to the philosophy and approach for all new designs."

The problem of perception with regard to sustainable design has been acknowledged in previous literature: "Frequently, environmental requirements are seen as a burden or as mandates that simply slow product development and add costs detracting funds from the main business of the company" [Ellram *et al*., 2008 p. 1620]. Design with consideration for environmental protection does not necessarily have to be a burden:

"I don't think it is generally a cost, but it is sometimes perceived that way."

To achieve commercial success, market demand and product function and cost are of primary importance. DfE can be defined as "the development of innovative, efficient products while satisfying commercial criteria such as cost, quality, and appearance and complying with environmental issues over the entire product life cycle" [Holdway and Walker, 2004 p. 9]. Participants emphasised how material choices had to be optimised for service rather than for the requirements of reprocessing, but that recyclable materials were chosen in favour of non-recyclable options where possible.

The effectiveness of recycling and the value of the materials and components recovered as well as the effect upon the environment of any remaining residues that are disposed of, are greatly affected by the properties and the values of the materials used within a product [Xing *et al*., 2003 p. 150]. Today there are a growing number of products on the market with reduced negative impacts, improved energy efficiency, and made with more recycled and biodegradable materials [Greenwood, 2008 p. 28]. Despite the importance of considering how products are to be reprocessed, this was seldom a top priority, as commented on by an electrical engineer and an electronics designer:

> *"By nature you tend to try to make things cost effective, functional and environmentally friendly, but I think environment would be third in the list."*
>
> *"We have a preference for eco-design but function and cost are the main drivers."*

Some of the product developers using BS 8887-1 had previous industrial experience in sustainable design and manufacture. The standard was not necessarily applied in its entirety as it is voluntary; and not all of the BS 8887-1 *Section 11: Life Cycle Considerations* are relevant to all products. Instead, the content of the standard was used selectively, based on the requirements of each project.

BS 8887-1 refers to the techniques of brainstorming, Quality Function Deployment (QfD), Failure Mode and Effect Analysis (FMEA), and Value Engineering (VE). Many of these are commonly used and so did not necessitate changes to corporate NPD procedures. The content and layout of the standard was said to be logical, purposeful, unambiguous and neither too specific nor too general, and not overly prescriptive:

> *"The authors of BS 8887-1 are clearly speaking from knowledge and experience."*

At the time of the study, the standard was relatively new and had often been ordered for inclusion in company standards libraries with a view to applying it to future projects.

6.5 Design for Assembly, Disassembly and Durability

In BS 8887-1 *Section 10: Requirements for Assembly*, Note 1 states "Minimization of the part count is necessary because it is the major contributor to the part holding and handling costs. If a part is eliminated, it need not be ordered, received, catalogued, handled or assembled." Supposing that a manufacturer can reduce the number of parts they use in their products, this can have a direct positive impact on profitability, it can also have a benefit for EoL processing as there will be fewer parts to separate. At companies visited, particular consideration was given to reducing product part count as this can lead to cost reductions. Also, if the variety of materials and components used can be reduced, there may be larger streams of each material or part which could be more valuable for recycling.

A reduction of the variety of material used in designs had at one factory proven to be an advantage with regard to injection moulding:

> *"Standardising the colours and types of plastic across our product range has had cost benefits. By buying in bulk the cost is lower and our orders are easier to handle for the supplier. Also, by only using a limited range of plastics, our engineers develop greater experience with them and are better able to predict how the material will flow within a mould. This has led to better quality and more consistent production."*

Developing products with consideration for assembly, disassembly, life cycle planning and adherence to the BS 8887-1 specification often did not necessitate the implementation of significant changes, as meeting these design requirements is arguably just good design practice:

"BS 8887-1 is a match for what we do because we are a best practice organization."

"We manufacture products that are designed to be serviced, we have always tried to make products that are easy to put together and take apart. That has always been part of our philosophy."

For high-volume production of complex products, design for ease of assembly is essential to keep costs down and remain competitive:

"We apply design for assembly to our products and call this 'not three handed assembly'. Location features are included in mouldings. We are familiar with the work of Boothroyd and Dewhurst and use foolproof design or poka yoke."

Most of the companies in the pilot study made products for industrial applications. These items often have long service lives, with durability and maintainability being high priorities. A benefit of designing for disassembly is that equipment can be repaired more efficiently, sometimes serviceable parts from broken products were used for repair and refurbishment work:

"Customers' products come back here for repair. We have the facility to recycle parts and keep control over their use and end-of-life. When they come back and are beyond economic repair, we speak to the customer and agree to either to replace the product with something else, with a discount, or we repair it."

"Old equipment is sometimes kept so that it can be used as a donor to

maintain other similar products. Warranty claims are usually dealt with by replacement with similar refurbished product. Design for disassembly is applied to all new products... Warranty replacements are sent out from stores. These are either new items or products that have been previously sent back, repaired and put into store. This means that the client can always get an equivalent item from us very quickly."

In addition to materials selection, the choice of fasteners or other bonding systems affects the ease with which a product can be disassembled and materials separated for recycling [Kirby and Wadehra, 1993 p. 34]. These choices also affect the ease with which parts and subassemblies can be removed for service and repair.

Snap-fits can be helpful in both production and EoL processing as they reduce assembly costs and avoid having fixings of different materials to separate during recycling. However, they can cause problems with disassembly [Sodhi and Sonneberg, 1999 p. 164]. "The common use of several types of plastic within a single product held together with a variety of fixing methods further complicates separation" [Hornbuckle, 2008 p. 163]. Material identification marking and DfD may help to reduce this problem. BS 8887-1 references standards including ISO 11469 *Generic Identification and Marking of Plastics Products*, and ISO 1043 *Plastics – Symbols and Abbreviated Terms*. Components, especially plastic parts, should be labelled to identify the material from which they are made. This is usually done with an in-mould mark. "Designers can take one simple step that will help at the end of the product's life: label the materials used. If components (especially plastics) are identified as being made from a particular material, they can be recycled far more cost-effectively" [Fuad-Luke, 2008 p. 23]. The ability to easily identify material grades helps to ensure that at EoL parts are placed in the correct recycling streams, thus contributing to the quality of secondary materials:

> *"If you strip one of our products down you will know what type of material it's made from whether it is ABS, polyethylene, polypropylene etc."*

Some materials are very much easier to recycle than others and there is a great variation in the scrap values. Material selection has a crucial effect on product recyclability [Lee *et al*., 1997 cited in Xing *et al*., 2003 p. 150]. Focusing on producing environmentally friendly products may create safer and less costly goods, which have greater scrap value [Porter and van der Linde, 1995 p. 126]. A product's recyclability can be measured by the ease with which it can be disassembled [Tsai *et al*., 2000 p. 1004]. Heat-staving involves softening and deforming the top of a plastic location pin that is used to fix a Printed Circuit Board (PCB) or other part. This method is often used to fix parts into an enclosure, since it is low-cost. However heat staving can be problematic when it comes to product disassembly.

At one company visited, new products were carefully planned for assembly without glue or heat staving, and with a preference for avoiding use of fixings or metal inserts in plastic mouldings. Their latest product that had been optimised for production, maintenance and EoL processing was a Radio-Frequency Identification (RFID) reader for door access control. For speed and efficiency in assembly, snap-fits were used to join the two parts of the reader housing. The mouldings also incorporated redundant screw bosses and screw location features. By avoiding the use of screws, but providing the option to use them later if required, the potential in-service life was extended and recyclability improved:

> *"Snap-fits are used instead of fixings. This saves time during assembly and helps to avoid having them in the waste at end-of-life. If products with snap-*

> *fits are disassembled, the clips are often broken or weakened. For this reason all our new designs incorporate redundant screw bosses and screw location features that can be used after repair or refurbishment. In this way the product life can be extended and the design is optimised for assembly, maintenance and disassembly."*

Design for durability can be an excellent strategy to reduce environmental impact and may be exactly what the customer wants. "A washing-machine producer who has enough confidence in his product to offer a five-year, no-strings-attached guarantee covering parts and service should quickly win a vast following of enthusiastic buyers" [Packard, 1960 p. 239]. Design for durability, disassembly and maintainability was the approach taken by a janitorial cleaning equipment manufacturer:

> *"Our machines are more industrial, so they are designed for maintenance and built to be overhauled, serviced and repaired. At end-of-life they should be easy to take to bits."*

DfD was already an established part of the product development procedure for several companies that purchased BS 8887-1. One regularly presented their products at environmental design seminars where it had been confirmed that they were well optimised for disassembly and recycling. "Designers can seek out these types of programmes to help find 'champions' for sustainable design from outside the company, as well as to find opportunities for the company to be recognized" [Thorpe, 2007 p. 92]. Other firms had reviewed their design process in light of the standard. EoL planning presents new challenges and it was often this content that generated the greatest interest in BS 8887-1.

6.5.1 Some Difficulties with Design for Disassembly

In a few instances design that facilitates disassembly and maintainability contradicted other functional requirements, especially regarding security:

> *"Sometimes product design is driven by the customer's requirements. We could be forced down routes that are not necessarily so eco-friendly e.g. tracking tags for offenders. The design requirements for this product required it to be chunky, robust and tamper-proof... The unit is completely sealed... Because of the functional design requirements it was difficult to do design for disassembly... The prototype offender tag has exposed security head screws holding it together. On the production items these are covered for additional resistance to disassembly. When fully assembled the only way to gain access to the interior of the tag is to break it. Snap-fits with one way harpoon features are used to prevent it from coming apart. Each tag is used for only one offender for periods of about six months."*

As with the tamper-proof offender tag, a Thatcham Category-C car security system had been designed to prevent access to its internal circuits. The Printed Circuit Board (PCB) was potted in resin thus preventing disassembly. Potting is used to improve the shock and vibration resistance of electronics. It also prevents water ingress and can provide protection from corrosive agents. This can improve durability but hinder reprocessing, as commented on by another designer of electronic security products:

> *"Repair is significant for us so we make sure things are easy to repair. We do have difficulty sometimes because some of our products have to be potted because of the environments they are working in and obviously repair can be*

difficult in those situations. You can't take all the potting off, repair the item and re-pot it easily..."

From these examples it can be seen that DfD is sometimes precluded by functional requirements which must take precedence. It may still be possible to retrieve some value from such products by shredding them instead of disassembling them prior to materials refining. Shredding is usually necessary for separated materials, but the output is likely to be of superior quality to non-separated materials.

6.6 Management Systems and MADE

The ISO 14001 EMS was of particular interest to many of the participants, as most of the companies in the pilot study had this accreditation or were working towards it. All but one of these companies had ISO 9001 QMS accreditation. Both ISO 9001 and ISO 14001 were often insisted upon by clients and were therefore helpful in attracting new business. It was also suggested that BS 8887-1 could be used with these systems:

"The concepts from BS 8887-1 could be built into the product introduction process. These would form part of the deliverables or gateways. Perhaps they could be worked into an internal process that would be audited as part of ISO 9001 continuous improvement. BS 8887-1 could perhaps be used with EMS and QMS."

Good environmental practices encouraged by ISO 14001 were beneficial for staff morale and sometimes provided greater opportunities to apply design for the environment. Morale is likely to improve if employees feel that the company they work for is behaving responsibly, this can increase productivity. Consumers are increasingly aware of environmental and social issues, and are demanding more responsibly produced goods [Thorpe, 2007 p. 93]. The following quotes are from a manager and an engineer at the same company:

> *"They feel they are contributing positively to the business, to the environmental aspects... rather than people at the top just dictating."*

> *"Now management are looking at ISO 14001 there is more scope for me to put forward some of the ideas I have come across."*

BS 8887-1 is specifically concerned with the design of products, whereas the EMSs have a broader influence:

> *"ISO 14001 has led us to improve our energy management, recycling and waste management. Waste going into landfill has been reduced."*

As part of continuous environmental improvement under ISO 14001, one firm identified heating buildings as their biggest impact. Installing insulation was both good for the environment as it saved energy and good for the company as it saved money. For this manufacturer, product-associated impacts were rated as being of less significance than other site-related issues. Another firm chose to focus on recycling under ISO 14001 and reduced their waste going into landfill by 85%.

6.7 Legislation and MADE

The priority for products to function correctly over being recyclable inevitably results in material choices and design being optimised for use rather than for EoL processing, but legislative demands must still be fulfilled:

> *"We make products which are over-moulded lead frame... They are plastic*

and metal usually bonded together so they are not great for recycling... We try to avoid any secondary finishes on plastics. We try to avoid, where we can, finishes on metallic materials; although you do have to have a range of finishes for anti-corrosion or to optimise contact... we obviously avoid anything that's required by RoHS."

In commercial design practice, when a customer commissions the development of a new product they will usually specify requirements. These requirements can include compliance with various pieces of environmental legislation as well as standards relevant to the particular product being developed and the country in which the item will be sold. Producers must be able to demonstrate that they have fulfilled necessary legislative requirements. Additionally, customers will often go beyond compliance and make extra demands based on their own purposes and goals [Donnelly *et al*., 2004 p. 45]. To supply electronic products into the UK market usually requires compliance with WEEE, RoHS and EuP etc. Both the EPR legislation and BS 8887-1 should help to reduce the environmental impact of industrially manufactured products in different ways. These pieces of legislation are also referenced in BS 8887-1, which arguably suggests a connection between them worth investigating.

Participants were asked about EPR legislation in relation to BS 8887-1 to see if the former had influenced their use of the latter. These quotes are from two different electronics manufacturers, one in the automotive parts business and the other making timers and sensors for central heating systems:

"BS 8887-1 came out at about the same time as people were talking about WEEE and RoHS and there seemed to be a link between them. BS 8887-1 does not go into exactly the same things, but it is related and was ordered so

that it could become a part of the way WEEE and RoSH were thought about."

"Obviously being in the electronics industry we are affected by the EUP directive as well as WEEE and RoHS. It actually ties in quite well with that."

Similarly, at a fabricated metal products company that used externally made electronic control circuits in their equipment, BS 8887-1 was seen as a useful supporting document in relation to the legislation:

"It is all part of the same thing really. We have to comply with RoHS and the WEEE directives and that's also part of the design development structure... I wouldn't say that it's been a motivator in purchasing this but it's all part of the same review which has led to us buying this standard."

Under the regulations, certain classes of products are exempt e.g. fixed installations, medical appliances and military equipment. Several firms chose to become RoHS compliant when they could have claimed an exemption. This was said to be driven by a desire to be environmentally friendly and in anticipation of the future tightening of legislation. Most electronics components on the market now meet the requirements of RoHS, so it is both convenient and a sales advantage if complete products or systems can be sold as RoHS compliant.

6.7.1 Some Difficulties with Design for Reprocessing and WEEE

The WEEE directive, and other similar legal requirements affecting producers, is sometimes referred to as 'take-back legislation'. In reality EoL products are rarely returned to the factory where they were made. Instead the work of recycling is outsourced leaving the producer free to concentrate on their core business. Reverse logistics could be a significant challenge to actually taking EoL products back:

> *"For the majority of customers, the problem of end-of-life products is passed on to other contractors. They would pay into a WEEE scheme. The problem with closed-loop production is knowing where products are when they reached their end-of-life. It is difficult to call an end-of-life product back in without knowing where it has gone. It is usually easier to pay into a WEEE scheme."*

Paying into a WEEE scheme is of course an unwanted expense for electronics producers, but it is convenient:

> *"We use* [a recycler] *to collect WEEE on our behalf, or to collect the equivalent weight. Our products tend to be installed into the fabric of buildings and probably have ten year plus life-spans, so we don't have to design for recycling at the moment."*

> *"Our recycler can deal with all types of plastic, so this* [DfR] *does not affect our materials selection. They convert used plastic into low quality products like garden furniture or drain pipes."*

Arguably, the form of EoL processing described in the last quote is not recycling but down-cycling. Commonly, recycled plastic is used in large quantities to make products that are used for their substance rather than appearance, examples include beams, buckets, boards, pipes and guttering [Hornbuckle, 2008 p. 165]. The plastics fraction of post-shredder material can sometimes be used as a fuel source for metals recovery during the recycling of electronic products [Donnelly *et al.*, 2004 p. 49]. This is another example of the down-cycling of plastics.

The convenience of paying into a WEEE scheme can reduce the incentive to develop products that can be readily disassembled and recycled, because products from multiple manufacturers will be reprocessed together in the same way at a common facility. As a result DfR may not benefit the producer.

The reality that EoL products are not typically retrieved by their original producers has proven to be a barrier to the acceptance of the 'active disassembly' technology previously developed within the Cleaner Electronics Research Group [as investigated in: Chiodo *et al*., 1998, 2002; Jones *et al*., 2003, 2004]. At EoL, products designed with active fasteners are heated to a specified temperature, causing them to come apart. This is achieved through a novel application of Shape Memory Alloy (SMA) or Shape Memory Polymer (SMP) material used for the fasteners. Unfortunately, these cost more than conventional fasteners and provide no advantage to a producer unless they really do retrieve their products.

The argument in favour of DfD with BS 8887 is perhaps stronger than the argument for active disassembly as the standard does not suggest the use of a novel disassembly technology which could add to production costs. Instead the designer is prompted to consider DfD throughout the design process, in the same way that they would consider DfMA. It is reasonable to expect that optimisation for assembly will in many instances also have a positive impact on the ease of disassembly.

6.8 Conclusions

The pilot study has shown how environmental concerns are of increasing importance in NPD, particularly with regard to legislation, especially WEEE and RoHS. Compliance with legal requirements was one of the primary motives for developing cleaner design strategies. Strong environmental credentials were also shown to be advantageous to business relationships and helpful in attracting and retaining clients. ISO 14001 accreditation was considered particularly important when selling to large commercial and public sector organizations. Companies with this accreditation continually make incremental environmental performance improvements and efficiency gains.

Planning for efficient parts manufacture and assembly can result in reduced production costs. In a number of instances, DfA aided disassembly, helping to facilitate product life extension since service and repair could be achieved more efficiently. However, pursuing sustainable design can present contradictions and challenges in determining the best approach while meeting functional requirements.

DfE is now an important aspect of most NPD work. BS 8887-1 supports this as well as some of the more conventional aspects of industrial design including the way in which products are optimised for production. Participants in the study emphasised the importance of designing products that could be manufactured efficiently, would function correctly and would be economically competitive. Eco-design must fit this framework to be attractive to producers.

CHAPTER 7 Main Study (Part 1) Design for Manufacture and Sustainability in New Product Development

This chapter considers comments from practicing designers and engineers made during field research into the use of BS 8887-1. It includes qualitative information from professionals working with the standard in all industry sectors known to have accessed it. Design and production strategies are considered, and each of the key product development stages reviewed.

7.1 Linear Production and Disposal versus Closed-loop Production

During the conventional product life cycle, materials move through a system comprising the following stages: Extraction, Production, Distribution, Consumption and finally Disposal. This is a linear system and has been called the materials economy. It is represented in *Figure 7.1: Conventional Production*. We live on a finite planet that cannot support this indefinitely. “Unsustainable consumption and production patterns in the developed world have led to increased generation of waste over many decades. The standard practice of dumping waste in landfills has led to soil, surface and groundwater contamination. Landfill sites can result in serious environmental pollution of groundwater and rivers due to the landfill leachate (the liquid produced from the decomposition of waste within the landfill)" [Staikos and Rahimifard, 2007 pp. 602, 605].

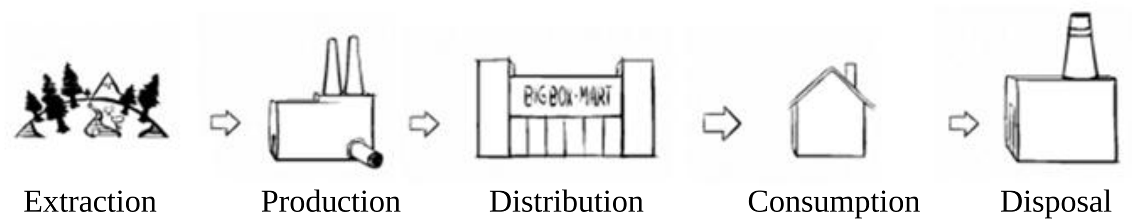

Figure 7.1: Conventional Production - Leonard, 2005

The main negative environmental impacts of a product occur either side of NPD i.e. during materials extraction and the diffuse processes of use and obsolescence. Design knowledge in these areas is generally weak [Holdway and Walker, 2004 p. 9]. Extraction, or natural resource exploitation, is a major limit to the economy since we are running out of resources. "In 2003, humanity's footprint exceeded Earth's capacity by over 25 percent" [Global Footprint Network, 2007]. This means that natural resources are being consumed faster than they can be replenished, a situation that continues to worsen. "A demand for bio-capacity greater than the available global supply is considered unsustainable - more resources are being consumed than can be regenerated" [Frey *et al.*, 2006 p. 201] Global bio capacity has declined for the past 30 years [WWF, 2000 cited in Frey *et al.*, 2006 p. 211]. "It is evident that, year by year, the entire problem of adequacy of natural resources for the maintenance and development of our civilisation is becoming more acute" [Fairfield and Osborn cited in Packard, 1960 p. 186]. It has been estimated that one third of the planet's resources, its 'natural wealth', has been consumed in the past three decades [Hawken *et al.*, 1999 p. 4].

As readily-accessible high grade metal ores are depleted, it becomes necessary to dig deeper, thus increasing the cost. Low-grade ores can be used but these require additional treatment steps, once again adding to cost [Packard, 1960 p. 186]. If materials with higher recycling potential and value are used in products, together with components that can be reused, there will be a greater incentive for producers to reprocess them [Rose *et al.*, 2001, p. 192].

Life cycle design strategies will play an increasingly important role as certain resources and materials become scarce. This was recognized in an interview with a company making high tech automation and control products:

> *"If we can stop putting stuff into the ground it is better for everybody. It*

saves more minerals from being excavated and also stops any possible contamination from landfill sites. This is very important for future generations."

One Research and Development (R&D) manager responsible for NPD in the commercial printing industry expressed similar concerns with regard to waste avoidance:

> *"In the R&D department there is a big motivation to be greener. I think scientists generally are aware of environmental issues, and most of them are supportive... If you can get through life consuming less, that has to be a good thing. Most scientists are logical enough to see the clear case that it is always better to use less if you can."*

Today's product designers should consider not only the "production and transformation processes, assembly line, administrative and technical aspects of the manufacture, but also the consumption of water and energy; the origins of raw materials; the types of generated residues and the destiny of these" [Platcheck *et al.*, 2007 p. 81]. Eco-design refers to NPD strategies that minimise environmental impact, reduce production costs and give companies a competitive differential in the market.

"It is reported that the common approach adopted by industry to eco-design, as opposed to sustainable design, is eco-efficiency, this is a linear cradle to grave approach" [DeSimone and Popoff, 2000 cited in Humphries-Smith, 2010 p. 11]. McDonough and Braungart, authors of the book Cradle to Cradle (2002), claim that eco-efficiency as a strategy only makes people less bad. Cradle to cradle is an attempt to emulate in an industrial context the constant recycling observable within the natural world. This may be regarded as a form of biomimicry [Benyus, 2000 cited in Humphries-Smith, 2010 p. 11].

The cradle-to-cradle approach has obvious environmental benefits and can deliver significant cost savings. EoL products become the 'technical nutrients' necessary for manufacture. There is no 'away' into which we can throw things any more [McDonough and Braungart, 2002 p. 27]. Closed-loop systems maintain the economic and consumer benefit of industry, while minimizing the requirement for virgin material and the disposal of waste, see *Figure 7.2: Closed-loop Production.*

Figure 7.2: Closed-loop Production - Leonard, 2005

Every day, markets give more emphasis to sustainable development because the Earth's capacity for raw materials extraction is being exhausted [Platcheck *et al*., 2007 pp. 84-85]. Salvaging existing materials can theoretically ease the shortages as there are millions of tonnes of motorcars, refrigerators and other products in dumps. Much of this material loses weight each year as rust devours it [Packard, 1960 p. 196]. As natural resources diminish, and the laws of supply and demand change the economics of recycling, it is possible that the landfill sites of the past will become the mines of the future. It is however a superior option to divert waste from landfill and back into production before it has caused any pollution or has degraded. Materials that can be separated from EoL products generally fall into five large groups: metals, precious metals, plastics, glass and others e.g. paper, rubber ceramics etc. [Henstock 1988; Graedle and Allenby, 1998 cited in Xing *et al*., 2003 p. 159]. Today, conventional production is still creating a significant problem with waste. This was discussed by a civil engineer as follows:

> *"In the long term, sustainable design is vital... I have had this argument that sustainable design is going to cost more and therefore increase prices. This led to a fear that they would lose their market. I explained that 'if everybody carries on the way you are going, the market, and the people you are trying to sell to, is going to start dying because the world is going to be piling up with rubbish.' Their response was 'Oh that's twenty years time and that's for the Government to do something about.' It's only a few companies and a few organizations that understand the message and the reasoning, that are actually going to do anything about it and are willing to accept it. They grab BS 8887 with both hands saying 'this is great, this is the sort of information we need and can we have more of it!'"*

Even if EoL products do not have an immediate financial value, there can still be other advantages for producers in taking back their products. This was acknowledged by an engineering manager responsible for the design and manufacture of railway track equipment:

> *"If we want to do effective product development for the next generation, it is necessary to know what is going wrong with the product currently being made. If designing a Mark II product then that information is necessary in order to know what needs to be improved. The value of returned product is*

in determining the reason for failure."

Recognition of the value of a design standard advocating sustainability was articulated by a manager at a consultancy specializing in closed-loop production. The consultancy was trying to prove the commercial value of the approach, based on the experience of a particular client:

> *"This is information that we are trying to glean ourselves, to make sure that it makes financial sense. This would make a stronger case to encourage other businesses to follow the same route. They are happy to associate profitability with the design changes resulting from taking a more eco-design approach, but it has not been quantified fully. They are also happy to associate the increase in sales and profitability with eco-design changes. I have had meetings about this to quantify it, but there are so many factors that it is difficult to apportion the sales to eco-design only. The one quantifiable thing that they have done is to save a great deal of money by diverting waste from landfill through closing the loop. The waste that is left now is negligible. They manage to bring the products back, take them apart, separate them into different streams and deal with the suppliers to return worn components for shredding and recycling into new components. This type of model is fairly well established. They have now acquired a recycling license so that they can handle waste. They set up a recycling facility on site. They also take back other competitors' products as well, but the focus is on their own. This is a step further than just applying the Cradle to Cradle protocol. They see material as having value. They don't see it as waste but as a resource. The lease agreements with customers are related to*

the principle that the materials have value and that value is built into the product. When they get the products back they can retain the value and keep the materials in the higher end of the chain, so they can be put back into a similar component or product. The business recognizes that there is value in the materials and in the design as well."

This highlights that it is difficult to accurately account for the financial gains from closed-loop production although the client business concerned has increased its profitability and market reputation having implemented the strategy. The product development process detailed in BS 8887-1 supports sustainability by incorporating the design requirements necessary for closed-loop production.

Meeting the demand for more environmentally friendly production can be difficult even with a ready market and willing producer. Part of the reason the above example works is that the company receives its own product back rather than trying to source suitable secondary materials externally:

"Costs should go down when recycled material is specified, but it is usual for the cost to go up because recycled materials are not readily available. It is cheaper and easier to get new material straight off the shelf than it is to get recycled materials. It is even more difficult to find fit for reuse components that can be used under the right circumstances. There isn't a sufficiently good end-of-life waste system. When a product gets to the end-of-life, the question is 'where do we throw it?' Nobody is saying 'now let's take this apart and the bits that can be reused, they will be put in this store, the bits that need re-working can go over here and the bits that need to be

broken down into raw materials can be processed in this way.' Until that infrastructure builds up, it's going to be more difficult and expensive to do what your customer really wants you to do."

There were several instances where interest in BS8887-1 related primarily to production, although DfD and DfE were regarded as related fields. This may be because these areas are often only considered during the optimization of a design prior to production. Ideally, they should be considered from the earliest concept as this is the stage where there is the greatest opportunity to make significant improvements. One participant made a clear distinction between two types of engineers. He suggested that 'innovators' proposed and developed new technologies, while 'adaptors' optimize designs for production. He saw sustainable engineering as part of the remit of the product adaptors. Sustainable design should be a part of the work of both, since it offers business opportunity that should act as a catalyst for innovation. Goods and services that efficiently meet people's needs at reduced negative social and environmental costs provide an opportunity for companies to gain a sustainable advantage [Greenwood, 2008 p. 29].

7.2 Design and Development Process

Using a typical design sequence, information from the research is considered here with reference to each of the key product development phases. These phases are illustrated in *Figure 7.3: Design Activity Model*.

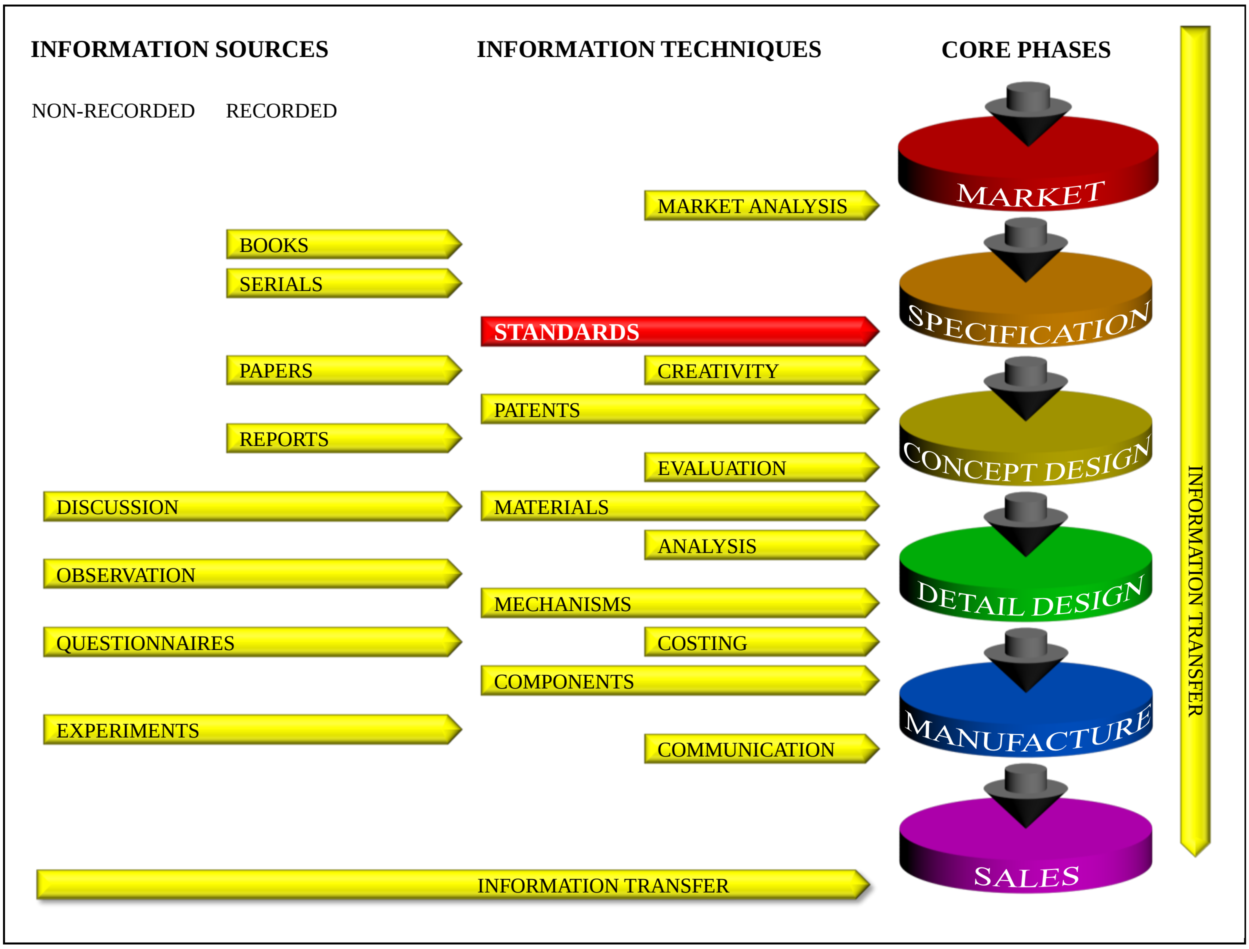

Figure 7.3: Design Activity Model - Adapted from Rhodes and Smith, (1987) in Pugh, (1991)

NPD begins with the market because if there is no demand for a product, or the service that it provides, then it cannot be a commercial success. Relevant environmental issues should also be considered at this stage. Maintaining tight control over NPD can be an advantage in this regard, as the following quote from an engineering director demonstrates:

> *"The company is fortunate in bringing green concepts into the design process because it manages the whole process in-house, and nothing gets designed for us outside. This starts with a development process normally*

driven by the sales and marketing department. It will be a requirement for a product that they feel will address a niche in the market, or it will be something specifically requested by a customer. If it is thought to have enough potential to warrant development, work will commence."

At the specification stage, design and engineering requirements are formalised and desired attributes detailed. These would be established with a client or through market research such as questionnaires, target user group workshops or observation. A chartered engineer at an automotive parts company suggested that customer observation was especially helpful in developing products to meet needs that may not have been previously identified:

"Others engaged in new product development ask customers what they want e.g. a consumer with a VCR might ask for a fast rewind feature, but not a DVD player. Innovative products are developed to meet needs. Needs are established by observing customers. Products are designed for customers that do not realize they need them."

The challenge of design is, in part, capturing in writing information pertinent to all user requirements and product attributes, as discussed by an engineering manager working in the industrial boilers sector:

"One of the parts of BS 8887-1 was used with the sales department who were requesting some new product development work. The senior design engineer asked for information relating to the product brief in order to fully understand it. The requested information was based on a list from Section 5 [BS 8887-1, 2006 p. 6 Design Brief, Table 1]. *This included market need, Opportunity, price, potential for ongoing development and time scale etc.*

This information request covered all of the 'Parameters for Consideration in the Preparation of a Design Brief'. The Sales Department baulked at trying to gather all of the requested information. The requirement was simplified to a basic design goal, context, criterion and constraints for the design brief. Effort is made to identify opportunities and consumer needs through user involvement, so users help design the products."

Relevant standards and legislation to be complied with can be stipulated in the specification. For manufacturers supplying to industry, these are often specified by their customers as highlighted in an interview with a specialist marine engineering firm:

"Anything that is supplied as a bespoke service will be dictated by the customer. Sometimes it is necessary to go back to various international customers and explain why certain stipulations can't be complied with because the legislation in the country of origin is slightly different... Normally a company would dictate that we work to whichever standard is the highest."

The specification is then used as a reference during concept design. In this phase concept drawings and sketch models of potential solutions are produced. This is one of the most important stages where DfE should be considered. The most promising of these concepts are verified with the client or members of the target market audience before moving forward to detailed design:

"At the conceptual stage the technical specification is drawn up for the product. This is put together with input from the sales and marketing department and production engineering. There is no point in planning to

build something that the company cannot produce. A clear fixed picture of the specification is developed so there will be certainty about what it is that we are supposed to be delivering. The project will then move to 'Specific Design'. At this stage it will be fleshed out exactly how the product will be delivered. It is at this point especially that standards become applicable. All the basic health and safety requirements will be applied, all the products will be built to the Machinery Directive and the Low Voltage Directive, Pressure Equipment Directive and now BS 8887-1, or whatever is appropriate."

The chosen concept is optimized for the selected production process and piece-parts assembly. The appearance, function and features are largely determined before this point; there is little opportunity for radical change at this advanced stage. When substantial changes are made to a design this late in this process, they tend to be very costly and should be avoided through good management, proof of principle testing and prototyping.

The design output then feeds into the manufacture phase. Production engineers are limited in how much they can improve a product by the position that they occupy in the development process. This is true in general as well as for ESD as described below by a quality consultant working in the manufacturing sector:

"It all starts with design. By the time a product goes to manufacture the impacts are a given, they are set. With design for end-of-life and recyclability, or any other environmental impacts, the manufacturer will be stuck with them. There is nothing stopping a design house from considering environmental impacts of the decisions they make. Perhaps by designing differently the costs could be reduced. Waste could be eliminated and the

weight of products reduced. A design saving of 2% in the use of material in a component will give a bigger impact than the manufacturer can by reviewing their processes. A manufacturer may be able to make improvements in not wasting metal when cutting it, but a designer could build that in. The design has an impact."

The Chief Design Engineer at another company took a similar view:

> *"Design aims to minimise material usage. This is good for the environment and if less material is used there is less cost in the product."*

The last stage in *Figure 7.3: Design Activity Model* is that of sales. Money and profit is fed back into the system from customers, thus providing income for retail, distribution, manufacture, design, marketing and investors. Design and manufacture are integral functions of our highly interdependent national and global economy. However, this model does not take account of the product use phase or what happens to it once its usefulness has ended.

The representation of the design process in *Figure 7.3* illustrates information transfer through each stage to the next. It also shows inputs from multiple sources entering the process as required. In addition to the information flows represented, ideas and problems encountered are fed back to earlier functions so that designs can be updated and improved following experience with previous iterations. This was described by an engineer at firm making sewage treatment equipment:

> *"Staff can easily go from the factory to the design office to report difficulties such as product being too difficult to put together or modify. Meetings are held regularly with company service engineers from all over the country.*

*They report directly on problems with the products operating in the field. These problems might include difficulties taking equipment apart or things that don't work. There is very close co-*operation *between design, production and the end user. The design manager also regularly takes the opportunity to accompany the salesman and service engineers and visit end users. Comments from the various concerned parties are then addressed in the design of future products."*

At another company, managing the design process efficiently to avoided late changes was sometimes challenging:

"It can be frustrating that once the design process has started and an accurate technical specification has been arrived at, the design requirements may change following the first iteration of a product. Very often other demands will grow out of that. One of the things that the company suffers from is the people who work in the sales department and many of the customers are ignorant of the engineering possibilities. A customer may request a list of features. The company will then build the specification and turn that into a real product. The initial feedback from that first iteration will probably be, and frequently does spark the reaction in the customer; 'Oh I didn't know you could do that. If you can do that then I want this.' Almost immediately the specification has to alter. Design tends to be a fairly organic process and it needs to remain flexible right up to the prototyping stage. Frequently there will be changes, sometimes fundamental changes, in the components of a specification right up to the point where the first

production prototypes are built. Even beyond that, and after validation, which generally involves field trials with customers. Often there will be feedback from that because there were unforeseen issues.”

A similar view was expressed by several other participants. Late design changes are expensive, difficult and frustrating for those involved. If requirements are clearly expressed early in the process good design can be achieved more easily, at a lower cost and probably with a more satisfactory result.

7.3 Review of the BS 8887-1 Design Process

The design process as detailed in the standard is now examined and compared with comments from participants. BS 8887-1 addresses the following stages in the life of a product: piece part manufacture; assembly; use; disassembly; piece part reprocessing and materials recovery or, if absolutely necessary, parts disposal. This sequence and the terminology used are shown schematically in *Figure 7.4: The Stages in the Life of a Product and the various DFX Terms*. The right hand side of the diagram shows product reprocessing as part the normal cycle.

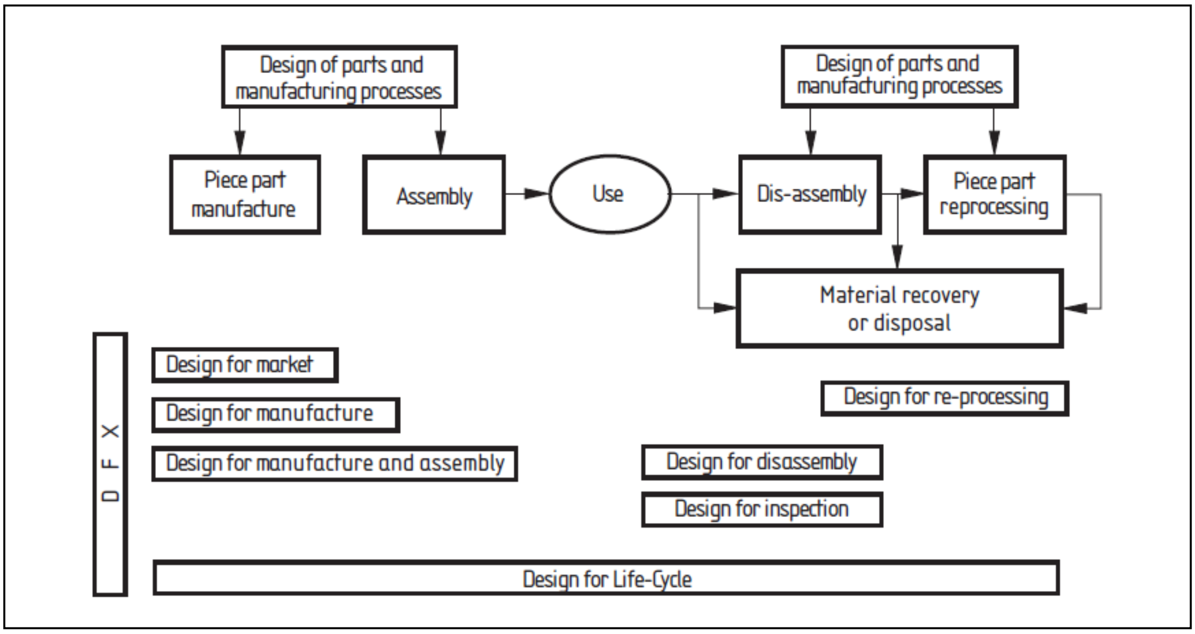

Figure 7.4: The Stages in the Life of a Product and the various DFX Terms - BS 8887-1 (2006 p. 5)

In *Section 6.2* of BS 8887-1, a *Best Practice Sequence of Events for NPD* is given as follows:

- Orientation Phase (consideration of marketing brief / design brief).
- Definition Phase.
- Outline Design.
- Feasibility Studies.
- Prototype Design.
- Prototype Evaluation and Feedback.
- Realization Phase.
- Detail Design.
- Life Cycle Considerations, Including End-of-life Processing.
- Design for Assembly and Disassembly.
- Risk Assessment.
- Handover Phase (finalization of design).

Each of these is a subtitle in the standard. For *Section 6.2.3.2* in BS 8887-1 *Life Cycle Considerations, Including End-of-Life Processing*, users of the standard are referred to *Annex C*. Importantly, this annex contains very practical recommendations on product sustainability including:

- Materials and Components Sourcing.
- Manufacturing Processes.
- Product Use.
- Demanufacturing Processes.

- Cost, Savings and Income.

For designers concerned with the environmental impact of products, this annex is especially useful as it can be directly applied to product development and used as a checklist. These considerations are preceded with the statement: "The recommendations in this annex should be considered alongside the requirements relating to performance, commercial viability and health and safety given in the body of the standard. It is for the designer and / or relevant design collaborators to decide on the relative priority to be given to issues once they have been considered" [BS 8887-1, 2006 p. 33].

The standard is not a prescriptive set of requirements against which a product can be certified as compliant, but highlights the design and planning issues that must be addressed to support sustainability. Designers have to use judgement in planning for sustainability, whilst at the same time ensuring that necessary functional requirements are met. Additionally, the cost implications of decisions play a significant role as illustrated below with a quotation from a medical products company:

> *"As much as possible is recycled. The parts that can't be reused are kept as small as possible for disposal. Much of this is based around the fact that it costs to dispose of electronic products. It makes sense to reduce the cost of disposal."*

In another example from an engineering company, the standard had been purchased specifically to guide a project which had an emphasis on sustainable design:

> *"In the past, environmental impacts were not considered. The bulk of the products are very old legacy designs. Much of the design work being done*

now is a response to environmental challenges. The older products can't be changed because of the acceptance process. With the newer product, we are trying to design for longer service life, less waste, and less need for maintenance."

In some instances engineers found it difficult to make changes to existing designs or to the materials selected for use in their products because of their proven performance. This example is from a marine engineering specialist:

"The standard was ordered for the design team. It was looked at, but because of the business we are in, making electrical connectors for the off shore industry, we were tied with regard to the materials we could use. We have been struggling with life cycle assessment. This is being worked on but we do not have much choice with regard to materials. Our clients prescribed what materials must be used. These will have a proven track record for use in extreme applications working off shore."

The BS 8887-1 *Best Practice Sequence of Events* [BS 8887-1, 2006 p. 8] features several differences from *Figure 7.3;* most notably with regard to sustainability it contains *Life Cycle Considerations, Including End-of-Life Processing* and *Design for Assembly and Design for Disassembly*. This latter requirement was sometimes unintentionally achieved through DfA:

"In terms of companies applying it, I think many of them are doing it as part of the design process they go through, sometimes without recognising it because they are designing for assembly. Obviously the links between that and disassembly and remanufacture are strong."

Just because something is designed to be easy to put together, doesn't necessarily mean that it can come apart easily. For example, a company working with lasers had designed their product for assembly, but had not designed for disassembly because they did not want it to be taken apart for security reasons, specifically they did not want competitors to disassemble and reverse-engineer it. To prevent disassembly, the commercially sensitive technology was encased in resin potting. The company concerned was a small and highly innovative pioneer in its sector. Major competitors had been known to steal their ideas in the past, using the resin was a method of protecting their Intellectual Property (IP) for longer.

7.3.1 BS 8887-1 Design Process and Management

Under BS 8887-1, a 'MADE Design Team' is required for the development of the design brief. This team should have competent representatives of critical disciplines including:

- *"Sales / Marketing.*
- *Research and Development / Design.*
- *Manufacture.*
- *Quality Assurance.*
- *Customer Service.*
- *Take-back Facilitation.*
- *Health and Safety.*
- *Environment"* [BS 8887-1, 2006 p. 8].

Critics of this approach might brand it as 'design by committee' and argue that product development could lack a unified vision. Strong leadership should overcome this problem, enabling a project to benefit from collaboration between people with various specialisms. "Cross-functional teams provide an avenue for participants to express concerns, as well as enhance organizational learning, and more effectively manage complex decision-making processes. Cross-functional project teams should be established early in the NPD process and include members from design engineering, manufacturing engineering, planning, marketing, purchasing and logistics. Early involvement allows for early problem identification, better cross-functional coordination and faster decision-making" [Ellram *et al.,* 2008 p. 1626]. Collaboration between representatives of various and diverse disciplines is common in commercial industrial design. Some views expressed by participants on this topic are as follows:

> *"When a project goes out, various members of the team discuss it and put together a specification. This can involve our moulding experts, the designers, the PCB designer, our motor expert or whoever is required. It will then be taken forward by the senior designer."*

> *"The design activity is concerned with bringing different disciplines together in different ways."*

> *"A multi-skilled engineering group can redesign things with whatever end-of-life requirement aims are specified. If we are asked to re-design a car body with more common materials and to do design for disassembly we could do that. It is well within our engineering capability."*

The early stages of the design process determines 70-80% of a product's features, manufacturing methods and costs [Andreasen and Hein, 1987; Cooper, 2001, cited in Dekoninck *et al.,* 2006 p. 123]. Inclusion of people with expertise in product *Take-back Facilitation* and *Environment* in the MADE team, should improve the EoL value of the product being planned.

There was unanimous agreement among those interviewed, that the beginning of the design process is the optimal time to apply life cycle planning, as shown in the following quotations:

> *"Design for the environment should be planned right at the beginning; you can't leave it too late. It needs to be right at the beginning or you get to the prototype stage and it is too expensive to go back. The concept needs to be applied right from the start."*

> *"Compliance with standards is something that's constantly revisited throughout the design process. If something doesn't meet the requirements, then it has to be changed, and it's easier to do that at the prototype stage than when you have got production tools."*

> *"The battle is to get engineers to think about the environmental impacts of what they are doing. I take issue with people who say you can't do it at the design stage. You have to do it at the design stage. That is the bit where you can have the biggest impact. The bulk of my experience is in manufacturing and quality. By the time I get the product it is too late to have a lasting impact on the design form. The original designer had more opportunity to influence the environmental impact than I am going to have as the manufacturing person."*

A commercial product designer's job is to interpret a client's brief into a product that can be manufactured and sold. Too often the brief is inherently unsustainable and the decisions that could make a significant difference are taken at management level before designers are even engaged in a project [Greenwood, 2008 p. 29]. EoL processing is a new area for design managers but it is starting to gain recognition. The financial implications of these processes can be an obstacle when the activity is not profitable, as commented on by an engineer at an auto parts firm:

> *"A good product should not die because it can't be recycled. In some instances recycling could cost as much as the product itself."*

There were instances where BS 8887-1 had been used to positive effect and had influenced working practices, as commented on by a design and development manager at a different automotive parts company:

> *"In reviewing the standard, I have been through each of the sections to tie it in with what we do, and if necessary I have changed what we do to help fall in line with that, as long as it doesn't contradict anything that we are already trying to do for other standards. The interesting thing for us is the end-of-life information because of the ELV regulations."*

This quote further supports the hypothesis that EPR legislation will stimulate the use of BS 8887.

Not all of the standard's users were motivated by its sustainable design content. The DfM information had prompted the acquisition of the standard by a company reviewing and applying Value Analysis (VA) to their product range. This was a construction firm specialising in building support systems. It transpired that BS 8887-1 was part of a batch of standards bought to assist with product optimization for manufacture. In this instance the working method was to gather relevant reference documents and develop a procedure for the company's product design review based on this information. Financial considerations can still be seen to dominate decision-making during the design process. The quote below is from the senior design engineer leading the review:

> *"The goal is to value analyse each item beginning with those with the highest volume of sales... and ask 'Can we reduce the cost?' or with the larger products 'Can we improve the efficiency and reduce the cost?'... If the weight of a casting can be reduced by 10%, the cost will be reduced by almost 10%."*

This highlights the relationship between efficient design, materials savings and financial savings. The use of standards can assist with each of these factors.

7.3.2 BS 8887-1 and Documentation

Documentation is the subject of *Section 13* in BS 8887-1, which lists documentation requirements for design, manufacturing and EoL. Design documentation has to be prepared, maintained, and archived so that the information is available for reference, maintenance and future product development. EoL documentation includes the following:

- *Identification of Materials*
- *Reception Location for any Take-back Scheme*
- *End-of-life Processing Instructions*

Finally, a method has to be implemented by which access to product documentation can be maintained for the foreseeable life of the product. It has previously been argued that designers should provide users with simple clear instructions for the disposal of products at EoL including recycling and reuse [Howarth, 2004 p. 13].

The value of BS 8887-1 in document management is discussed below:

> *"BS 8887-1 has been helpful in... creating a set of documents... with recommended methodologies and processes including: design brief, specification, technical documents, marketing materials and through the whole range of recommended documentation."*

Proper documentation and a full audit trail were important to some environmentally aware commercial customers:

> *"The company is currently looking at more environmentally friendly ways of producing electronics. This is an ongoing process as designs are updated. This is not only for internal purposes but is being driven by customers. More and more customers are requiring us to find out where the components have come from and to see the audit trail. There is a minimisation of the environmental impact of our products, and that is being driven by the general market itself."*

7.4 Criticisms of BS 8887 and Closed-loop Production

It is tempting to write about BS 8887 in wholly positive terms as it takes a valuable step towards making industrial production more sustainable through the application of good product life cycle planning. The standard is a high quality series of documents, produced with professional but largely voluntary labour, and is from one of the world's most respected institutions. It is however a usual part of the research process to critically evaluate the subject [Denscombe, 2002 pp. 27-28]. Critical analysis helps to build a fuller and more representative picture of a situation and can help to identify opportunities for improvement and development.

During the course of the research there were many interesting examples of companies trying to make their products more environmentally friendly. A whole chapter of this thesis could be filled with case studies in the many, varied and often highly technical challenges faced by environmentally responsible manufacturers grappling with the complexities, conflicts and compromises involved in selecting the most appropriate design solutions for their products. Instead, a focus on BS 8887 and closed-loop production has been maintained. The comments included are limited to only those directly concerning the standard, the production philosophy that it promotes and some closely associated issues.

During the research interviews, participants were asked if they had any criticisms of BS 8887-1. They were also asked about their experience and views regarding closed-loop production. Some of the resulting comments are considered below.

7.4.1 Criticisms of BS 8887

Standards are written by consensus; therefore they are sometimes not as demanding as they could be. They may be regarded merely as statements of basic requirements. This was the view taken in relation to BS 8887-1 by an eco-design consultant:

> *"The standard can be part of the process, but we tend to apply other types of frameworks and see standards as a minimum requirement. We don't see them as the solution, but as part of the overall approach."*

Another participant questioned the intended audience for BS 8887-1:

> *"The standard is very well written but it doesn't tell me anything I wouldn't expect a designer to be doing. I don't know who this is aimed at? It is possibly aimed at people who don't know what the design process is about.*

If I gave that to my staff and said 'We are now going to work BS 8887-1' they are going to say, because I am dealing with men not school-kids, 'We are experienced designers and we already do this.' I have yet to see the benefit in this because to me it just states what you should be doing in any case. To me it is just another document saying this is what you are supposed to be doing - yet another document!"

Perhaps this view is to be expected, since standards are based on established knowledge and best practice. They are not about radical or even new ideas, although steady effort is made to keep them up-to-date. By contrast, the well-proven nature of the content of BS 8887-1 was commented on more positively by another design consultant as follows:

"Many experienced people have been working hard to develop it. The wording is right for somebody who is new to this area. It can be a very useful guidance document."

There was some uncertainty about how the standard was presented and how it was to be treated. The following comments are from engineers at three different companies:

"Should it be viewed as a guide, or is it something that a company could certify against? I wouldn't read it and think I need to adhere to all these points, but I would if I had to certify to something. There are aspects in the standard that could be cherry-picked and taken on board. Only applicable sections will be read."

"BS 8887-1 is a voluntary standard so we don't have to be certified. We are a best-practice company and so we use some but not all of the principles in

the standard."

"The standard is voluntary and not a diktat. The requirements of the standard must become a compulsory diktat if they are to be applied universally. If it is not a diktat it is not a standard. Instead it is guidelines."

BS 8887-1 is a specification, and like all standards except those referenced in legislation, it is voluntary. It has not been prepared as a standard against which organizations or products can be certified. There is no BS 8887-1 Kitemark, although the development of a certifiable BS 8887 standard has been a subject of discussion at TDW4/7 meetings. The notion of a scheme of accreditation to an environmental design standard was a generally popular idea and is something that may be worth developing:

"If the designer could say that the design was based on BS 8887-1, that would infer a measure of conformity as there is nothing else around like it."

One difficulty of making compliance with a product life cycle planning standard certifiable is that judgement is required in the application of life cycle design principles. The best life cycle solution may be different for specific types of products. As a comparison, automotive glass is commonly Kitemarked to demonstrate compliance with BS 857 (1967) *Specification for Safety Glass for Land Transport*. This is relatively straightforward as the product can be tested against the requirements of BS 857. It may be possible to overcome this difficulty by developing product specific sustainable design standards against which relevant goods may be tested.

The need for both specific and general BS 8887 standards was recognised by an engineer as follows:

> *"One of the problems is that the standard has to be general while we are really looking for information relating to our own product. Our product does not have many standards specifically relating to it."*

Not only did users of BS 8887-1 want more information relating to their own industry, there was also a demand for greater depth concerning some of its core areas. The need to extend the BS 8887 series beyond the *General Concepts* of Part 1 was particularly evident from the following:

> *"I was more interested in end-of-life and remanufacturing. I wanted to see what it suggested and what best practice was. I was hoping that would be in there but there isn't much advice on that at the moment. With remanufacture and refurbishment, there is a lot of confusion over what exactly these things are."*

The difficulties of understanding the BS 8887 terminology should now be largely resolved following the introduction of BS 8887-2 which gives terms and definitions. As well as addressing specific requirements, it was also suggested that more general environmental strategy be included:

> *"Other sustainability information that could be included in the standard might relate to ideology, such as using sustainable energy for the manufacture of products."*

This suggestion is probably beyond the remit of BS 8887 as it is a DfM and product life cycle standard. The scope of BS 8887-1 does not expressly include sustainability or eco-design but does include aspects of product design that influence these issues. "In addressing end-of-life requirements, this British Standard extends beyond specification for the manufacture and assembly of products to incorporate recommendations on how best to incorporate into the documentation, guidance on the ultimate reuse, recovery, recycling and disposal of the components and materials used" [BS 8887-1, 2006 p. 3].

Some of the participants questioned whether sustainable design requirements should be written into a standard. The following comment is from the director of one of the consultancies contacted:

> *"Standards imply 'you have got to do it like this.' A multitude of different ways might be acceptable, which raises the question of why should a standard be necessary?... Perhaps it just needs design guides?"*

Another consultant at a different practice raised a similar objection:

> *"There are quite a few problems with standardization in sustainable design. You can't standardize it to the point where a company can apply a generic framework. The application of eco-design or life cycle thinking varies a great deal between sectors and businesses. Sustainable design is more than just the design of the products, processes and services; it is also about the culture of the organization."*

Eco-design becoming part of an organization's culture may be ideal, but meeting the requirements of a relevant standard should be helpful. There is nothing to stop front-runners exceeding the minimum. The content of BS 8887-1 associated with eco-design mainly appears in *Annex C Life Cycle Considerations*. This is purely informative and not prescriptive.

Part of the purpose of BS 8887-1 is to specify the use of ISO standards in the design process. The referencing of other standards was a source of frustration for some:

> *"...you can't pick up a specification without needing five or six others that are referred to, which gets very annoying."*

> *"I would like to have all that information in one place but this might lead to duplication of information."*

Avoiding the duplication of information is indeed the reason standards frequently reference other standards. By limiting the scope of individual standards, and thus having more of them but each with a tighter focus, it is possible to update only those affected by recent advances in a given field.

In addition to industry practitioners questioning the need for BS 8887-1, its presentation as a standard was also of concern:

> *"It's just the simple fact that it is a text document. You have to sit down and read it. If for example BS 8887-1 could be made into a very user friendly website where it is easy to access the information, that would be good. Also, you have to pay for it. That is a negative that puts stops on people reading it."*

> *"It's just the reality that if a designer is faced with a bulky written document that they don't necessarily have to look at ... they will try and avoid it."*

The criticism that it is a text-based standard and therefore not user-friendly may be more of an issue of perception than reality. There may be a case for expanding and presenting selected aspects of the standard in an alternative format as supporting material. Many of the people who had read the standard commented favourably on its style:

> *"It is very much a how to guide. Reading through it there is some technical information and some maths but it is almost conversational when compared with older standards... The principles contained in it are easy to understand."*

> *"BS 8887-1 is readable and usable on a practical level when compared with other standards. Normally standards can be a little bit impenetrable. They are highly technical documents by their nature."*

> *"BS 8887-1 is practical and well written. It is one of the best written reports or standards I've read. Some standards use very technical language that is difficult to understand. BS 8887-1 is simple because it describes solid principles."*

The price of standards varies depending on their complexity, ranging for BSI standards between £12 and £1,800 [BSI, 2009a]. At the time of writing, BS 8887-1 was priced at £85.00 for BSI members and £170.00 for non members. This may be prohibitive for some. Standards are copyright material and income from their sales supports the work of BSI, as do government contributions and membership fees. However, standards are available to view free of charge in some public libraries, often through BSOL.

The significance of BS 8887-1 comes from it being a full British Standard. Some participants questioned the value of the BS 8887 series given that it is not an ISO standard and because Britain is losing its place as a global leader in manufacturing. The high perceived value of

ISO standards as opposed to national standards is demonstrated by the following comments. These are from an off-shore engineering company and a vehicle components producer:

> *"...even though we generally work out of the UK, we are not specifically tied to the UK. We are dealing globally. The International Standards would be the first point of call..."*

> *"BS 8887-1 was reviewed to keep ahead of end-of-life requirements. We had a genuine interest in the standard despite there being no specific need. The standard will never formally be used. Our products are sold worldwide so only ISO standards are used in the design process. Some products may have to meet standards specific to their intended market. Generally British Standards are only used for reference purposes. BS 8887-1 would have to become an ISO Standard before it would be considered for formal application... BS 8887 needs to be an ISO Standard."*

The BS 8887-1 MADE standard did not meet the needs of all those that bought it. In an example relating to the nuclear power industry BS 8887-1 had been ordered, considered, and rejected because of pre-existing constraints. The organization specialised in decommissioning work and had been drawn to the standard by its title. However, they could not use it as they were prevented from making changes to their working methods:

> *"If something is to be removed from a plant, safety procedures have to be considered. Different methods of doing it are assessed. This process is called 'optioneering'. Various disciplines are involved to understand what will be affected by the removal of the equipment. There are different Hazard and Operability (HAZOP) phases for each process. We had wondered if*

there was anything in BS 8887-1 that was of interest but we were bound by existing procedures."

Despite these criticisms and constraints the standard has been generally well received, although opportunities for further development remain.

7.4.2 Criticisms of Closed-loop Production

One of the major challenges of closed-loop production is the logistical difficulty of retrieving post-consumer products. This was mentioned by several engineers, and examples from four different companies are given below:

"Our products should be reasonably easily to recycle but, will it get put into the correct waste stream by the end user when they replace it?"

"The end user can be difficult to persuade to recycle. Not everyone wants to save the planet. Design for the environment requires lots of effort. We can do it but will the user?"

"The problem is that once a component has been sold, it becomes the customer's property. The customer won't necessarily bring it back for recycling."

"End-of-life product is never returned. The supply chain works in one direction. The reason is that military products are exempt, and secondly our equipment would be used in the middle of a battle field, for example in Afghanistan. We are certainly not going to go out there and get it."

"Business will only embark on large scale eco-design if this will contribute to their internal and external value chain" [Tukker *et al*., 2001 p. 159] An important advantage of closed-loop production from a business perspective is that "The reverse logistics process may be a source of competitive advantage for the firm: assets can be recovered, costs can be reduced, value can be recaptured from the disassembled products, customer service levels can improve and loyalty may increase" [Dault, 2002 cited in Ellram *et al.*, 2008 p. 1625].

If product is returned to the producer, often the next challenge is how to deal with contamination:

> *"When they are retired from service, because they have been on the battle field, they cannot come back to the company directly because of all the contaminants that they will have picked up. It is not worth the company at the other end sending anything back to us, because of the cost of putting it through decontamination chambers and shipping... We do get some products returned for repair. These have to go through a cleaning and decontamination process before being opened."*

> *"At the end of the product's life the equipment will be contaminated either medically or with sewage and this creates its own problems. The materials from which the products are constructed can easily be re-processed as they are not exotic. The main materials used are stainless steel and cast iron, so their recyclability is very high."*

Issues of contamination were of high importance for medical device producers given the potential to adversely impact patient safety:

> *"The majority of our work is concerned with the development of medical*

devices. Patient safety is a key driver with these types of products. Having devices that are reusable is difficult. Using regrind material is clearly not acceptable from a medical device perspective. Typically the drivers are more to do with patient safety and drug compatibility. The compatibility is a key driver rather than whether it is sustainable... The products are inhalation devices for drug delivery. They have intimate contact with the patient. We are also involved with surgical equipment which would typically be for single use. The type of products commonly developed by us would be incinerated after use. This makes things easier with regard to issues such as the transfer of diseases. It is sometimes difficult to clean and sterilize products to the level that one can be confident that everything has been got rid of. Sometimes it is easier to make a single use device and then incinerate it."

Contamination of secondary materials from used products was discussed by a large UK manufacturer that makes automotive parts, military equipment and medical devices. During one interview an example product was shown. This was an oil filter constructed from two different types of plastic, metal gauze and paper held together with glue and sealed in place with a rubber O-ring. It was recognised that these could be redesigned for disassembly, but the additional cost could not be justified for the following reasons:

1) *The filter was distributed worldwide. At the EoL stage it would be logistically difficult to collect used filters.*

2) *The filters would be contaminated with oil or whatever other fluid they had been used with - similar products were supplied to the brewing*

industry. This contamination would necessitate a cleaning step prior to any parts re-use or recycling.

3) If it were made possible to recycle the filters in some way, there would still be the difficulty of changing the user's behaviour to return them, or place them in the appropriate waste stream.

As a result of these anticipated problems and costs, it was not considered economical to recycle the product, and there were no plans to redesign it in a way that optimised it for remanufacture or recycling. It was thought likely that the cost of manufacturing a new filter would be considerably lower than that of collecting, cleaning and reprocessing a used one.

"For similar reasons to the filters, medical devices would be difficult to reprocess, and would present the additional problem of being biologically contaminated."

Despite an awareness of the environmental impact of the products being manufactured at the company, and a desire to move towards more sustainable production through the use of life cycle analysis, closed-loop production was considered wholly impractical for the products under review. It was however noted that recycling technology is rapidly improving and that ultrasonic component cleaning might form part of a viable process in the future.

Even if the end user can be persuaded to return a used product, and if this becomes logistically feasible and the product can be cleaned and decontaminated satisfactorily, there are still further challenges in changing the altitudes of users:

"Remanufactured product is perceived to be of lower quality."

For some types of equipment the solution can be to lease rather than sell. Leased equipment is not necessarily expected to be new. Instead the user or customer pays for the service the product provides, rather than the product itself. The OEM, subsidiary or agent will retain greater control. This approach can also increase product utilisation.

Adherence to BS 8887-220 should help to change the poor perception of remanufactured products. A fundamental requirement of true remanufacture is that the equipment going back into service following this form of reprocessing is equivalent to new. Some participants argued that this is not possible with certain items as they may have been fatigued by their first use cycle:

> *"There is no call for refurbishment or remanufacture because we deal with* [railway] *points... Safety is the critical area of concern. When dealing with old parts, you never know what kinds of stresses have been applied to them. You wouldn't risk it; you just go for a new part where you know the life it has had so far. If an old product is returned to the factory, it is put in the metal recycling bin."*

Despite these challenges there are strong reasons for continuing to work towards closing the conventional linear production model:

> *"We are keen to go down a more sustainable route. It's... good for the environment, and sometimes it can make economical sense."*

Criticisms of closed-loop production relate to:

- User behaviour.
- Perceived lower quality of remanufactured products.

- The difficulty of fatigue-life in safety-critical applications.
- Products or product groups where there are additional specific difficulties with reprocessing, especially contamination.

The principle of closed-loop production met with general approval, but product specific requirements and the economics of closed-loop operations meant that this type of production was seldom considered to be viable.

7.5 New Product Life Cycle Model

An original diagram of the industrial product design sequence and life cycle management is presented in *Figure 7.5: New Product Design Process, Materials Cycle and End-of-Life Routes Model.* This is an idealised view of how products should be developed and managed more sustainably. It is a combination of previous diagrams that have for the first time been developed into a single unified model. The left-hand side of the diagram is based on *Figure 7.3: Design Activity Model*. The output from the design process enters the *Materials Economy* portion of the diagram from *Figure 7.1: Conventional Production* towards the top of *Figure 7.5*: New Product Design Process, Materials Cycle and End-of-Life Routes Model.

Both design and manufacture are concerned with adding value to materials through the creation of useful products. As the process requires considerable investment, there should be economic advantages to keeping products, or at least parts of them, in use through extended service life strategies. If service life extension is not feasible, then value should be recovered through recycling. The triangular section of *Figure 7.5* is a hierarchy of options for products following their initial use phase. It is based on the *Product Life Cycle* diagram in BS 8887-220 which places the various options in order of being more environmentally preferable, as indicate by the arrow on the right hear labelled 'Benefit to Sustainable Development'.

Remanufacture is at the top of this hierarchy as it brings products back to a condition equivalent to new. The process requirements for remanufacture and reconditioning are specified in BS 8887-220 and BS 8887-240 respectively. BS 8887-240 features a similar diagram to that in BS 8887-220 but with the arrow removed following a comment from industry that there are exceptions where remanufacture is not the most environmentally preferable option. However both versions are published and current and the hierarchy remains true in most cases.

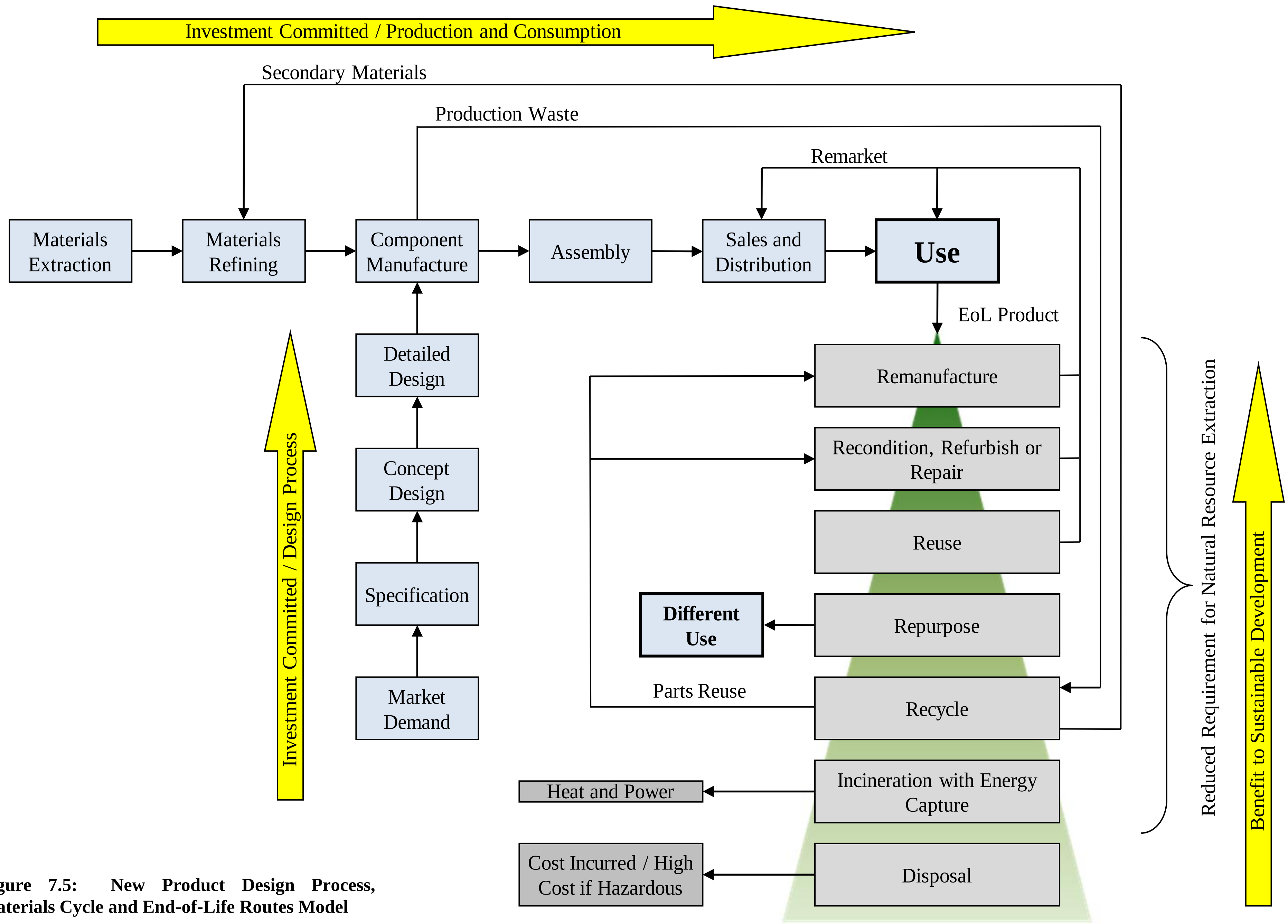

Figure 7.5: New Product Design Process, Materials Cycle and End-of-Life Routes Model

Closed-loop design and manufacture may also increase the opportunity to collect in-service product performance data. Service engineers and remanufacturers, as well as OEMs who take back their own product can pass performance information into the design and development of the next generation of that product. The collection of this data should help to enable the identification of weaknesses with a design thus informing future product development.

The emphasis of the model is the direction of design and production effort towards the use phase. It also represents a continual movement of post-consumer product back to a high value saleable usable condition, whilst diverting waste from landfill and incineration.

7.5.1 Validation of New Product Life Cycle Model

The diagram shown in *Figure 7.5* combines three established models to produce a novel, unified view of the product life cycle. The work was reviewed by several academics at Brunel University before being presented at the 16th Sustainable Design Network (SDN) Seminar. Minor improvements and adjustments were made to the model in response to comments.

CHAPTER 8 Main Study (Part 2) Integrating Life Cycle Design Standards in New Product Development

In this chapter emphasis is given to both profitability attained though DfMADE and methods of incorporating BS 8887-1 requirements into NPD. The aim was to determine where and how in the design process BS 8887-1 may be usefully applied.

8.1 Financial Benefits of MADE

This section presents examples where the BS 8887-1 product life cycle planning approach has had an economic benefit for its users.

At a manufacturer of cellar cooling systems for public houses, the standard was purchased because the company was asked by one of the breweries to provide information about whole life costing for their product and particularly end-of-life:

> *"The reason for purchasing BS 8887-1 initially was so that we could bring the reliability of a British Standard to the information that we were providing to our customer and to show them that rigour had been applied..."*

Following this, the company used concepts from BS 8887-1 in their new designs:

> *"There were a number of reasons for us to start the process. At the top of the list was ease of manufacture. We found that many of the processes and practices that BS 8887-1 encourages fitted-in well with our production engineering philosophy. Usually, the easier you make something to build, the easier it is to disassemble. There will be fewer parts, fewer fastenings and the mass of certain parts will be reduced."*

Planning for product EoL processing was also an advantage in winning business:

> *"It is taken as read that at some point in time the customer is going to have to dispose of the equipment... Someone is going to have to deal with it. If it is us, and we are offering to do that, we want to make it as easy as we possibly can... If we are to deal with end-of-life products, we will want to reduce the burden as much as possible. Also, we want to reduce the leverage of the customer... We do not want issues of disposability to be a barrier to sale."*

The company's latest product, a new package condensing unit that had recently moved to production, was developed with reference to the standard:

> *"Some of the principles of BS 8887-1 were adopted into that, so the unit is now 98% recyclable. We try to use parts that can either be completely reused at the end of the unit's life, or if they cannot be reused then it will be possible for them to be recycled and used again in something else."*

This approach had strong commercial advantages:

> *"A customer will calculate the cost of disposal... and demand that this is deducted from the sale price. A package condensing unit probably would cost £50-60 to dispose of. This reverse calculation may make only a small difference to the overall cost of each individual product, but when in the business of selling many hundreds of units of a particular piece of equipment, this soon becomes significant."*

In a similar way, DfD and recyclability was used as a selling point by a catering equipment manufacturer:

> *"We are trying to design equipment with fewer parts so that it is easier to recycle. This makes it attractive for customers to take responsibility for it rather than us... Stainless steel is a high value commodity... To make it attractive for the end user to pay their own recycling fees to dispose of their products, we make sure that the electrical panels are removable rather than integrated into the unit. These parts can then be taken out at a low cost and recycled. The high value stainless steel then gets apportioned accordingly."*

In addition to designing products to be suitable for reprocessing, design for maintenance and durability should be given serious consideration in design specifications. Improved durability can help to reduce the demand for replacement goods and support the secondary market. Products that have been designed for durability are likely to be particularly suitable for leasing, an approach that can provide a constant revenue stream for the supplier whilst enabling the OEM to retain greater control of their products. Leasing reduces the maintenance and upgrade burden for the customer, and passes EoL responsibility back to the supplier. This model was used by a producer of medical beds. The beds featured various powered articulated sections as well as electronically controlled pneumatic mattresses that constantly varied the pressure on the patient's body to prevent bed-sores from forming. For this company it was preferable to offer both a product leasing option as well as sales. The participant was from the company's UK design office where he was an engineer. He was also responsible for the management of regulatory standards for his team:

> *"Our products are sold globally, predominantly for hospital use, but also for home use as well... Used products are returned to the repair centre via the*

service centres in more than twenty countries... The beds are supplied as a mixture of rental and sales. If equipment is leased, we have full responsibility. When it is sold, it remains in service for many years, often with multiple refurbishment cycles... Consideration is given to how product can be recycled or refurbished... As long as the functional performance of a material meets the design requirements, is reasonably inexpensive and can be recycled, it should be suitable. Some parts from used products are refurbished for reuse. This is anticipated at the design stage. Refurbished components are used in leased product and not sale items..."

Design for durability, disassembly and maintenance in line with BS 8887-1 has been used to promote the sale of a company concerned with the development of aircraft components that last longer, and can be disassembled and repaired more easily than the current equivalent in-service versions. This use of the standard was prompted by the author's paper 'Design for Life (and Beyond)' published in *The Journal of the Institution of Engineering Designers*. The company's director described his ducting jointing product and discussed the advantages and disadvantages of design for durability as follows:

"Ducting is used to take air from the engine and along the wing for cabin pressurisation as well as for transferring air to other areas around the nacelle for de-icing. Ducting is also used for crossover air starting with another engine. The clamps are used wherever there is a joint in the ducting. The joints also require flexibility. There may be as many as twelve flexible joints on an engine installation and 20-30 rigid joints. Air is taken from the compressor on the engine. This is the section before the turbine.

What the air is to be used for will determine which section of the compressor it is taken from. This may be a mixture of intermediate and high pressures. Air is taken out from tappings on the side of the compressor. This is passed through a series of reducing valves. Most of it makes its way through the ducting for cabin pressurisation. The air is passed through various filters before entering the cabin. Without air from the engines the passengers couldn't breathe...

We have designed a new product that falls in line with DfMA ... Boothroyd and Dewhurst have organizations around the world promoting the concept of DfMA. We were doing this long before they came into the picture, but they have only got as far as DfMA. Expanding DfMA to DfMADE that's fine, but... if we are going to design for life that could put many companies out of business if we are not careful. Many businesses in the world today make ... significant profits from supplying the parts that need replacing on in-service aircraft. They don't just sell a power plant, they sell a package including all the parts that go with it over a number of years... If someone comes along and offers a new part that is designed for life, [the OEM] *will say 'this is fine, this is going to save us some money' where we are not replacing as many parts. However, the people who are producing these parts will say 'if we provide a unit that is designed for life you won't buy so many units from us. That's going to reduce our business.' If you are going to have long durability you are not going to sell so many."*

The aircraft parts example illustrates the challenges of designing for durability verses obsolescence, through the wear-out cycle in this case. The OEM was motivated to use more durable components since this would enable them to fulfil their service contracts at a lower cost as they would not have to replace the ducting components as frequently. The component manufacturers were not keen to start producing the improved design because they could foresee a fall in sales as a result. Reducing the number of replacement parts required over the life of an aircraft may be environmentally less negative. The design attributes of the new ducting system fell in line with the DfMADE concept, as well as being more durable. Adherence to the concepts of BS 8887-1 was used to promote the sale of the company and its IP to potential buyers in America.

As consumers become more environmentally aware and large organizations with significant buying power develop procurement policies with an emphasis on sustainability, the business case for DfD and reprocessing increases. This is evident in the following example from a manufacturer of extractor fans. The limited influence of private individuals is also apparent:

> *"Businesses from the social sectors, social landlords such as borough councils are into appearing green. They like to have whole life cycle costing for products. They like to know that they can be stripped-down and have components replaced... They want the products to last longer, require replacing less often and run at lower cost than before... For privately built houses it is just about cost... They just need the product to be energy efficient enough to pass the SAP calculation* [Standard Assessment Procedure for energy rating of dwellings]. *The public sector is pushing for the product to be made sustainable."*

Design with consideration for maintenance can help to reduce warranty repair costs, as with this example of a lift to assist disabled people:

> *"We are making products simpler to take apart so the end users can do things themselves, rather than our having to send out an engineer to service items… Now customers can be given a guide on how to replace parts themselves. This is more cost-efficient."*

At the same factory, benefits were also gained through disassembly of returned product:

> *"By separating products into their various parts, the cost of WEEE disposal is greatly reduced."*

Interest in the standard frequently related to its DfM content, as with this example from a company producing equipment for the construction industry. BS 8887-1 had been purchased to help with reducing costs through design improvements. It was used along with computer aided engineering (CAE) software as part of a Value Analysis (VA) review. BS 8887-1 lists the steps necessary for the similar technique of Value Engineering (VE).

> *"The design for manufacture part of the standard was the motive to order it rather than the end-of-life processing content. Today we have new equipment for FEA* [Finite Element Analysis]*... to reduce the weight of castings by removing unnecessary material from the design"*

BS 8887-1 explains that VE is used in NPD, whereas VA is applied to existing products. VE is a process of eliminating features and components that add cost without adding value to a design. The objective of VA is to deliver equal or better value at a lower cost than the previous generation of the same product. Part of the purpose of industrial design is to gain a competitive advantage through the economic use of materials.

8.2 Techniques in New Product Development

In this section, a number of different methods of integrating requirements of BS 8887-1 into the design process are described and considered.

8.2.1 MADE with Management Systems

ISO 14000 exceeds ISO 9000 in its requirements to consider the inputs and outputs of organizations [Sambasivan and Fei, 2008 p. 1428]. With ISO 14000, environmental impact of an organization is reduced through the implementation of good procedures and continual improvement. Environmental consciousness within industry is partially motivated by the creation of certain standards. In an earlier study, ISO 14000 was cited by companies as being a reason to consider the environmental issues associated with their products owing to the demands being made on them by customers operating to this standard [McAloone, 2000 p. 114].

An independent quality management consultant suggested that BS 8887-1 may be appropriate for use with ISO 14001:

> *"The standard could be referenced in a product design specification under ISO 14001 as part of reducing environmental impact... It could be used as part of the main compliance with ISO 14001, or as part of continuous improvement."*

A similar idea was expressed at engineering company working to improve its environmental performance:

> *"Following an ISO 14001 audit, it was identified that as a technical department we aren't yet putting enough focus on such things as product life*

cycle assessment and end-of-life disposal etc. Following the audit we are now in the early stages of addressing the environmental impacts of our products by prompting engineers to consider, during the design review process, such things as:

- *Use of materials with low toxicity*
- *Effects of product usage or product failure on the environment*
- *Designs that avoid wasteful machining operations*
- *Ability to recycle product and packaging*
- *Recycling of waste from the manufacturing process*
- *Requirements for new controls for spillage and waste management*
- *Environmental impact at end-of-life*
- *Communication of environmental controls to the customer"*

A quality manager from a small automotive manufacturer and an electronics engineer from another company had considered BS 8887-1 in connection with management systems:

> *"We have used the standard for awareness purposes, to complement our approach, especially in our environmental management system for the benefit of our ISO 14001 certification and any potential customer requirements."*

> *"We were looking at the third part of the standard; particularly post-design*

services, and how to design for the future. We were aware of it through work on the company's quality system. There was a sense that we should have it on the system as a point of awareness for the people doing the design work."

ISO management systems require organizations to have manuals formalizing the processes that will be adhered to. ISO 9001 and ISO 14001 manuals are sometimes merged into an Integrated Management System (IMS):

"The quality manual is a top level overview of the system. In the procedures and work instructions that cascade down from that, standards are cross-referenced."

"The computer-based quality system... features a checklist of all the standards and relevant documents to be worked to including ISO 13485. If BS 8887-1 were felt to be relevant to the product being developed, it would be included as part of the checklist... The quality manual references standards directly e.g. ISO requirements. During auditing, we have to provide evidence of compliance with the referenced standards. This makes the audit more challenging as there are more standards to be complied with. This may be the reason why BS 8887-1 is not referenced in the quality system, but kept as a non-referenced standard to avoid that problem."

Combining eco-design and EMSs is the basis of the Product-Oriented Environmental Management System (POEMS) [Charter and Tischner, 2001 p. 114]. Both BS 8887-1 and ISO 14001 can have a positive influence in reducing the negative environmental impacts of industry, but they focus on different aspects:

> *"BS 8887-1 and ISO 14001… complement each other in that BS 8887-1 provides ways of designing products, whereas ISO 14001 sets the requirements and the checks that you need to put into place."*

If BS 8887 became an ISO standard, this would give it additional authority and international influence. However, the ISO 14000 series already includes ISO 14040 *Life Cycle Assessment. Principles and Framework*, ISO 14041 *Life Cycle Assessment. Goal and Scope Definition and Inventory Analysis*[1]. ISO 14040-14043 provide systems for addressing the environmental impacts of products throughout their life cycle [Hutchins and Sutherland, 2009 p. 241]. ISO 14006 offers *Guidelines for Incorporating Eco-design* and ISO 14062 addresses *Integrating Environmental Aspects into Product Design and Development*. In BS 8887-1, ISO 14040 and ISO 14041 are listed under *Section 2: Normative References*[2], while ISO 14062 appears as an informative reference in *Note 1* under *Section 4: Design Process*. However, BS 8887 itself may be most relevant to designers and engineers as it is practical and less management orientated.

8.2.2 MADE with Advanced Product Quality Planning

Two participants, both of whom worked for manufacturers in the automotive supply chain, discussed their use of Advanced Product Quality Planning (APQP) and linked it with BS 8887-1. APQP encourages communication between various stakeholders concerned with the development of a product. The primary goal is to raise quality through improvements to the

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[1] ISO 14041 has now been withdrawn and superseded by ISO 14044 *Life Cycle Assessment. Requirements and Guidelines*.

[2] Normative references have their own section and only call up other standards which must be used in order to fully comply with the standard in which they appear. An informative reference, often included in the notes, supports a standard by suggesting further information. For example, in BS 8887-1there is a reference to Boothroyd *et al* (1994). This appears as an in-text reference with full details in the bibliography. There is no obligation on the part of users to look at these informative references.

design process and production while involving the customer, thus guaranteeing that the customer's requirements are met [Singh *et al.*, 2007 p. 4192]. APQP was developed by Ford, General Motors and Chrysler (now merged with FIAT). The customer is often an automotive OEM, Tier-1 or Tier-2 supplier, rather than a consumer. The system has proven to be useful in a wider manufacturing context as it can facilitate significant financial savings [Piszczalski, 2002 cited in Carbone, 2005 p. 228]. The objectives of APQP are achieved through standardized procedures and reporting formats [Mitchell, 2003]. One of the companies visited used a series of customized flowcharts, the titles of which are listed below:

Phase 0:	Raise Project
Phase 1:	Feasibility
Phase 2:	Quotation
Phase 3:	Design Freeze
Phase 4:	Prove Tooling
Phase 5:	Pre-production
Phase 6:	Production

A section of their *Phase-3* APQP flowchart is shown in *Figure 8.1*.

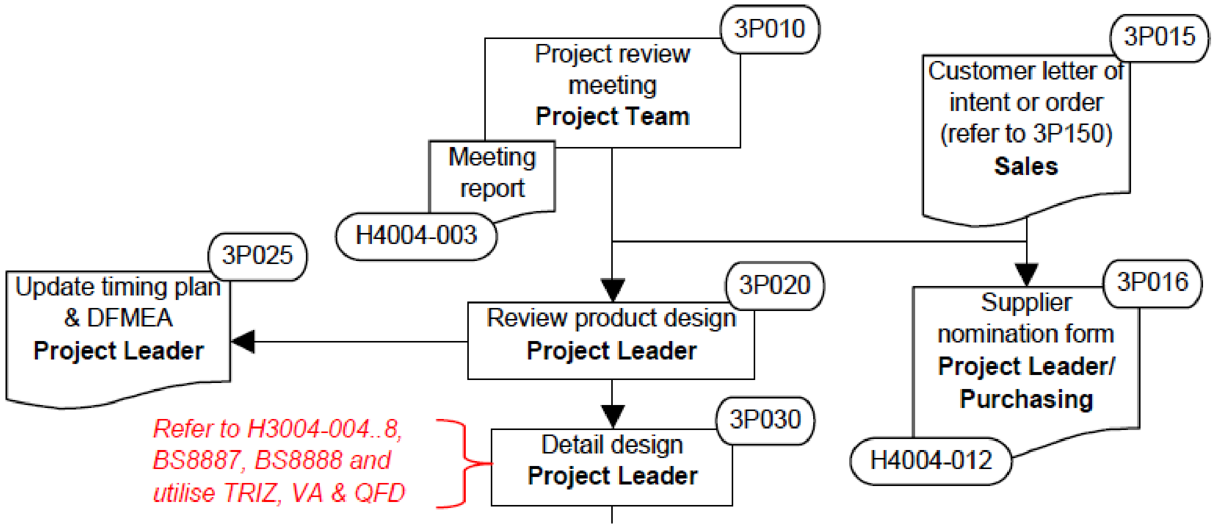

Figure 8.1: Phase-3 Part of a Company's Design Freeze APQP Flowchart

The text relating to step 3P030 in the company's internal *Work Instructions - New Product Development and Design Control* document requires the project leader to make reference to BS 8887, BS 8888, VE/VA and QFD during the detail design phase for all new products. It is important to note that referencing BS 8887 in the flowchart may result in the standard informing every design developed by the company:

> *"Although the mention is fairly cursory, these flowcharts are used regularly in project management and tend to be taken step by step. Thus each element is covered."*

APQP does not control product environmental impact but there is a link between quality planning and environmental quality [Madu, *et al.*, 1995 cited in Singh *et al.*, 2007 p. 4191]. "The overall environmental strategy in the APQP context is to subject the component to a design and process study that prevents the generation of defective products that would otherwise be disposed to landfill" [Singh *et al.*, 2007 p. 4195]. A Production Part Approval Process (PPAP) with an Initial Sampling and Inspection Report (ISIR) is used. The process requires that customer approval is obtained in advance of the full production run. Savings are thus realized through reductions in waste from production errors. APQP does not specifically address environmental issues as it is focused on product quality [Singh, *et al*., 2007 p. 4193]. The integration of BS 8887 with APQP was also considered at a vehicle body-in-white manufacturer:

> *"The automotive industry is an example of an established industry with good new product development processes, from concept through to the management of the product and every aspect of it including end-of-life. We need to put BS 8887-1 in the context of APQP…"*

8.2.3 MADE with Theory of Inventive Problem Solving

Theory of Inventive Problem Solving, 'TRIZ' was listed under the *3P030* reference on the APQP flowchart in *Figure 8.1*. TRIZ is a diverse set of structured innovation methods based on knowledge extracted from nearly three million patents [Altshuller, 1984]. The idea of combining TRIZ with BS 8887-1 and other standards was suggested:

> *"We use TRIZ quite often when developing new products. I want to end up with something that's not the same but similar, which will call up appropriate standards. Consider where you are in the design process, and the inputs and outputs, it will then act as a guide to the most appropriate elements of standards."*

It has been argued that there is an overlap in the underlying principles of TRIZ and eco-innovation [Jones *et al.,* 2001 cited in Dekoninck *et al*., 2006]. Simplified elements of TRIZ tools have been used in early-stage design experiments at Brunel University [Dekoninck *et al*., 2006].

8.2.4 MADE with House of Quality

Quality Function Deployment (QFD) uses a cascading sequence of House of Quality (HoQ) matrices through Product Planning; Part Deployment; Process Planning and Production Planning [BS 8887-1, 2006 p. 27]. These matrices are used to capture and evaluate multiple issues that are important in the product planning process and relate customer requirements with product attributes. Their purpose is to focus the design activity on fulfilling customer requirements, where the customer may be a person, company or other entity. One engineer had considered using recommendations from BS 8887-1 as inputs to HoQ. The adaptability of HoQ is one of its strengths and it has been used in different ways by various researchers to address sustainable design and EoL processing requirements [e.g. Rahimi and Weidner, 2002; Yüksel, 2010]. If the life cycle design elements of BS 8887-1 were used as inputs to the HoQ matrix, these would be evaluated and integrated into the product development process.

8.3 MADE in Education

The SIC study showed that the second largest section of BS 8887-1 customers was associated with education. Notably, one institution was using BS 8887 as the basis for some of theory elements in engineering design modules in Bachelors and Masters Level courses [University of Wolverhampton, 2009 p. 15]. The standard's product development process and life cycle approach makes it suitable for inclusion alongside the wider areas of engineering and design. Sustainable design should not be a separate subject but a set of values to be adopted by all designers [Papanek, 1995 p. 12].

The personal advantage for students in learning about sustainable design was explained as follows by a lecturer in engineering:

> *"Knowledge of sustainable design will be useful to the graduate in*

promoting himself within the jobs market. It is logical that companies would expect graduates to have end-of-life product planning knowledge, as engineers within companies will know about WEEE and upcoming legislation. They will recruit people according to what they need."

At a sixth form college, sustainable design was taught on their engineering and design course and BS 8887-1 was used as a supporting reference:

"Sustainability is now on the marking scheme and students would be downgraded if their work failed to address such issues... they are also genuinely concerned about the environment."

At another University, the motivation for teaching sustainable design came principally from members of the teaching staff:

"It is driven by the fact that the University has several members of lecturing staff who are interested in sustainability."

Despite strong interest in sustainable design, there were some perceived problems with the use of standards and BS 8887-1 as student teaching materials:

"In my experience they are often put off them by the style in which they are written... a journalistic, lightweight document... does not fit with the standard for writing standards [BS 0] *as they all have to conform to the same style... There is a perception that standards are rather dry documents..."*

This is unfortunate as standards are a source of exceptionally high quality information; and

BS 8887 is relatively approachable. By contrast, at a further education college, students were often referred to the standards collection and BS 8887-1 as part of their training:

> *"The standard itself, compared to most of them, is straight-forward. Its style doesn't really map to their expectations. Compared to the majority of standards, BS 8887-1 is more straight-forward but perception is a huge issue. Standards may be seen as impenetrable and as a necessary evil for certain things."*

At another further education college that was running Foundation Degree and Higher National Diploma courses, students were often referred to the standards collection and BS 8887-1 as part of their training:

> *"We use it mainly because we deal with automotive manufacturing and are particularly concerned with recycling... That's the biggest area where we would use BS 8887-1. We also refer to it in Design for Manufacture modules... When design specifications are written, sustainability is an aspect that would be included and particularly end-of-life cycle and product recyclability... At a very early stage in the design process they are thinking not just about the product, but what is going to happen to it at end-of-life and are considering sustainability."*

It is apparent that sustainability is an area of significant importance in various design and engineering course curriculums but the extent to which it is taught is dependent on the knowledge, expertise and interest of the lecturer charged with delivering the course content. Additionally, it can be seen that BS 8887-1 has been used as an underlying foundation to support design teaching as well as being used as a reference source for students developing product specifications with consideration for life cycle planning.

8.4 Environmentally Sensitive Design in New Product Development

A second new variation on the design process is presented in *Figure 8.2: Model of the Use of Standards in New Product Development.*

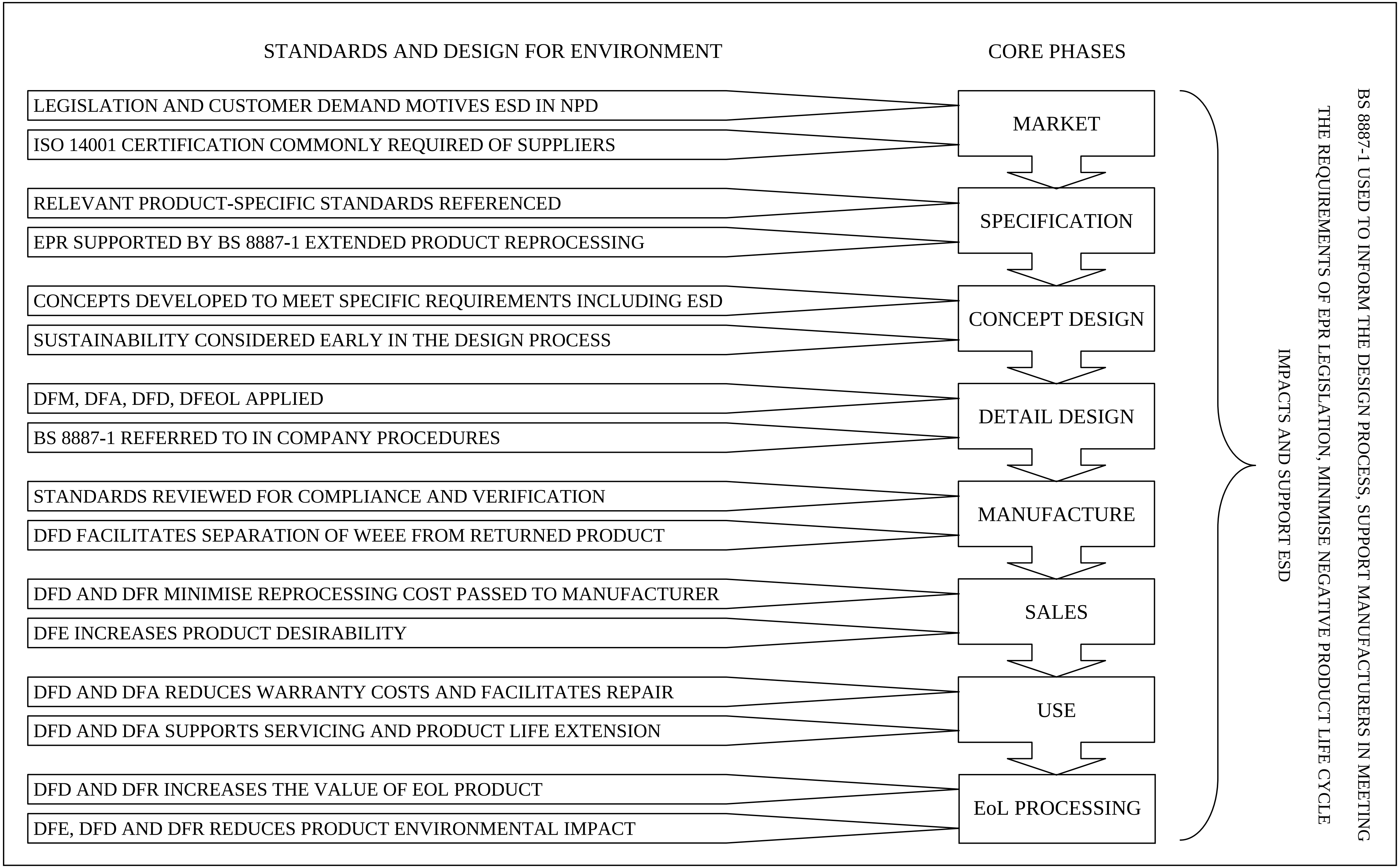

Figure 8.2: Model of the Use of Standards in New Product Development

8.4.1 Market

A producer must make certain that the products they place on the market are compliant with the relevant legislation. For example, in the UK electrical and electronic products must be RoHS and WEEE compliant. Such legislative measures provide far greater influence towards ESD than purely voluntary standards like BS 8887-1. The powerful influence of legislation and the necessity for compliance was strongly evident from the interview series. Assuring product compliance was frequently found to be an important element of the engineering designer's function.

As awareness and concern relating to environmental issues continues to rise, markets are giving greater preference to demonstrably environmentally and socially responsible products and services. This may explain the proliferation of certification schemes concerned with environmental responsibility e.g. Forest Stewardship Council (FSC) approval for timber and wood based products.

EMS certification to ISO 14001 is desirable for suppliers to certain large companies and public sector organizations, leading managers, designers and manufacturers to consider the impacts of their activities and products. This study has found evidence that ISO 14001 encourages organizations to reduce the environmental impact of their products, and BS 8887-1 has been occasionally purchased to help with achieving that objective.

8.4.2 Specification

Compliance with standards relevant to the type of product under development is commonly written into design specification documents. For producers working under contract, compliance with certain standards was often required by the client or included by convention.

BS 8887-1 had been ordered by some manufacturers as supplementary information following the introduction of EPR legislation. DfD and DfR have the potential to improve the economics of product recycling and increase the value of secondary materials. However, OEMs may not always be encouraged by this when recycling operations are externalized. Nevertheless, the interviews provided evidence that early interest in BS 8887-1 from industry was generated by the introduction of EPR legislation.

8.4.3 Concept Design

Once the Product Design Specification (PDS) has been established, a variety of concepts with the potential to meet its requirements are generated and the most promising of these are selected. A recurrent theme of the ESD literature is the importance of early stage design decisions and how they influence a product's properties and value recoverable through reprocessing. The interview series found strong agreement with this view from practitioners.

8.4.4 Detail Design

Product components, materials, finishes, fixing methods and manufacturing processes are finalised at this stage. Decisions taken will have a bearing on both the cost of production and EoL processing. The interview series revealed two industrial examples of BS 8887-1 being used at this level. One of these was the use of BS 8887-1 in the 'Design Freeze' stage as a reference under APQP, and the other where the standard was used as an information source for a design review conducted with the purpose of reducing production costs.

8.4.5 Manufacture

BS 8887-1 is a manufacturing standard relevant to the realization of product design concepts. Most of its content is intended for the design stages to achieve production and product life cycle cost savings. Several examples of DFMA yielding cost savings for manufacturers were outlined by participants during interviews. DFD also helped to reduce costs, particularly by minimizing the expense of WEEE disposal from factory sites and the cost of scrapping certain equipment.

Initial samples and production output for new designs are tested for compliance with relevant specification standards to make sure that essential requirements are met. Testing may be conducted with in-house rigs. For Kitemarking certification, samples are sent to BSI's test centre at Hemel Hempstead.

8.4.6 Sales

Environmentally aware customers will be attracted to products that have been designed with consideration for minimizing their ecological impact. In some instances this can additionally yield cost savings for the producer.

In one example, design in accordance with BS 8887-1 and particularly DfD and DfR were used to justify maintaining premium product pricing since disposal costs at end-of-life were kept to a minimum. CE marking, the use of the WEEE compliance logo and various other certification marks are necessary for certain classes of products.

8.4.7 Use

DfD is often an important consideration for designers developing products that are planned for maintenance and repair. Such forethought and planning help to facilitate efficient fulfilment of service contracts and warranty repair, thus improving customer service. Increased durability and improved feasibility of servicing, product life extension and even upgradeability are attractive to potential customers.

8.4.8 End-of-life Processing

For ESD the DfD and EoL planning elements of BS 8887-1 are particularly relevant as they improve the feasibility of reprocessing. Post consumer equipment can in some cases be returned to a high value state through remanufacturing, or used as high quality secondary parts and materials. The importance and benefits of this approach were recognised by many who had accessed the standard.

8.5 Conclusions

One of the findings of this research has been the identification of where in the design process BS 8887-1 is being used in practice. This is important since “It is difficult, costly, time consuming and inefficient to attempt retrospective matching of designs already finalized to such standards” [Pugh, 1991 p. 56]. In *Figure 7.3: Design Activity Model* standards are shown to enter the design process at the *Specification* phase. While the evidence supports this happening in practice, it can also be seen that standards are referred to throughout NPD, as represented in *Figure 8.4.*

CHAPTER 9 Discussion and Conclusions

Evidence from industry supports TDW4/7's decision to develop the DfMADE process and specify a product life cycle planning approach to NPD. The feedback gathered during the course of this research should prove useful in the continuing development of the standard.

Product life cycle planning and sustainable design can yield both direct short term gains through efficiency savings, and long term economic benefits through the preservation of resources. Legislation and customer requirements are major motivators for industrial companies to develop sustainable design strategies. The BS 8887 series supports industry in its necessary transition through the development of lower-impact products and into closed-loop production.

Under BS 8887-1 the practical design requirements for product life-extension strategies such as maintenance, repair and refurbishment are included in the NPD process. These strategies help to retain the original production investment and embodied energy present in EoL products, leading to enhanced profitability for manufacturing companies that embrace the specification and develop the necessary supporting business structures. The combination of planning for more efficient production, extended service life and EoL processing may also reduce the negative impacts of industrially manufactured goods and help to preserve the availability of resources into the future.

Industry has benefited from this research through an increased awareness of BS 8887-1. Publicity for the standard has been generated in the form of journal and conference papers about BS 8887-1, as well as through direct contact with industrial design practitioners and the project website at www.alexplant.co.uk.

The initial project brief was to seek patterns in the distribution data for BS 8887-1 and investigate its use in practice. The research results are summarised in this chapter along with some *Generalized Answers to Research Questions* in *Section 9.2* and some suggestions for *Further Work* and *Further Research* in *Sections 9.4* and *9.5* respectively.

9.1 Summary of Findings from Each Original Research Chapter

For the first time, market acceptance and use of BS 8887-1 has been investigated. Preliminary research established what is known in this field, the gap in knowledge to be filled by this research and the best way to conduct the investigation. The results of the preliminary research were presented in *CHAPTER 2: Literature Review* and *CHAPTER 3: Methods Review*. Original quantitative research was undertaken and is presented in *CHAPTER 4: Distribution of BS 8887-1* and *CHAPTER 5: Quantitative Analysis of Interview Results*. This was followed by the qualitative research *Pilot Study – The Use of BS 8887-1 in the Electronics Industry, Main Study (Part 1) Design for Manufacture and Sustainability in New Product Development* and *Main Study (Part 2) Integrating Life Cycle Design Standards in New Product Development* in *CHAPTER 7* and *CHAPTER 8* respectively. The following sections list the contributions to knowledge that may be drawn from the original research in *CHAPTER 4 - CHAPTER 8*.

9.1.1 CHAPTER 4: Distribution of BS 8887-1

In the initial study Standard Industrial Classification (SIC) was used to determine the proportions of different types of organizations that purchased or downloaded BS 8887-1. Based on the evidence of the SIC study, and the frequency of occurrence of other specific attributes, it was found that the majority of organizations that accessed BS 8887-1 have the following characteristics:

- Commercial businesses.
- Based in England.
- Aged between 21 and 50 years old.
- Medium or large enterprises.
- Engineering companies that manufacture products and equipment, especially electrical, electronic and mechanical goods.
- ISO 9001 certified.

Several hypotheses were investigated using SIC in combination with other numerical techniques. These hypotheses are listed in *Section 4.2*. The evidence from the study largely supported the proposed hypotheses, which are summarised below with relevant findings:

- It appears that the introduction of EPR legislation has helped to generate interest in BS 8887-1. There has been strong uptake of the standard from the electronics sector which is affected by WEEE, RoHS and EuP. These legislative measures demand consideration for the whole product life cycle. The BS 8887 DfMADE approach supports these legislative measures.
- Most of the organizations that accessed BS 8887-1 were based in Britain, as anticipated, although there was some international distribution as well. UK companies were seen to be buying, and therefore presumably using, the standard, suggesting that BS 8887 is helpful to them. Perhaps therefore its content may be relevant to a larger audience. International acceptance and use would probably be greater with support from ISO. BS 8887 could become the basis of a similar ISO series.
- The age and size of commercial businesses accessing BS 8887 was

investigated. It was found that the standard appears to be relevant to companies of all sizes. Customers buying BS 8887-1 included multi-national manufacturing businesses, medium sized companies employing fewer than 250 people, as well as small and micro enterprises. The latter largely being consultants working for, and advising a variety of clients.

- Among the BS 8887 customer organizations, high rates of certification to ISO 9001 QMS and ISO 14001 EMS were evident. This finding suggests that BS 8887 users are committed to continuous improvement with regard to both quality and environmental management. Continuous improvement is the core principle of the management systems. BS 8887-1 can support continuous improvement in product development as well as product-related environmental impact reduction. It is possible that BS 8887 could be used to support elements of the continuous improvement demanded by management systems.

9.1.1.1 Recommendations Based on the standard Industrial Classification Study

It would be desirable to increase sales and distribution of BS 8887 among its target audience. Uptake by automotive producers has been low, despite the standard's relevance to this sector, suggesting that further promotion may be advantageous.

It is important that educational institutions provide training in BS 8887-1 to their design and engineering students, because it is today's students who will influence the sustainability and environmental impacts of tomorrow's products. "Sustainable product development is the designer's future" [Howarth, 2004 p. 10]. A BSOL subscription has already proven to be a popular means for educational institutions to have access to standards.

UK manufacturing companies with ISO 9001 and ISO 14001 certifications have shown considerable interest in BS 8887-1, suggesting that similar firms would be receptive to the standard. However, the design and sustainability value of this manufacturing standard needs to be promoted more widely to producers that have not yet developed ESD strategies.

9.1.2 CHAPTER 5: Quantitative Analysis of Interview Results

For the purposes of academic rigour and to place the qualitative findings of this research in context, in terms of the numbers of organizations using or at least considering BS 8887-1, the transcripts were reviewed and certain data extracted. The study revealed:

- It was possible to find design engineers and managers who had read BS 8887-1 at over 25% of the organizations contacted. Within that group at least 9 had used it.
- More than 50% of those who acquired and read BS 8887-1 did so because they were interested in aspects of the standard other than ESD. These included use as a general reference document, in support of design for efficient production and its link with BS 8888 TPS. However, use in ESD was the most commonly cited single reason for buying BS 8887-1.
- The major incentives for ESD and cleaner operations among readers of readers of BS 8887-1 were found to be customer demand and EPR legislation. Individuals with a personal interest in sustainability and design working within manufacturing and academic organizations were found to have influenced the uptake and use of BS 8887-1.
- Some evidence of the use of BS 8887-1 in support of ESD under ISO 14001 EMS was found.
- Participants were primarily interested in the commercial benefits of BS 8887-1 attainable through DfM and meeting legislative requirements.

9.1.3 CHAPTER 6: Pilot Study – The Use of BS 8887-1 in the Electronics Industry

The initial pilot study based on qualitative information gathered through semi-structured interviews with users of BS 8887-1 in the electronics industry re-confirmed some established thinking on sustainable design and yielded a number of original findings, summarized below:

- British Standards are held in high regard in industry. The combination of their quality, achieved through a highly rigorous development process, combined with the authority and respect commanded by BSI makes these documents important and influential.
- The product life cycle planning aspects of BS 8887-1 were found to be of particular interest within the electronics sector. Although the standard covers design requirements for efficient production, it was often the EoL content that was of particular interest to designers working in this sector.
- BS 8887 was chosen as an authoritative reference source by environmental champions working within companies designing and manufacturing electronic products.
- The hypothesis that EPR legislation will have stimulated sales of BS 8887 was confirmed by the pilot study, at least in relation to electronics. Environmental legislation targeting the EEE sector was one of the reasons for high levels of interest in BS 8887-1 among electronics producers.
- BS 8887-1 has influenced producers to develop cleaner design and management strategies.
- Customer demand for low total cost of ownership has caused some designers and manufacturers to consider DfD and reprocessing.

- Companies were motivated to improve DfA and DfD by the requirements of service and repair. These improvements increased the ease and reduced the cost of fulfilling service contracts. They also reduced cost of ownership, as parts could be readily replaced instead of the owner having to purchase entirely new units.
- Where products were leased rather than sold, or a service contract was in operation, there was a greater incentive for producers to develop durable and maintainable products as supported by BS 8887-1.
- DfD was inappropriate for certain types of product, especially where security was a priority.
- Increased environmental awareness and market demand has encouraged some suppliers to achieve certification to ISO 14001 EMS, especially where their customers are already certified.
- ISO 14001 certification assisted companies in attracting new business. It also improved staff morale and afforded environmental champions the opportunity to apply principles from BS 8887-1 in NPD.

BS 8887-1, like all standards, is based on established knowledge. It specifies best practice in the design of products and their life cycle management. Its DfMA content fits well with the established NPD processes used in many commercial design and manufacturing businesses. This was less true for the closed-loop production aspects of the standard:

- It can be difficult to retrieve a manufacturer's products when they reach EoL as they may have been distributed globally.
- Products or materials that are said to be recycled are often in fact down-

cycled, meaning that they are made into low-tech items that are valued more for their bulk than their sophistication e.g. park benches made from recycled plastic.

Compliance with the WEEE legislation is achieved through payments made into a scheme that covers the cost of recycling an equivalent weight of electronic products to that which the company places on the market. This reduces the incentive for DfR, as it ceases to be the producer's responsibility to process EoL goods.

The pilot study focused on EEE business and found through interviews, that legislation was a major driver for more sustainable design, especially WEEE and RoHS. Cost savings were also made as a result of improved design for manufacture, assembly and maintenance. The main motivations for sustainable design in the EEE industry were legislative demand and commercial reward.

9.1.4 CHAPTER 7: Main Study (Part 1) Design for Manufacture and Sustainability in New Product Development

The conventional industrial design content in BS 8887-1 was important to users. This has not been overlooked despite the focus of this thesis being sustainable design. The relationship between BS 8887 and BS 8888 (the successor to BS 308) has led to greater distribution and use of BS 8887-1. The standard has also been used by manufacturers seeking to reduce costs through the development of improved designs with better optimisation for production. In many instances, such optimisations have environmental benefits through reduced material and energy use as well as lower rework or reject rates during manufacture.

In this chapter an established model of the design process from Pugh's (1991) 'Total Design' was reviewed and contrasted with the design process as detailed in BS 8887-1. These variations of the design process were compared with comments gathered during the qualitative research phase of the investigation and published literature on the subject. A new model of the design process and product life cycle was proposed. The chapter also argues the business case for closed-loop production while exploring some related issues.

Key points from *CHAPTER 7* include the following:

- Today, designers and manufacturers have a responsibility to minimise the negative environmental impacts of their goods across the whole product life cycle including EoL. This should be considered early during the design process and ideally should go beyond merely complying with legislation.
- Some environmentally aware producers are applying sustainable design strategies and addressing requirements from BS 8887 in NPD.
- EoL products that are returned to their producers can be used to provide insight into design weaknesses. This knowledge, acquired from the inspection of EoL products - particularly those that have failed in some way, can be used to inform the development of the next generation of equivalent products, thus helping to ensure that each new iteration or model is superior to the last.
- True closed-loop production was, in one instance, demonstrated to yield significant financial savings through the retention of value embodied in the materials used, as well as the design and manufacture of components. Waste was diverted back into production reducing the expense associated with disposal.

The conventional product development process follows a sequence of stages requiring various inputs at each. These stages are:

- Market.
- Specification.
- Concept Design.
- Detailed Design.
- Manufacture.
- Sales.

Key points relating to the design process and relevant to BS 8887-1, as discussed by participants during the research interviews are as follows:

- Market demand drives NPD. Increasingly products designed with consideration for minimizing environmental impact are more highly valued by the market as there is a steadily growing environmental awareness among both commercial customers and consumers.
- Specifications are written to encapsulate product design requirements, including the attributes necessary to meet the needs of users and any relevant legislation. The specification may be based on a design brief, and issues relevant to the brief are listed in BS 8887-1 (2006, p. 6). The use of these 'parameters for consideration in the preparation of a design brief' has been attempted in practice by at least one firm.
- Standards are usually written into product specifications and used to inform the development process as required.
- Commercial customers will often specify standards that a product should be compliant with. These will be referenced in a design brief. ISO standards will typically be specified since they may be regarded as having precedence over

national standards.

- The design concept stage is a critical opportunity to reduce the negative environmental impact of a product, or Product Service Systems (PSS), since this is the stage where radical change may be possible.
- At the detail design stage the product is optimized for manufacture, and consideration of the economic use of materials can yield savings. Choices made with regard to assembly and fixing methods can play a significant role in determining the maintainability and EoL value of a product.
- Once a product design progresses to manufacture, its impact is largely determined, but there may be some opportunities for minor optimizations. Site-specific issues and environmental management practices are important at this stage.
- The conventional product development process ends with the sale of products. Contemporary manufacturing operations should extend beyond sales to include take-back schemes and closed-loop production. As the latter becomes more common it should provide motivation for producers to develop durable, reliable equipment with a lower cost of ownership and reduced environmental impact per unit of service delivered by each product.

The BS 8887-1 product life cycle is superior to the older conventional model, since it features various return loops through which value may be recovered. There was some evidence from interviews that industry is currently undergoing a shift away from the old linear model of the product development process, towards closed-loop design. DfE and DfR are increasingly considered in NPD. The design process specified by BS 8887-1 is a good match with Pugh's

(1991) version, however the former additionally requires designers and business strategists to consider the complete life cycle management of products.

DfD requirements were often achieved through DfA, although the relationship did not exist in all cases. BS 8887-1 is particularly helpful in supporting incremental improvements and reductions in the environmental impact of products. It specifies principles that improve properties of products affecting the viability of various EoL processing techniques.

NPD can be improved by drawing upon the knowledge and experience of multiple experts who can advise on product and systems optimizations that influence each stage of the life cycle. Under BS 8887-1 multiple experts become involved in the design process through the development of a MADE team. Although no companies were found to have a designated MADE team, there were many of examples of collaboration between various required disciplines.

One aspect of product life cycle management is the creation and maintenance of design documentation. BS 8887-1 has already proven helpful in this regard since it specifies subject areas to be covered by certain documents that should be produced at the various stages of NPD.

9.1.4.1 Criticisms of BS 8887-1 and Closed-loop Production

Criticisms of BS 8887-1 included:

- The standard describes a best practice approach to NPD. Several designers and engineers felt that this was unnecessary as they were already doing it.
- There was uncertainty about whether BS 8887-1 had to be complied with or if it was just a set of guidelines.

- Part 1 of BS 8887 is general in scope and may not necessarily meet the specific needs of specialist industries.
- For those with some knowledge of sustainable design, BS 8887 did not present anything new.
- The standard was criticized for not including more guidance on design for EoL. This content was of particular interest to many of the people who ordered it.
- The BS 8887-1 specification could extend further to demand more consideration of materials and energy sources used in manufacture.
- Referencing multiple standards from within BS 8887-1 means that not all the necessary product life cycle design and management standards information is available in one place. This criticism also applied to the multiple parts of the BS 8887 and BS 8888 series.
- The standard is a text-based document and there is a perception that standards are impenetrable and dull. This reduces the likelihood of BS 8887 being read and used as widely as it could be.
- Sometimes it is difficult to make changes to designs owing to rigorous acceptance processes that have already been passed.

Criticisms of closed-loop production included:

- It can be difficult influence user behaviour so that EoL products are returned, or at least placed in the correct waste stream for reprocessing.
- It is often difficult and uneconomical to return EoL products, especially after they have been distributed globally.

- The low value of certain EoL products can make reverse logistics economically unattractive.
- Decontamination of EoL products can increase the cost of recycling. Sometimes it is not possible to sufficiently decontaminate a material to a condition where it can be used in a high value application, e.g. medical devices.
- It can cost more to recycle a used product than it does to make a new one.
- Remanufactured products tend to be perceived as lower quality than new, even though this is not the case under the robust definition of the term as used in the BS 8887 series of standards.

9.1.4.2 New Product Design Process, Materials Cycle and End-of-Life Routes Model

A new model combining the design process and material**s** economy with a hierarchy of EoL reprocessing routes for post-consumer products was presented in *Figure 7.5*. This illustrates some of the complexities and interactions to be considered in NPD and strategy planning for closed-loop production. The model shows how material cycles in industry should function in order to meet the needs of a growing population, rising living standards and diminishing resources.

9.1.5 CHAPTER 8: Main Study (Part 2) Integrating Life Cycle Design Standards in New Product Development

Interviews with design practitioners from all types of organizations that have purchased or accessed BS 8887-1 have revealed how the standard is already being used in the design processes and how in some instances it is proving commercially advantageous. These organizations include large manufacturing companies, independent design consultants, medical device specialists and educational institutions.

Moving towards sustainability requires industry to pursue cleaner production, eliminate waste and reduce resource consumption. The BS 8887-1 product life cycle planning approach supports sustainability through improved industrial design, and field research suggests that it is already successfully being used to assist designers and manufacturers in making the necessary improvements to their products. The standard also specifies the way in which design output should be structured. It summarizes techniques and methods to convert user or customer requirements into products that can be efficiently manufactured. These methods include QFD (HoQ), LCA, VE, VA and FMEA. It also specifies design principles, the application of which can have economic and environmental benefits.

It can be seen from the case study evidence that BS 8887-1 has been used in both industry and design education. The standard's product life cycle design requirements have been applied in NPD both in isolation and combination with the various techniques and methods it prescribes. It has additionally been used to support APQP and EMS, and has been proposed for use with TRIZ.

The implementation of more sustainable product development and production necessitates appropriate design knowledge and support from management, as well as an extended scope of operations including post-consumer product recovery and reprocessing.

The first half of *CHAPTER 8* argues for the financial benefit of applying principles from BS 8887-1 in NPD. The second half discusses the use of the standard in combination with management systems and various design methods.

9.1.5.1 Financial Benefit of BS 8887-1

In industry, the use of BS 8887-1 and the principles it describes have been commercially motivated in the following ways:

- Demonstrating rigour in DfD / DfR to customers concerned about the cost of product disposal at EoL.
- DfD can benefit the manufacturer if EoL product is returned.
- DfD makes it possible to separate materials and sub-systems easily so they can be divided into the most appropriate waste streams, reducing the cost associated with disposal, especially for WEEE.
- Valuable materials from EoL items can be sold at a higher price if they are separated and sorted. Ideally there should be no waste at all.
- DfD, DfE and compliance with relevant legislation all help to remove barriers to sale.
- Public sector organizations, often with significant buying power, increasingly have procurement policies that make demands with regard to the environmental impact of products they order. These demands are also concerned with the total cost of ownership, encouraging design for durability, maintainability and energy efficiency.
- Guarantees or service agreements are often attractive to customers, but can be a cost to producers that must honour them. This generates an incentive to design for durability and serviceability, which may in some instances extend as far as making products more user-serviceable, at least to a limited extent.
- BS 8887-1 has been used to promote the sale of an aircraft parts company that had developed a system of durable and repairable ducting components. The

director believed the design of his company's product was in line with the requirements of the standard.

- DfD and serviceability increases the speed and efficiency with which technicians can rectify faults, and therefore lowers the cost of repair.
- DfM and VE are well established approaches to minimising production costs through efficient design. BS 8887-1 is a current standard covering this area and much of the commercial interest in it was associated with improving manufacturing efficiency through good design.
- Reducing the number of components used in each product lowered manufacturing costs by removing the expense associated with ordering, handling, storing and assembling unnecessary parts.

9.1.5.2 Environmental Management Systems and BS 8887-1

It was suggested that BS 8887-1 may be used as part of demonstrating continuous environmental improvement under ISO 14001. For example, one company purchased the standard following an ISO 14001 audit because it was identified that they needed to focus on reducing the environmental impact of the products they manufactured. Another producer kept the standard as a reference source to demonstrate that issues of sustainable design were being addressed. It was also appreciated that BS 8887 and ISO 14000 are concerned with different aspects of reducing the environmental impact of industrial activity.

9.1.5.3 Novel Methods in the Use of BS 8887-1

One of the interesting findings from this research has been the variety of systems and structured design methods or problem solving tools used, or at least considered for use, in applying requirements from BS 8887 to NPD.

APQP is a system for managing the new product introduction process that was developed in the automotive sector. It is not mentioned in BS 8887-1; however use of the standard was found to be formally specified by one company in the automotive supply chain as part of their standard APQP process. This is one of the strongest single examples of the standard's use in design practice.

Novel ideas being considered to integrate the principles of BS 8887 into the design process included the standard's use in new variants of QFQ (HoQ) and TRIZ.

Finally, in *Figure 8.2: Model of the Use of Standards in New Product Development*, a new version of the design process is presented. This features EoL product reprocessing and lists relevant techniques that have been shown to be useful at each stage, including standards and design methods as well as other significant requirements. The diagram illustrates some of the methods influencing the use of standards in the design process.

9.2 Generalized Answers to Research Questions

In this section research questions put to participants are answered in a generalised format, based on the responses of multiple participants.

Why was BS 8887-1 bought or downloaded?

- Frequently the standard was acquired as a reference document for inclusion within an organization's standards library.
- Often it was not obtained for a specific project but was thought likely to be relevant to future design work.
- BS 8887 is referenced within BS 8888 and it was therefore purchased to support TPS.

- The standard has been purchased as a guide for product life cycle planning.
- Take-back legislation, especially WEEE, stimulated sales of BS 8887-1 since it can be used to assist with product EoL planning.
- Some users who were not necessarily interested in sustainable design or product-related environmental impact reduction found the standard helpful for its DfM content.

How did you become aware of BS 8887-1?

- BSI publications e.g. 'Update Standards' magazine.
- E-mail communications from BSI.
- Articles and papers about BS 8887 in the trade press.
- BSI newsletters.
- The BSI+ scheme sells standards to customers that BSI suggests will be helpful based on their business activities. Several standards users received BS 8887-1 through this scheme.

What, if anything, has motivated you or your company to pursue sustainable or cleaner design?

- Compliance with legislation was the biggest single driver for cleaner design.
- Cost-savings achieved through more efficient use of materials and energy.
- Cost-savings achieved through design that facilitates efficient repair and maintenance.
- Reducing the cost of disposing of waste.
- Improved corporate identity or image.

- Employees who are environmental champions promote sustainable design from within their organizations.
- Continuous improvement as part of EMS.

How has product-related environmental legislation affected the business?

- Payments made into a WEEE compliance scheme.
- Designs reviewed and amended to achieve compliance with RoHS.
- Replacement of ozone-depleting chlorofluorocarbon (CFC) with more benign alternatives in refrigeration and air-conditioning equipment.
- Components supply-chain audits to confirm RoHS compliance.
- Proactive achievement of RoHS compliance in anticipation of tightening regulations i.e. some manufacturers producing certain classes of products exempt from the legislation are choosing to comply.
- Products are now marked with the WEEE logo where applicable.
- Increased use of DfD.

What has been the reaction to BS 8887-1?

- The standard is a well written guide to the design process.
- It would be useful to someone unfamiliar with the design process e.g. an employee new to working in a design office. It was suggested that BS 8887-1 could form part of initial commercial design training.
- BS 8887-1 achieves an appropriate balance between being generic and specific.
- The standard is an authoritative source of data that specifies what needs to be

done and the requirements that a design needs to meet.

- The standard can be used to give clarity and detail to general design objectives.
- It is written by experts with input from industry, so it is practical rather than idealistic.

Has DfE been profitable for your company?

- DfE can be used to demonstrate the environmentally friendly ethos that many businesses today choose to project.
- It can sometimes be cheaper to use recycled rather than virgin materials in manufacture.
- Reducing the variety and number of materials and components used in a product helps to lower its cost to manufacture, the cost to reprocess it also usually falls.
- DfD / DfA helps to reduce the cost of product servicing.
- Disassembly, and therefore DfD, can help reduce the cost of product disposal as materials can be readily separated into appropriate waste or recycling streams.
- Repairing, servicing and retaining returned faulty products ensures a supply of equipment suitable for use as service replacement items at a lower cost than manufacturing them. In this way a customer can have an equivalent replacement item fast, without having to wait for their original item to be repaired.
- Value can be recovered from returned EoL products. Some parts may be

reusable and some materials may be recyclable.

- Environmentally conscious customers may be prepared to pay a premium for ‘greener’ products.

Who uses BS 8887-1 and what are their job positions?

- Product Designers.
- Design Engineers.
- Quality Engineers.
- Design Managers.
- Production Engineers.
- Quality Consultants.
- Design Consultants.

How has BS 8887-1 been used?

- It has been used a reference source detailing best practice in design, particularly by companies seeking to improve their NPD process, and evaluate their design process against BS 8887-1.
- For some consultants, it was purchased as an additional reference source with the expectation that it may be useful to them when advising clients.
- BS 8887-1 has been used while reviewing existing products, with the intention of improving the design of the next generation of equivalent product.
- The standard has been used as a way of demonstrating rigour in the application of life cycle design planning and to support a manufacturer in product price negotiations.

- BS 8887-1 was often used as background reading material rather than being considered for a specific project.
- Some of the more novel methods of incorporating the standard into the design process came from the commercial sector. These included the use of elements in combination with techniques including:
    - VE/VA.
    - QFD (HoQ).
    - APQP.
    - TRIZ.
    - EMS.
    - LCA.

How useful has BS 8887-1 been?

- It was anticipated that the standard would be used more in the future as the economic situation improves, and as sustainability and the importance of care for the environment increasingly influence customer purchasing decisions.
- It was frequently said that BS 8887 would be more widely used if it were an ISO standard.

At what stage within the design process are standards and BS 8881-1 referred to?

- Commercial customers that commission design work or bespoke systems will usually specify the standards with which the finished product must comply.
- Specified standards are referred to throughout the design process, especially for compliance.

- Prototype and initial production items are tested against specified standards. Kitemarking is done by BSI.

What motivated your firm to become ISO 9001 / 14001 accredited?

- Customer demand.
- ISO 9001 / 14001 accreditation simplifies the process of convincing potential commercial customers that QMS and EMS systems are sufficient.
- ISO 14001 accreditation and the continuous environmental improvement that it demands was said to have a positive influence on staff moral and even helped to attract new staff.
- ISO 14001 accreditation helped to attract and retain environmentally conscious customers.

How has BS 8887-1 been used in Education?

The use of the standard in education is a particularly positive finding:

- BS 8887 has been used as the underpinning design theory document for certain Bachelors and Masters level university courses.
- The standard has been accessed by students whose lecturers referred to it in their classes. Occasionally it was also found independently.
- Automotive engineering students learning DfM and DfE have used BS 8887-1 during their research.
- The use of BS 8887-1 has featured in student design portfolios.

What are the incentives for teaching sustainable design?

- Design training based on principles from the standard has been used to give graduates a competitive advantage in the jobs market.
- BS 8887-1 has been used as a reference source for inclusion in the specification parts of student design projects.
- Its application has been used to help meet sustainable design assessment criteria.
- Some examination boards include sustainable design in marking schemes. BS 8887-1 has been referred to in student coursework to satisfy their assessment criteria.

Are there any criticisms of BS 8887-1?

- Standards specify minimum requirements to be met or exceeded, but some users of BS 8887-1 argued that more stringent requirements should be set.
- Life cycle design standards are required for specific industry and product-types.
- BS 8887-1 is expensive for individuals and small businesses.
- Some users were annoyed at having another document prescribing what must be done and how.
- There was some frustration at having to refer to other standards referenced within BS 8887 and not having all relevant information in a single document.
- Part 1 of the standard was thought to be too general for some producers looking for information that could be more directly applied to their own products.
- It was even argued by some users that sustainable design cannot be

standardised. There are a number of ways to approach product life cycle planning, and these should be selected and tailored to specific products and circumstances on an individual basis.

9.3 Summary of Contribution to Knowledge

The academic contribution made by this thesis is:

- An analysis of the distribution of BS 8887-1 by industry sector and other quantifiable data.
- The identification of factors that have motivated businesses and other organizations to use BS 8887-1.
- Industrial examples of the financial benefits of applying design principles from BS 8887-1.
- Identification of methods and techniques for incorporating product life cycle planning into the NPD process.
- Development of two new variants of the design process, shown in *Figure 7.5* (p. 152) and *Figure 8.2* (p. 172).

9.4 Further Work

It may be possible for BS 8887 to have greater influence if progress is made in the following areas:

- Produce a BS 8887 pack containing all the MADE standards and referenced ISO standards, so that all relevant product life cycle standards information is available in a single resource. This could be provided in a digital format, with cross-references as hyperlinks for convenience.

- New parts to the BS 8887 series should be written to meet the needs of specific industry sectors as they are identified, and with input from those sectors.
- Elements of the BS 8887 series should be used as the basis of a similar ISO Standard.
- Supplementary material with broader appeal than a conventional standard should be developed to convey the requirements of BS 8887.

The last three points are discussed in the following sections.

9.4.1 New Parts to BS 8887

The research identified a need for more product-specific and industry-specific standards in the BS 8887 series. Additional parts will be developed when they are requested by industry, as happened with BS 8887-211 *Remarketing of Computing Hardware*. Examples of industries where specific BS 8887 standards might be helpful are: EEE, white and brown goods, automotive engineering, packaging and furniture.

Expertise and input from relevant industry sectors would be essential for new parts of BS 8887 to be meaningful and become incorporated into conventional working practice.

9.4.2 BS 8887 into ISO

BS 8887-1 was written partially as a guide to ISO DfM standards. In a similar way, BS 8888 was written as a guide to ISO TPS standards. However, BS 8887 also establishes the design requirements for product life cycle planning and could even be used to support closed-loop production. Product life cycle planning should become conventional practice by default, rather than being viewed as a novel idea promoted by green thinkers. Over time this may have a significant impact. BS 8887-1 and the DfMADE concept has proven popular in its home country and should now be communicated internationally through ISO.

ISO standards usually carry more influence the British Standards because they are approved by multiple NSBs, and command higher status among standards users. The successful transition of British Standards into ISO has been achieved many times before, most famously by BS 5750 and BS 7750 which became ISO 9001 and ISO 14001 respectively. A good case can be made for elements of BS 8887 to become a series of ISO standards:

- BS 8887-1 specifies practical design requirements for product life cycle planning with consideration for reprocessing. This is different from anything currently offered by ISO.
- BS 8887 is ideal for use by practising designers as well as design management.
- If appropriate elements of the BS 8887 series become the basis of a similar ISO series, this would extend the reach of this potentially environmental and economically beneficial standard.

ISO 14001 could be updated to include a reference to the ISO version of BS 8887, thus promoting consideration of life cycle planning in NPD. It may not be appropriate to include it directly within the ISO 14000 series as it is targeted at managers rather than designers. At the time of writing this thesis, a new ISO working group was being formed to consider taking BS 8887 into ISO.

9.4.3 Supplementary Material Supporting BS 8887

During the research interviews, alternative presentation ideas were briefly described and opinions sought. The suggestion of a graphical handbook was popular. A handbook could consist of quotes from BS 8887 with additional illustrations, discussion, interpretation and elaboration on the meaning and implications of each point. The format would be free from the constraints of BS 0, but still cover the same points as BS 8887-1, and possibly some aspects of the other standards in the BS 8887 series. TDW4/7 in now developing a book based on this idea.

It has been decided that six sub-editors will be required. Four of these will write the sections concerned with each stage of the MADE process and a fifth will address the holistic life cycle planning philosophy, whilst the sixth sub-editor will focus on the development of design tools. To date, five out of six of the sub-editors have been selected.

9.5 Further Research

The concept of a BS 8887 handbook provides an opportunity for further academic research. It may be worth trialing the concept to discover whether it assists in the interpretation and use of the standard in practice. Contributing to the development and evaluation of such a handbook could be the basis of another Ph.D. project.

REFERENCES

Standards

BS 0 (2011) A Standard for Standards.

BS 16001 (2009) Energy Management Systems. Requirements with Guidance for Use.

BS 308-1 (1993) Engineering Drawing Practice. Recommendations for General Principles.

BS 378-1 (2008) Refrigerating Systems and Heat Pumps. Safety and Environmental Requirements. Basic Requirements, Definitions, Classification and Selection Criteria.

BS 50419 (2006) Marking of Electrical and Electronic Equipment in Accordance with Article 11(2) Directive 2002/96/EC (WEEE).

BS 5750-1 (1979) Quality Systems. Specification for Design, Manufacture and Installation.

BS 7750 (1992) Specification for Environmental Management Systems.

BS 857 (1967) Specification for Safety Glass for Land Transport.

BS 8887-1 (2006) Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE). General Concepts, Process and Requirements.

BS 8887-2 (2009) Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE). Terms and Definitions.

BS 8887-210 (Development) Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE). Remarketing of Products.

BS 8887-211 (Development) Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE). Remarketing of Computing Hardware.

BS 8887-220 (2010) Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE). The Process of Remanufacture. Specification.

BS 8887-240 (2011) Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE). Reconditioning.

BS 8888 (2008) Technical Product Specification - Specification.

BS 8889 (pending) Technical Product Verification.

PD 6470 (1975) The Management of Design for Economic Production.

ISO 1043 Plastics – Symbols and Abbreviated Terms.

SA 8000 (2008) Social Accountability.

ISO 9001 (2008) Quality Management Systems - Requirements.

ISO 9004 (2009) Managing for the Sustained Success of an Organization - A Quality Management Approach.

ISO 11469 Generic Identification and Marking of Plastics Products.

ISO 13485 (2003) Medical devices. Quality Management Systems. Requirements for Regulatory Purposes.

ISO 14006 (2011) Environmental Management Systems - Guidelines for Incorporating Ecodesign.

ISO 14001 (2004) Environmental Management Systems - Requirements with Guidance for

Use.

ISO 14001 (1996) Environmental Management Systems. Specification with Guidance for Use.

ISO 14040 (2006) Environmental Management. Life Cycle Assessment. Principles and Framework.

ISO 14044 (2006) Environmental Management. Life Cycle Assessment. Requirements and Guidelines.

ISO 14041 (1998), Environmental Management. Life Cycle Assessment. Goal and Scope Definition and Inventory Analysis.

ISO 14062 (2002) Environmental Management. Integrating Environmental Aspects into Product Design and Development.

ISO 16949 (2009) Quality Management Systems. Particular Requirements for the Application of ISO 9001 (2008) for Automotive Production and Relevant Service Part organizations.

ISO 26000 (2010) Guidance on Social Responsibility.

Literature and Other Media

Abu Bakar, M.S. and Rahimifard, S. (2007) Computer-aided Recycling Process Planning for End-of-Life Electrical and Electronic Equipment. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal Engineering Manufacture*, 221, pp. 1369-1374.

Adams, W. M. (2006) Item 2: The Idea of Sustainable Development 'The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century', *Report of the IUCN Renowned Thinkers Meeting, 29–31 January 2006*, IUCN: The World Conservation Union. Available at: http://cmsdata.iucn.org/downloads/iucn_future_of_sustanability.pdf (Accessed: 9 November 2010).

Allen, R. E. (Editor), (1984) *The Pocket Oxford Dictionary.* 7th edn. Oxford: Oxford University Press.

Altshuller, G. S. (1984) *Creativity as an Exact Science. The Theory of the Solution of Inventive Problems*, New York: Gordon and Breach Science Publishers.

American Society of Mechanical Engineers, (2009) *ASME General Position Statement on Technology and Policy Recommendations and Goals for Reducing Carbon Dioxide Emissions in the Energy Sector* [Online] Available at: http://files.asme.org/asmeorg/NewsPublicPolicy/GovRelations/PositionStatements/17971.pdf (Accessed: 17 November 2011).

Automotive Industry Action Group (1995) *Advanced Product Quality Planning and Control Plan: Reference Manual*. Southfield, MI: Automotive Industry Action Group.

Bell, J. (1999) *Doing your Research Project: A Guide for First-time Researchers in Education and Social Science*. 3rd edn. Buckingham: Open University Press.

Belz, F. M. and Peattie, K. (2009) *Sustainability Marketing: A Global Perspective*. Chichester: John Wiley and Sons Ltd.

Bereketli, I., Genevois, M. E. and Ulukan, H. Z. (2009) 'Green Product Design for Mobile Phones', *World Academy of Science, Engineering and Technology*, 58, pp. 213-217.

Birkeland, J. (2002) *Design for Sustainability: A Sourcebook of Integrated Eco-logical Solutions*. London: Earthscan.

Blaxter, L., Hughes, C. and Tight, M. (1996) *How to Research.* Buckingham: Open University Press.

Blumer, H. (1969) *Symbolic Interactionism: Perspective and Method*. New Jersey: Prentice-Hall.

Boothroyd, G., Dewhurst, P., and Knight, W. (1994). *Product Design for Manufacture and Assembly*. New York: Marcel Dekker.

Brett Davies, M. (2007) *Doing a Successful Research Project: Using Qualitative or Quantitative Methods*. Basingstoke: Palgrave Macmillan.

British Standards Institution (2009a) *About BSI British Standards*. Available at: http://www.bsigroup.com/en/Standards-and-Publications/About-BSI-British-Standards/ (Accessed: 18 October 2010).

British Standards Institution (2009b) *Glossary*. Available at http://www.bsigroup.com/en/Standards-and-Publications/About-standards/Glossary (Accessed 19 June 2009).

British Standards Institution (2009c) *History of BSI Group*. Available at: http://www.bsigroup.com/en/About-BSI/About-BSI-Group/BSI-History/ (Accessed: 18 October 2009).

British Standards Institution (2011a) *BSI the Superbrand*. Available at: http://www.bsigroup.com/en/Standards-and-Publications/How-we-can-help-you/Distributors/Sales-tips/BSI-the-superbrand/ (Accessed: 20 September 2011).

British Standards Institution (2011b) *Standard in development: BS 8887-211 Design for Manufacture, Assembly, Disassembly and End-of-life processing Part 211: Remarketing of Computing Hardware*. Available at: http://standardsdevelopment.bsigroup.com/Home/Project/201101650 (Accessed: 26 August 2011).

Brouwer, M.A.C. and Van Koppen, C.S.A. (2006) 'The Soul of the Machine: Continual Improvement in ISO 14001', *Journal of Cleaner Production*, 16, 450-57.

Buzan, T (1988) *Make the Most of Your Mind*. 2nd edn. London: Pan Books Ltd.

Carbone, T. A. (2005) 'Integrating Operations and Product Development Methodologies for Improved Product Success Using Advanced Product Quality Planning', *Proceeding of the Advanced Semiconductor Manufacturing Conference*, Munich, Germany pp. 228-233.

Casadesús, M., Marimon, F. and Heras, I. (2008) 'ISO 14001 Diffusion after the Success of the ISO 9001 Model', *Journal of Cleaner Production*, 16, pp. 1741-1754.

Caterpillar Inc. (2009) *Remanufacturing: a New Era of Profitability*. Available at: http://www.cat.com/parts/remanufactured-products (Accessed 3 June 2009).

Charter, M. and Tischner, U. (2001) *Sustainable Solutions: Developing Products and Services for the Future*. Sheffield: Greenleaf Publishing Ltd.

Chiodo, J., Billet, E. and Harrison, D. J. (1998) 'Active Disassembly', *The Journal of Sustainable Product Design*, 7, October pp. 26-36.

Chiodo, J., Jones, N., Billett, E. H. and Harrison, D. J. (2002), 'Shape Memory Actuators for

Active Disassembly', *Journal of Materials and Design*, 23, pp. 471-478.

Council of the European Union (1999) *The Landfill of Waste*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1999:182:0001:0019:EN:PDF (Accessed: 28 November 2011).

Connett, P. (1997) 'Science Education, Overconsumption, and Survival on a Finite Planet' *Frontiers*: *The Interdisciplinary Journal of Study Abroad,* 3 Fall [Online] Available at: http://www.frontiersjournal.com/issues/vol3/vol3-13_Connet.htm (Accessed: 7 November 2011).

Davis, G. and Song, J. H. (2006) 'Biodegradable Packaging Based on Raw Materials from Crops and their Impact on Waste Management', *Industrial Crops and Products*, 23 (2), 147-161.

De Vaus, D. 'Survey Research' in Greenfield, T. (2002) *Research Methods for Postgraduates*. 2nd edn. London: Arnold pp. 172-182.

Dekoninck, E.A., Harrison, D. J. and Stanton, N.A. (2006) 'New Tools for the Early Stages of Eco-innovation: An Evaluation of Simplified TRIZ Tools', *Journal of Design Research*, 6, (1/2) pp. 122-141.

Delmas, M. (2002) 'The Diffusion of Environmental Management Standards in Europe and in the United States: an Institutional Perspective', *Policy Sciences,* 35 (1), pp. 91-119 *JSTOR* [Online] Available at: http://www.jstor.org.v-ezproxy.brunel.ac.uk:2048/stable/pdfplus/4532551.pdf (Accessed: 19 November 2011).

Denscombe M. (2002) *Ground Rules for Good Research: A 10 Point Guide for Social*

Researchers. Maidenhead: Open University Press.

Department for Environment, Food and Rural Affairs (2007) *Guidance notes on the Eco-design for Energy-using Products Regulations*. Available at: http://www.defra.gov.uk/environment/business/products/energy/documents/energy-products-regs-guide.pdf (Accessed: 8 November 2010).

Devoldere, T., Willems, B. and Duflou, J. R. (2009) 'The Eco-efficiency of Reuse Centres Critically Explored – The Washing Machine Case', *International Journal of Sustainable Manufacturing*, 1 (3), pp. 265-285.

Doh, H. H. and Lee, D. H. (2010) 'Generic Production Planning Model for Remanufacturing Systems', Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 224 (1), 159-168. *SAGE Journals* [Online]. Available at: http://pib.sagepub.com.v-ezproxy.brunel.ac.uk:2048/content/224/1/159.full.pdf+html (Accessed: 19 November 2009).

Donnelly, K., Olds, R., Blechinger, F., Reynolds, D. and Beckett-Furnell, Z. (2004) 'ISO 14001 - Effective Management of Sustainable Design', *The Journal of Sustainable Product Design*, 4, pp. 43-54.

Ellram L. M., Tate W. and Carter, C. R. (2008) 'Applying 3DCE to Environmentally Responsible Manufacturing Practices', *Journal of. Cleaner Production*, 16, pp. 1620-1631.

Engineering Integrity Society (2009) 'Industry News: British Standards Institute', *Journal of the Engineering Integrity Society*, October, p. 20. [Online] Available at: http://www.e-i-s.org.uk/docs/EIS%20Journal%2027.pdf (Accessed: 8 November 2010).

Esty, D. C. and Winston, A. S. (2009) *Green to Gold: How Smart Companies Use Environmental Strategy to Innovate, Create Value, and Build Competitive Advantage*. New Jersey: John Wiley and Sons, Inc.

Europa (2010) *End-of-life Vehicles*. Available at: http://europa.eu/legislation_summaries/internal_market/single_market_for_goods/motor_vehicles/interactions_industry_policies/l21225_en.htm (Accessed: 8 November 2010).

European Commission (2001) *Green Paper on Integrated Product Policy*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2001:0068:FIN:EN:PDF (Accessed: 28 November 2011).

European Commission (2003) *Communication on Integrated Product Policy*. [Online] Available at: http://ec.europa.eu/environment/ipp/ippcommunication.htm (Accessed 27 November 2011)

European Commission (2008) *What is Integrated Product Policy?* [Online] Available at: http://ec.europa.eu/environment/ipp/integratedpp. htm (Accessed: 25 November 2008).

European Communities (2010) *Energy Labelling of Household Washing Machines*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:314:0047:0063:EN:PDF (Accessed: 28 November 2011).

European Parliament (1994) *Packaging and Packaging Waste*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1994L0062:20050405:EN:PDF

(Accessed: 28 November 2011).

European Parliament (1997) ...*Pressure Equipment*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1997:181:0001:0055:EN:PDF (Accessed: 28 November 2011).

European Parliament (2000) *End-of-Life Vehicles (ELV).* [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2000L0053:20050701:EN:PDF (Accessed: 28 November 2011).

European Parliament (2003) *The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations (RoHS)*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0019:0023:en:PDF (Accessed: 28 November 2011).

European Parliament (2003) *Waste Electrical and Electronic Equipment (WEEE)*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0024:0038:EN:PDF (Accessed: 28 November 2011).

European Parliament (2005) *Ecodesign Requirements for Energy-Using Products (EuP).* [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:191:0029:0029:EN:PDF (Accessed: 28 November 2011).

European Parliament (2005) *Establishing a Framework for the Setting of Ecodesign Requirements for Energy-using Products*...[Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:191:0029:0058:EN:PDF

(Accessed: 28 November 2011)

European Parliament (2006) *Batteries and Accumulators and Waste Batteries and Accumulators...* [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:266:0001:0014:EN:PDF (Accessed: 28 November 2011).

European Parliament (2006) *Fluorinated Greenhouse Gases*. [Online] Available at: http://iklim.cob.gov.tr/iklim/Files/Mevzuat/o01.pdf (Accessed: 28 November 2011).

European Parliament (2006) *Harmonisation of the Laws of Member States Relating to Electrical Equipment Designed for Use Within Certain Voltage Limits*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:374:0010:0019:en:PDF (Accessed: 28 November 2011).

European Parliament (2006) *Machinery Directive*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:157:0024:0086:EN:PDF (Accessed: 28 November 2011).

European Parliament (2006) *Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:396:0001:0849:EN:PDF (Accessed: 28 November 2011).

European Parliament (2009) *Voluntary Participation by organizations in a Community Eco-management and Audit Scheme (EMAS)*. [Online] Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:342:0001:0045:EN:PDF

(Accessed: 28 November 2011).

Fiksel, J. (1996) *Design for Environment: Creating Eco-Efficient Products and Processes*. New York: McGraw-Hill.

Frey, S. D., Harrison, D. J. and Billett, E. H. (2006) 'Ecological Footprint Analysis Applied to Mobile Phones', *Journal of Industrial Ecology*, 10, (1-2) pp. 199-216. *Wiley* [Online]. Available at: http://onlinelibrary.wiley.com.v-ezproxy.brunel.ac.uk:2048/doi/10.1162/108819806775545330/pdf (Accessed 29 November 2011).

Frijns J, Vliet B. V. (1999) 'Small-Scale industry and Cleaner Production Strategies', *World Development*, 27(6):967-983.

Fuad-Luke, A. (2008) 'Sustainable Design', *The Journal of the Institution of Engineering Designers*, March/April, pp. 22-25.

Gehin, A. Zwolinski, P. and Brissaud, D. (2008) 'A Tool to Implement Sustainable End-of-life Strategies in the Product Development Phase', *Journal of Cleaner Production*, 16, pp. 566-576.

Global Footprint Network (2007) *National Footprints*. Available at: http://www.footprintnetwork.org/gfn_sub.php?content=national_footprints (Access: 9 July 2008).

González-Benito, J. and González-Benito, O. (2005) 'An Analysis of the Relationship Between Environmental Motivations and ISO 14001 Certification' *British Journal of Management*,16 (2), pp. 133-148.

Gore, A. (2007) *An Inconvenient Truth,* Directed by Guggenheim, D. [DVD] Paramount Pictures Corporation.

Great Britain. Environmental Protection Act 1990: Elizabeth II. Chapter 43. [Online] Available at: http://www.legislation.gov.uk/ukpga/1990/43 (Accessed: 25 May 2012).

Greenfield, T. (2002) *Research Methods for Postgraduates*. 2nd edn. London: Arnold.

Greenwood, T. (2008) 'Sustainable Design: Reality or Dream?', *The Journal of the Institution of Engineering Designers,* May/June, pp. 28-29.

Griffiths, B. (2008a) 'The New Suite of Design for Manufacture British Standards', *The Journal of the Institution of Engineering Designers,* November/December, pp. 21-24.

Griffiths, B. J. (2003) 'Standards Design', *IEE Manufacturing Engineer,* June/July p. 4

Griffiths, B. J. (2008b) 'Design for Manufacture', *Quality Manufacturing Today Magazine,* January. Available at: http://www.qmtmag.com/display_eds.cfm?edno=9828271 (Accessed: 01 June 2009).

Grix, J. (2004) *The Foundations of Research*. Basingstoke: Palgrave Macmillan.

Harding, A. (2008) 'Getting on Top of the WEEE Regulations', *The Journal of the Institution of Engineering Designers*, July/August, pp. 26-28.

Hawken, P., Lovins, A. and Hunter Lovins, L. (1999) *Natural Capitalism: Creating The Next Industrial Revolution,* London: Little, Brown and Company.

Hennock, M. (2005) *Hammering Midlands Metal Bashers* [online]. Available at: http://news.bbc.co.uk/1/hi/business/4316529.stm (Accessed 20 July 2009).

Herring H. (2006). *Consumption: Innovation for Sustainability,* Milton Keynes: Open University.

Hickman, L. and Longman, C. (1994) *Case Method: Business Interviewing,* Bracknell: Oracle Corporation UK Ltd.

Hillary R. (2004) 'Environmental Management Systems and the Smaller Enterprise', *Journal of Cleaner Production,* 12 pp. 561-569.

Holdway, R. and Walker, D. (2004) 'The End-of-Life as We Know It', *The Journal of the Institution of Engineering Designers*, March/April, pp. 7-9.

Holliday A. (2002) *Doing and Writing Qualitative Research.* London: SAGE Publications Ltd.

Hollins, B. (2007) 'What's in a Name?', *The Journal of the Institution of Engineering Designers*, May/June, pp. 28-29.

Hollins, B. (2008) 'British Standards: The Suite of British Standards on Design Management. A Personal view by Bill Hollins.' *The Journal of the Institution of Engineering Designers*, March/April 2008, pp. 16-18.

Hornbuckle, R. (2007) 'Utilising waste plastic in Design Practice' International Conference: *Plastics – Looking to the Future and Learning from the Past,* V&A Museum, London, 23-25 May 2007.

Howarth, G. (2004) 'In a Sustainable World... The Designer's Future', *The Journal of the Institution of Engineering Designers,* March/April, pp. 10 - 13.

Hughes, M. 'Interviewing' in Greenfield, T. (2002) *Research Methods for Postgraduates*. 2nd edn. London: Arnold pp. 209-217.

Humphries-Smith, T. (2010) ‘Several Shades of Green’, *Journal of the Institution of Engineering Designers*, July/August, pp. 10-12.

Hutchins, M. J. and Sutherland, J. W. (2009) ‘The Role of the Social Dimension in Life Cycle Engineering’, *International Journal of Sustainable Manufacturing*, 1 (3), pp. 238-250.

Hutton, P. F. (1990) *Survey Research for Managers: How to Use Surveys in Management Decision Making.* 2nd edn. Basingstoke: Macmillan.

IED, (2006) ‘RoHS Compliance: A Simple Explanation and Frequently Asked Questions’, *The Journal of the Institution of Engineering Designers*, May/June 2006, pp. 26-29.

Ijomah, W. L. (2002) *A Model Based Definition of the Generic Remanufacturing Business Process.* Ph.D. thesis. University of Plymouth [Online]. Available at: http://pearl.plymouth.ac.uk:8080/pearl_xmlui/handle/10026.1/601 (Accessed 14 December 2011)

International Organization for Standardization (2010) *Discover ISO: ISO’s Name*. Available at: http://www.iso.org/iso/about/discover-iso_isos-name.htm (Accessed: 18 October 2010).

Johansson, G. (2008) ‘Product Innovation for Sustainability: on Product Properties for Efficient Disassembly’, *International Journal of Sustainable Engineering*, 1 (1), pp. 32–41.

Jones (Dekoninck), E., Stanton, N. A. and Harrison, D. (2001) 'Applying structured methods to Eco-innovation. An evaluation of the Product Ideas Tree diagram.' Design Studies, Elsevier Science, Kidlington, Oxford, U.K. (2001) Volume 22, Issue 6, pp. 519-542.

Jones, E., Harrison, D. and McLaren, J. (2001) ‘Managing Creative Eco-innovation:

Structuring outputs from Eco-innovation Projects', *The Journal of Sustainable Product Design*, 1, pp. 27-39.

Jones, N. (2003) *Active Disassembly Applied to End-of-Life Vehicles*. Ph.D. thesis. Brunel University [Online]. Available at:. http://bura.brunel.ac.uk/handle/2438/5397 (Accessed 28 November 2011).

Jones, N., Harrison, D. J., Hussein, H., Billett, E. and Chiodo, J., (2004) 'Electrically Self Powered Active Disassembly', *Proceedings of the Institution of Mechanical Engineers, Part B: Journal Engineering Manufacture,* 218, pp. 689-697. *Sage* [Online]. Available at: http://pib.sagepub.com.v-ezproxy.brunel.ac.uk:2048/content/218/7/689.full.pdf+html (Accessed 29 November 2011).

Kirby, J.R. and Wadehra, I. (1993) 'Designing Business Machines for Disassembly and Recycling', Proceedings of IEEE International Symposium on Electronics and Environments (ISEE). Arlington, VA , USA, 10-12 May. Available at: http://xplorebcpaz.ieee.org.v-ezproxy.brunel.ac.uk:2048/stamp/stamp.jsp?tp=&arnumber=302842 (Accessed 29 November 2011).

Kobayashi, H., Hongu, A., Haruki, K. and Doi, S. (1999) 'A Framework of Eco-design Support'. *First International Symposium on Environmentally Conscious Design and Inverse Manufacturing,* Tokyo 1-3rd February. IEEE. Available at: http://xplorebcpaz.ieee.org.v-ezproxy.brunel.ac.uk:2048/stamp/stamp.jsp?tp=&arnumber=747697 (Accessed: 17th November 2011.

Leipziger, D. (2009) *SA 8000 The First Decade: Implementation, Influence, and Impact*. Sheffield: Greenleaf Publishing Ltd.

Leonard, A. (2005) *The Story of Stuff* [Online] Available at: http://www.storyofstuff.com (Accessed: 9 July 2008).

Macleod, I. (2007) 'All Gain No Pain? BS 308 to BS 8888: A Brief History of Geometrical Product Specification', *The Journal of the Institution of Engineering Designers,* July/August 2007 pp. 26-29.

McAloone, T. C. (2000) *Industrial Application of Environmentally Conscious Design*. Bury St. Edmunds, Suffolk: Professional Engineering Publishing Ltd.

McDonough, W. and Braungart, M. (2002) *Cradle to Cradle*. New York: North Point Press.

Mitchell, E. (2003) 'Web-based APQP keeps everyone connected', *Quality Magazine,* May, [online]. Available at: http://www.qualitymag.com/Articles/Feature_Article/c66a785824c38010VgnVCM100000f932a8c0 (Accessed 29 November 2011).

Norman, D. A. (2002) *The Design of Everyday Things*. 2nd edn. New York: Basic Books.

O'Leary, Z. (2004) The Essential Guide to Doing Research. London: Sage Publications Ltd.

O'Shea, M. A. (2002) 'Design for Environment in Conceptual Product Design – a Decision Model to Reflect Environmental Issues of all Life cycle Phases', *The Journal of Sustainable Product Design*, 2, pp. 11–28.

Office for National Statistics (2000) *Number of Enterprises, Employment and Turnover in the Private Sector by Size of Enterprise and Industry Group – 2000 – All Industries.* Available at: http://www.statistics.gov.uk/STATBASE/xsdataset.asp?vlnk¼4280 (Accessed 13 April 2009).

Office for National Statistics (2003) *UK Standard Industrial Classification of Economic Activities* . London: Her Majesty's Stationery Office (HMSO).

Office for National Statistics (2008) *Enterprise Size.* Available at: http://www.ons.gov.uk/aboutstatistics/user-guidance/lm-guide/concepts/employers/enterprise/index.html (Accessed 1 July 2009).

Office for National Statistics (2008) *Standard Industrial Classification*. Available at: www.statistics.gov.uk/methods_quality/sic/ (Accessed 6 June 2011).

Packard, V. (1960) *The Waste Makers*. Aylesbury: Penguin Books Ltd.

Papanek, V. (1995) *The Green Imperative: Ecology and Ethics in Design and Architecture*. London: Thames & Hudson Ltd.

Patton, M. Q. (1990) *Qualitative Evaluation and Research Methods*. 2nd edn. London: SAGE Publications Ltd.

Platcheck, E.R., Schaeffer, L., Kindlein Jr, W. and Cãndido, L.H.A. (2008) 'Methodology of Eco-design for the Development of More Sustainable Electro-electronic Equipments', *Journal of Cleaner Production*, 16, pp. 75-86.

Pli Design (2009) *Eco-Friendly Furniture.* Available at: http://www.plidesign.co.uk (Accessed: 8 June 2009).

Porter, M. and van der Linde, C. (1995) 'Green and Competitive: Ending the Stalemate', *Harvard Business Review*, 37 (5), pp.120-134.

Pugh, S. (1991) *Total Design: Integrated Methods for Successful Product Engineering*. Harlow: Pearson Education Ltd.

Punch, K. F. (2003) *Survey Research: The Basics.* London: SAGE Publications Ltd.

Punch, K.F. (2000) Introduction *to Social Research: Quantitative and Qualitative Approaches*. 4th edn. Boston: Allyn and Bacon.

Rahimi, M. and Weidner, M. (2002) 'Integrating Design for Environment (DfE) Impact Matrix into Quality Function Deployment (QFD) Process', *Journal Sustainable Product Design*, 2, pp. 29-41.

Rahimifard, S. and Clegg, A. (2008) 'The Role of the Engineering Community in Sustainable Development', *International Journal of Sustainable Engineering*, 1 (1), pp. 1–2.

Rhodes, R. G. and Smith, D. G. Information retrieval: Preparation material for design teaching, 1987 (SEED Publication). In Pugh, S. Total Design: Integrated methods for successful product engineering, 1991 (Pearson Education Ltd., Harlow, Essex).

Rose, C. M., Ishii, K. and Stevels, A. (2001) 'ELDA and EVCA: Tools for Building Product End-of-Life Strategy', *The Journal of Sustainable Product Design*, 1, pp. 181-195.

Sambasivan, M. and Fei, N. Y. (2008) 'Evaluation of Critical Success Factors of Implementation of ISO 14001 Using Analytical Hierarchy Process (AHP): A Case Study from Malaysia', *Journal of Cleaner Production,* 16, pp. 1424-1433.

Seiffert, M. E. B. (2008) 'Environmental Impact Evaluation Using a Cooperative Model for Implementing EMS (ISO 14001) in Small and Medium-Sized Enterprises', *Journal of Cleaner Production*, 16, pp. 1447-1461.

Shaughnessy, J. J., Zechmeister, E. B. and Zechmeister J. S. (2000) 5th edn. *Research Methods in Psychology*. Boston: McGraw-Hill.

Simmons, C, (2006) 'BS 8888 Gain from Improved Specification', *Journal of the Institution of Engineering Designers*, May/June, pp. 16-19.

Simmons, C. H., Maguire, D. E. and Phelps, N. (2009) *Manual of Engineering Drawing: Technical Product Specification and Documentation to British and International Standards*. 3rd edn. Oxford: Elsevier.

Singh, S., Goodyer, J. and Popplewell, K. (2007) Integrated Environmental Process Planning for the Design and Manufacture of Automotive Components. *International Journal Production Research*, 45 (18-19), pp. 4189-4205.

Sodhi, R. S. and Sonnenberg,. M. (1999) 'Use of Snap-fit Fasteners in the Multi-Life-cycle Design of Products', Proceedings of IEEE International Symposium on Electronics and Environments (ISEE). Danvers, MA, USA, 11-13 May. Available at: http://xplorebcpaz.ieee.org.v-ezproxy.brunel.ac.uk:2048/stamp/stamp.jsp?tp=&arnumber=765869 (Accessed 29 November 2011).

Sommer, B. and Sommer, R. (1991) *A Practical Guide to Behavioural Research: Tools and Techniques.* 3rd edn. New York, Oxford University Press.

Staikos, T. and Rahimifard, S. (2007) 'An End-of-life and Decision Support Tool for Product Recovery Considerations in the Footwear Industry', *International Journal of Computer Integrated Manufacturing,* 20 (6), pp. 602-615.

Stake, R.E. (1994) *Case Studies,* In: Denzin, N.K. and Lincoln, Y.S. (eds), *A Handbook of Qualitative Research.* Thousand Oaks, CA: Sage. pp.236-247.

Thorpe, A. (2007) *The Designer's Atlas of Sustainability: Charting the Conceptual Landscape through Economy, Ecology, and Culture*. Washington: Island Press.

Tsai, C. K., Zhang, H. C. and Huang, S. H. (2000) 'Disassembly Analysis for Electromechanical Products: A Graph Based Heuristic Approach', *International Journal of Production Research*, 38 (5), pp. 993-1007 Taylor and Francis [Online]. Available at:http://www.tandfonline.com.v-ezproxy.brunel.ac.uk:2048/doi/pdf/10.1080/002075400188988 (Accessed 29 November 2011).

Tukker, A., Eder, P. and Charter, M. (2001) 'Eco-design: The State of Implementation in Europe: Conclusions of a State-of-the-Art Study for IPTS', *The Journal of Sustainable Product Design*, 1, pp. 147-161.

United Nations Environment Programme (1992), *Agenda 21: Changing Consumption Patterns*. [Online] Available at: http://www.unep.org/Documents.Multilingual/Default.Print.asp?DocumentID=52&ArticleID=52 (Accessed 17th November 2011).

University of Wolverhampton (2009) *A Guide to Your Course - Engineering Design Management*. Available at: https://smsweb.wlv.ac.uk/si/previouscg/cg_20090/SEBE/EAT/2009_0%20MEng_BEng_BSc%20(Hons)%20Engineering%20Design%20Management.doc (Accessed: 05 October 2010).

Walsh, B. (2009) 'Remanufacturing Standard Developed in the UK', *Recycler Trade Magazine*, November 2009. Available at: http://www.therecycler.com/news/13599/Remanufacturing-standard-developed-in-the-

UK.aspx (Access: 11 August 2010).

Woodward, C. D. (1972) *The Story of Standards*. London: British Standards Institution.

World Commission on Environment and Development (1987) *Our Common Future.* Oxford: Oxford University Press.

Xing, K., Abhary, K. and Luong, L. (2003) 'IREDA: An Integrated Methodology for Product Recyclability and End-of-Life Design', *Journal of Sustainable Product Design*, 3, pp. 149-172.

Yin, R. K. (1989) *Case Study Research: Design and Methods*. 2nd edn. London: SAGE Publications Ltd.

Yin, R. K. (2003) *Case Study Research: Design and Methods*. 3rd edn. London: SAGE Publications Ltd.

Yüksel, H. (2010) 'Design of Automobile Engineers for Remanufacture with Quality Function Deployment', *International Journal Sustainable Engineering,* 3 (3), 170-180.

Zuidwijk, R. and Krikke, H. (2008) 'Strategic Response to EEE Returns: Product Eco-design or New Recovery Processes?', *European Journal of Operational Research*,191 (3), pp. 1206-1222.

APPENDIX

Appendix 1: **Invitation to Participate**

«Title» «First_Name» «Surname»
«Job_Title»
«Organization_Name»
«Building_Name»
«Building_Number_and_Street»
«City_Town»
«County»
«Postcode»

«Date»

Dear «Title» «Surname»,

Re: BS 8887-1

I am investigating the use of BS 8887-1 (2006) Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE). The project is a collaboration between British Standards Institution and Brunel University. I should be grateful if you would permit me to interview either yourself or an appropriate member of staff from your product development team. I am particularly interested in the use of the standard with regard to sustainable product design.

BS 8887-1 is the first British Standard to include information on how to design products for efficient end-of-life processing. I would appreciate the opportunity to learn about your experiences of using the standard and your company's general approach to sustainability.

It would be particularly helpful if I could meet with you. Perhaps you could e-mail me and suggest an appropriate time, or we could arrange this over the telephone. I hope you will not object if I call in the next few days if I do not hear from you earlier.

Any information you provided by will be kept anonymous. If you would like to know more about the project I have created a website at **www.AlexPlant.co.uk**.

Many thanks for your time and help.

Yours sincerely,

Alex Plant

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Appendix 2: **Participant Information Sheet**

BS 8887-1 Industrial Survey

Participant Information Sheet

The purpose of this research is to investigate the use of BS 8887-1 (2006) Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE). Organizations selected to take part have been chosen because they are known to have ordered or downloaded the standard.

The research session will take the form of a semi-structured interview, the themes of which are listed below. With your permission, it would be helpful to record the meeting as this will aid accurate data collection. A typed transcript will be e-mailed to you for verification and to provide you with an opportunity to make amendments.

Interview Themes

- Motives for acquiring the standard.
- Implementation.
- Closed-loop production.
- Extended Producer Responsibility legislation.
- Standards and management systems.
- Product service systems.
- Criticisms of the standard.

Confidentiality
All information provided will be treated in confidence and no reference to you or your organization will be made in any published work resulting from the study. You have the right to ask for your data to be removed if you so wish and you may withdraw from the study at any time.

Thank you for your assistance and contribution

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Appendix 3: **Informed Consent Form**

BS 8887-1 Industrial Survey

Informed Consent Form

I have received both verbal and written explanation of the study, and have also been given the opportunity to ask for clarification or further details.

I freely give my consent to take part in this study and understand that I have the right to withdraw from it at any time. I also understand my responses will be stored and may later be published in an anonymous form.

Permission given to record the meeting: Yes ☐ No ☐

Name

Signed

Date

Organization

Position

cleaner electronics BSi Brunel UNIVERSITY WEST LONDON

Appendix 4: **Example Edited Transcript 1**

This transcript has been produced from a recording of a meeting that took place in a public house in late 2009. The participant signed the *Informed Consent Form* and was given a *Participant Information Sheet*

AP introduces subject and asks about the business.

I am a quality engineer working for a first tier automotive manufacturer that produces pressings, stampings, welded sub-assemblies and other parts for vehicles. Clients included several high prestige brands. My role is a contracted position so I am able to be involved with several other things particularly TS 16949. This is an automotive management system standard. I also undertake quality consulting for other companies, however, [the body-in-white producer] is my most significant client. Other clients are mainly from the automotive sector. In addition to being a quality engineering I am involved with other types of work included working in prisons…

AP asks about Quality Management and ISO 9000.

In my role as a consultant I have implemented ISO 9000 in companies. My primary expertise is in TS 16949. This standard is like ISO 9000 but includes automotive requirements. ISO 9000 is the core of TS 16949.

AP asks about how ISO 9000 is implemented.

It may be that a company does not have ISO 9000 but has aspirations and wants to do better or maybe their customers are asking for ISO 9001 certification. The demands of customers are a common reason for companies to become ISO 9001 certified. If a company is reasonably well organized, often all that is required is that they review their processes and approach and developed a quality manual.

AP asks about referencing standards.

ISO 9000 is a general standard. The idea is to identify the client's requirements. In addition to these, there will be regulatory requirements and not just engineering standards. Often reference to standards will not be to those from BSI, but customer specific standards. For example, the customer will specify compliance with a particular kind of engineering product introduction process and test. If working with big customers, they will have their own standards. If it is a medium size company it will reference multiple British Standards. A recent example: a medium size client company had to satisfy particular paint and welding specifications linked to British Standards. The specification of standards implies a particular performance level in terms of materials, process and test.

AP asks about ISO 14001.

I am a lead auditor for QMS and EMS. When I'm working within companies I manage these systems, and as a consultant I would implement QMS or EMS. At the moment I am working with a company and successfully taking them through TS 16949. They have now become interested in ISO 14001. Having implemented a QMS I make a practice of performing another gap-analysis relating to environmental management and the opportunity for integrating QMS and EMS and even ISO 18001 *Occupational Health and Safety*. The good companies will be certified to all three standards and they will be integrated. The best practice companies will have ISO 9001, ISO 14001 and ISO 18001... These can all be integrated into a combined quality manual.

A new client, also in the engineering business, has an existing quality policy. Initially a separate environmental policy and manual was developed. Later they will be integrated. It is helpful to begin with separate manuals so that specific procedures can be built-in. ISO 14000 requires more in terms of regulatory requirements than ISO 9000.

If you really take ISO 14001 to heart, you take on board the improvement side of it... The idea is to improve all the time and to build really good environmental practices and not just to comply with legislation. Challenging targets will be set that improve on energy use, waste or any number of aspects.

AP asks about the minimum size of companies that can be ISO 9001 or ISO 14001 accredited.

There is no minimum size. A one man company can be accredited. As a one man quality consultant looking to expand the business it would be useful to be ISO 9001 accredited. If I am to go out and sell the benefits of ISO 9001, there is no reason why I should be non-compliant. It is possible for a one man business to be ISO 9001 certified, or even ISO 14001 certified if he is running a business that gets involved with environmental aspects and impacts. For example, a waste carrier as a one man operation could be ISO 14001 certified.

Approximately 75% of my work comes from [the body-in-white producer]. They manufacture panels and doors as well as other parts for general automotive manufacturers. The engineering division within the group also do styling and engineering development for various prestige car makers and niche producers.

AP asks about design for disassembly and recycling.

One of the sad things about some niche producers is that they are working with exotic materials. I don't not want to bring specific customer names into the discussion. Our customers will tend to use aluminum panels with a special rivet processes and not with traditional spot welding. Bonded assemblies are also used. From an ISO 14001 perspective these adhesives contain environmentally damaging chemicals. They are also difficult for end-of-life processing. A front end module or windscreen assembly may be made from aluminium and steel. It will have had a sub-assembly process of spot welding, mig-welding and bonded elements. This makes crash repair for these vehicles difficult and expensive and a greater cost for insurance companies. If the front end is crash damaged, panels cannot just be taken off and replaced. A garage can't do that, it has to be done at the OEM level. They will have to replace the whole front end, or more likely replace the whole body shell. This makes end-of-life reprocessing very difficult because the body contains a mix of components and assembly methods. They can be disassembled but they have been designed with performance in mind and not end-of-life.

A [high volume manufacturer] component will have been designed for mass production and assembly techniques. A number of elements will be built up to create the floor pan and other elements will be joined onto it. It will go down an automated line with robotic spot welding and small amounts of mig-welding. Final components such as the fender will be bolted on. If this becomes crash damaged there is scope to remove the panels and take parts out. The outer panels for a [high volume manufacturer] model are likely to be bolted on. One step inside and the components will be spot welded.

For high specification luxury cars the assembly process will be similar with the body built up from the floor pan or sub-frame with parts being bonded or bolted to it. The engine would be mounted into the sub-frame. A windscreen assembly of bonded steel aluminum and various bits of plastic and glass would be bonded together. This sub-assembly would then be bonded to a mix of materials including carbon-fiber.

AP asks about the performance benefits of bonded assemblies.

The key performance benefit of using bonded assemblies is through weight savings. Performance is driven in part through weight reduction. There are also crash performance benefits from having a carbon-fiber body that a steel construction would not have in terms of the way it crushes and absorbs impact. Mass produced cars are designed the collapse in a crash. Niche vehicles have to meet the same stringent standards but fewer vehicles would be used for crash testing in the development process. Because these vehicles are capable of much higher speeds there is a higher crash performance requirement. This necessitates the use of more exotic materials to absorb energy and protect the occupant.

[A high volume manufacturer] will have a structured program of CAE and FEA. Their model will be crash tested in a virtual environment a number of times. They will know that they have a robust design before they start making real cars. Once they have a physical car they will have a phased program of crash testing. Niche producers don't have the luxury of having as many cars. They will still have to go through that stage but would not crash as many. The niche producers will do more of their development within CAE software to verify the design. The aim is to do as much as possible in the virtual world.

If an unproven exotic material is used, the virtual testing becomes even more important. If a [high volume manufacturer] were to bring out a new model, they would have 60-70% carry over from the previous model. They might start with the same floor and chassis structure. Much can be done to adjust the appearance of a car by changing the external skin panels. [Another high volume manufacturer] uses a common floor in 60% of their models but with different skin panels fitted. Stylistically they make various vehicles look different whilst having a common floor. They can appear stylistically very different but in a crash test and from an engineering perspective they will be very similar.

AP asks about QMS and EMS auditing and UKAS accreditation.

My job is concerned with internal audit of management systems. As a consultant I help clients to build management systems and supporting structures as well as doing internal audits that are required as part of their system. It is not enough to be able to claim ISO 14001. They have to have third party accreditation. An external auditing body such as BSI or Lloyds Register of Quality Assurance (LRQA) will then accredit their system. This usually takes about three days. When a company is being audited, the consultant cannot speak for the company. At a recent LRQA audit I was allowed to sit-in on the meetings with the company and the auditors and was able to guide my clients through the process. The certification auditors are United Kingdom Accreditation Service (UKAS) accredited.

AP asks about BS 8887-1.

Part of the reason for purchasing BS 8887-1 was to support a project with an OEM. One of the requirements was to do with Geometrical Dimensioning and Tolerancing (GD&T) work. This customer was based in India. The work was straightforward and simple but the standard was purchased to provide knowledge. The BS 8888 set of standards includes all of the GD&T standards. BS 8888 was a start point that led to other engineering requirements including BS 8887-1 MADE.

AP talks about the TPR triumvirate, DfEoL and eco-design.

The standard was reviewed briefly for interest. What did strike me is that the automotive industry do a lot of those things... especially DfA. We have to do it, it's part of being successful. If we didn't, we would produce more waste and increase costs. We do it because it is good practice. These practices are also enshrined in the automotive standards. As a supplier we have to satisfy client APQP. The big automotive producers often have their own standards. They build in lean manufacturing approaches, poka yoke, and waste reduction. They are also driving their suppliers towards ISO 14001 accreditation. Much of this effort is driven by cost reduction. The automotive industry is good at reducing costs throughout the supply chain. The environmental gains are a by-product.

Some companies are very proactive in their approach to environmental matters and end-of-life requirements because they recognize that it is good business practice. Some of the German automotive companies are particularly good at planning for end-of-life. The niche producers don't have the luxury of thinking in terms of end-of-life, but we do need to be thinking about it. [The body-in-white supplier] has the ability to plan for end-of-life, however this would have to be requested by the customer i.e. the OEM.

Components, sub-assemblies and material selection can be reworked to improve environmental performance. The engineering department is proud of a prestige car that they redesigned from a primarily steel and aluminum construction to use various other materials. This resulted in a 40% weight reduction and improved assembly mechanisms. Despite using a greater variety of materials the vehicle was easier to disassemble because of the attention to design for assembly. The weight savings also improved fuel efficiency and performance.

Some of the third world producers, for instance Brazil, use more plastic and Sheet Moulding Compound (SMC) material in their car construction. They have a different view on what constitutes a car. They require assemblies to go together easily and to be able to be replaced or repaired when crash damaged. Panels must be easily replaceable.

A multi-skilled engineering group can redesign things with whatever end-of-life requirement aims are specified. If we are asked to re-design a car body with more common materials and to do design for disassembly we could do that. It is well within our engineering capability.

AP talks about BS 8887 and avoiding composite materials.

When considering environmental impacts of prestige cars, they are small in number relative to mass produced vehicles, and this should be taken into consideration. Any global end-of-life diktat or Government policy should focus on companies that have the biggest impact i.e. the mass market producers. If a million [a high volume manufacturer] cars can be efficiently processed at end-of-life compared with perhaps 500 [niche producer cars], the [high volume manufacturer] re-design will have the greatest possible impact.

An aircraft manufacturer assessing performance, safety and environmental impact would have a hierarchy of importance favoring safety and performance over end-of-life planning. It's necessity versus nicety.

AP asks about ELV directive requirements and BS 8887-1.

We were considering using aluminum as an alternative material for a car body shell or as part of a sub-structure. The Aluminum Association has a very good website information resource. This raised awareness of end-of-life requirements. BS 8887-1 was also relevant to several other issues under consideration. The engineering group are aware of end-of-life requirements and would be able to apply the principles but it is not integrated. Design is driven by customer requirements. Your message needs to go out to the OEMs.

AP asks about tier-1, 2, 3 etc.

A tier-1 automotive company would supply the OEMs. A tier-2 company would supply tier 1. [A prominent steel producer] is both a tier-1 and a tier-2 company. It would supply the OEMs directly and supply the tier-1 companies. Screws, fixings, nuts and bolts, weld equipment and all of the other parts required for our products are from tier-2 suppliers.

For example, a painted roof panel is supplied to the car manufacturer with an e-coat. The panel would be made by the tier-1 manufacturer. It would then be e-coated and sent to another firm for painting and then shipped directly to the OEM. The panel maker is still the first tier supplier but contracting another firm to paint it.

AP asks about e-coating.

Mass market vehicle bodies, particularly in Europe and America will be e-coated. The e-coating process involves dipping a body, or sometimes just a panel, in a tank of electrophoretic compound and applying a charge to the metal work to be coated. The coating material then sticks to the charged surfaces. The work being coated is then removed from the tank and heat is applied. The electrophoretic material will then bond to the surfaces like paint. This process covers every crevice and area.

In another example, whole car body shells and some separate panels are e-coated before being shipped to the OEM where they go through another paint process. E-coating is the stage before painting. The e-coat gives corrosion and environmental resistance and makes the bodywork outlast the ten year guarantee offered by manufacturers. An aluminum body shell will go through a different process as it is inherently corrosion resistant.

AP asks about the use of fixings.

Generally, but not always, materials will be matched. Weld materials have to be similar in terms of strength and properties. Weld-nuts are commonly used. The nut becomes part of the panel. A weld nut has four projections on it. They are sandwiched together within the panels. Pressure, high voltage and heat are applied so that they fuse together and the nut is captive. In many instances it is not possible to access both sides of a bolted, welded assembly and so a weld nut is required on the inside.

AP asks about the use of BS 8887-1.

Looking through the standard my conclusion was that we do some of it already and that this is automotive good practice... particularly design for assembly. Some of those things we would do as a natural part of our practice. The next step of promoting the implementation of any new ideas within BS 8887-1 has not yet been taken.

AP asks about auditing.

You couldn't audit against that standard and say a company is BS 8887-1 compliant. Elements of ISO 9001 and ISO 14001 incorporate elements of other voluntary codes that could be audited against. ISO 9000 has a voluntary part ISO 9004 *Managing for the Sustained Success of an Organization*. After becoming ISO 9001 certified, a continuous improvement approach should be adopted. Few of the companies I have worked with have taken on ISO 9004. It gives more guidelines on continuous improvements and exceeds ISO 9001.

ISO 9000 and ISO 14000 are less about 'do what you say and document what you do.' They are more about demonstrating performance process and improvement. ISO 9004 was never set up or intended to be an auditable standard. It could be applied to business management. This would improve the business, and the management process would be stronger than a company that was purely ISO 9001.

AP talks about ISO 14001 and its relevance to design.

The standard could be referenced in a product design specification under ISO 14001 as part of reducing environmental impact. This would count as good evidence of ISO 14001 compliance. Part of ISO 14001 is about demonstrating compliance. It could be used as part of the main compliance with ISO 14001, or as part of continuous improvement.

AP asks about ISO 14001 and its relevance to the design process.

Yes indeed. ISO 14001 is concerned with impacts of various aspects such as FMEA. It all starts with design. By the time a product goes to manufacture the impacts are a given, they are set. With design for end-of-life and recyclability, or any other environmental impacts, the manufacturer will be stuck with them. There is nothing stopping a design house from considering environmental impacts of the decisions they make. Perhaps by designing differently the costs could be reduced. Waste could be eliminated and the weight of products reduced. A design saving of 2% in the use of material in a component will give a bigger impact than the manufacturer can by reviewing their processes. A manufacturer may be able to make improvements in not wasting metal when cutting it, but a designer could build that in. The design has an impact.

The battle is to get engineers to think about the environmental impacts of what they are doing. I take issue with people who say you can’t do it at the design stage. You have to do it at the design stage. That is the bit where you can have the biggest impact. The bulk of my experience is in manufacturing and quality. By the time I get the product it is too late to have a lasting impact on the design form. The original designer had more opportunity to influence the environmental impact than I am going to have as the manufacturing person.

AP asks about built-in obsolescence within the automotive industry.

The automotive industry is very customer driven and there are a number of competing pressures. Japanese and German manufacturers are offering vehicles that last well and have a six to ten year warranty. They are supporting the longevity of vehicles.

The industry has always been driven by reducing the time taken for new product development. In the past a new model might have taken four years to develop. This has gone down steadily and is now about two years or even eighteen months. This is managed by issuing many minor model changes. Longevity is built-in so the customer can be given a good warranty and product service life. At the same time customers demanding a new car every year or every eighteen months are also satisfied by offering minor style changes and extras.

Car manufacturers are taking on ideas to support end-of-life. The ELV directive is a bigger driver for them than the good practice voluntary standards. This directive will impose legal constraints on the manufacturers and it will impose cost responsibilities. It is the cost and legal implications of the directive that will influence them.

The ELV directive requires the OEM to be responsible for the financial cost of recovery. When the car has finished its life, it is effectively going to come back to its producer with regard to the cost of taking it apart. This cost will be built into the vehicles. Design for end-of-life will permeate first and second tier suppliers and all the way down.

AP asks for criticisms of BS 8887-1.

The standard is easy to understand and contains a large volume of information. It has been used as a reference source to be looked at in parts as required rather than as a body of information to be taken on in one go. It would be helpful to have a guideline document to give insight into what is in the deeper standard when faced with a particular question. This would be a two tier approach.

AP asks what could be done to have BS 8887 used more in industry.

An engineer will not necessarily read a hundred page standard just because he is asked to. If a customer asks for a design that meets the requirement of BS 8887-1 it will be taken on board. The idea of the standard needs to be sold to the OEMs for tier-1 and tier-2 suppliers to adopt.

Good engineers keep their skills up-to-date. BS 8887-1 could be packaged as part of their Continuing Professional Development (CPD).

AP talks about training.

It would be useful to have a series of workshop sessions perhaps with IMechE [Institution of Mechanical Engineers] or IEEE [Institute of Electrical and Electronics Engineers]. Every week these organizations offer multiple seminars. This is a way to reach the right people on mass. The standard must be sold in terms of the benefits to the engineer and what he will get out of it. It should be presented with reference to current industry pressures such as the ELV directive, cost performance and managing the cost of end-of-life as OEMs. This will filter down to first tier suppliers.

AP talks about BS 8887 computer based training.

Yes absolutely e-training would be helpful. Engineers are very good with tangible objects that can be looked at and felt. A training system would have to anticipate some of the questions they might face and then provide some examples of how they can be solved.

AP talks about BS 8887 design handbook.

With ISO 9000, I adopt an approach of: do things simple, do things visual. If a process is simple, it can be seen and mapped out and it will work. Much of the work of product development is simplifying designs and paring them down to that which is essential. We need to turn this into a simple guide, a step by step tool kit explaining what should be done at each stage with more detail as required. In marketing these ideas you will have only a limited time span within which to attract their attention. A guide document should help engineers connect requirements and solutions quickly and lead them to more detailed information. We need to give context to it to explain where it fits in.

The automotive industry is an example of an established industry with good new product development processes, from concept through to the management of the product and every aspect of it including end-of-life. We need to put BS 8887-1 in the context of APQP. APQP is not part of ISO 9000. Most of the automotive OEMs, especially American, specify that suppliers will be TS 16949 compliant. As part of that there is a core tools package. APQP is one of those core tools along with the PPAP, SPC and FMEA. TS 16949 does not specify the use of APQP, but does require a new product introduction process. The OEMs will require APQP of their suppliers. In some ways it is a requirement of TS 16949. BS 8887-1 could be one of the toolkits that sit one layer behind TS 16949 and would be drawn on and built into the supply chain.

Devise a tangible benefit that people are going to get from it. Case studies would be helpful in selling BS 8887-1. There may be examples of compliant designs and processes that would meet the standard's requirements even though they have not been specifically designed with it. A company's current product and processes could be compared against BS 8887-1 to seek opportunities for improvement.

We do ISO 9000 partly because we have to. It can be a struggle to meet the requirements that are absolutely necessary before adding BS 8887-1 to that.

End of interview, thank you etc.

Appendix 5: **Example Edited Transcript 2**

This transcript has been produced from a recording of a meeting that took place on company premises in late 2009. The participant signed the *Informed Consent Form* and was given a *Participant Information Sheet*

AP talks about environmental information relating to the company presented on their website.

We achieved both ISO 9001 and ISO 14001 accreditation this year. These were awarded within 4-5 months of each other. We used to be ISO 9001 registered but voluntarily relinquished these six or seven years ago at a time when the company was going through one of its changes of ownership. It was felt by the management at that time that maintaining ISO 9001 accreditation was not going to be feasible given the amount of management time required to address the change of ownership. Rather than losing this, it was voluntarily given up. Since that time it has been a personal bugbear of mine not having ISO 9001 accreditation. Once everything was settled after the latest round of turmoil, ISO accreditation was made a priority. A project was put in place to achieve ISO 9001 first, and followed closely by ISO 14001. We didn't have ISO 14001 before and we are back to ISO 9001 working to the latest 2008 version. For the first time, ISO 14001 was achieved early in the year and so has now been in place for nearly a whole year.

We tried to go forwards with an environmental management system. Next year the intention is to add Occupational Health and Safety [OHSAS] 18001. These will be moved into a combined integrated management system.

AP asks if ISO 14000 implementation has been profitable.

The effect has been two or even threefold. Achieving the standard made us more aware than we otherwise would have been, of things that we were doing poorly with regard to the environment. We weren't a horrible polluter but it certainly focused our attention. [An external consultancy] was contacted for advice and input. The survey that they did revealed many opportunities to save fuel and water. This has resulted in some definite savings. Subsequently, the business has been positively affected. ISO 14001 is one of those standards whose time has come. We didn't feel any pressure to adopt ISO 14001 until about eighteen months to two years ago when more and more of our customers asked the question 'have you got an environmental management process within your business?' If the answer is 'yes we have ISO 14001 accreditation' the rest of the questions on that section of the form don't have to be answered. A few of the people that asked the question really mean 'you need to answer yes otherwise we won't do business with you' or at least they will be disinclined to deal with a company without an environmental management system. Supermarkets like to see ISO 14001 accreditation. They like to be seen to be dealing with companies with ISO 14001 and definitely with ISO 9001. There is definitely a benefit. For a long time ISO 14001 did not offer a huge business benefit with regard to interaction with business customers. However, the standard is coming into its own now.

Even in the space of the last 6-7 months we can probably accredit £75,000 worth of business to having ISO 14001. This is business that we probably would have struggled to get if we had not been ISO 14001 registered. It is not that the company would not have won it but they would have had to work harder. Some of the supermarkets are very careful about the image of the companies that supply them.

AP asks about the company's combined quality manual.

The systems are run in parallel rather than being entirely combined. This is largely because they are at an early stage. ISO 9001 is still quite new and I don't want some of the priorities within ISO 9001 to become subsumed into a broader umbrella. The intention is to completely integrate the management systems over the next year. ISO 14001 and ISO 9001 are run side by side. Nearly all of the associated documentation is kept on the company network rather than as a paper system.

AP asks about referencing BS 8887-1

Standards wouldn't be referenced in the quality manual directly. The quality manual is a top level overview of the system. In the procedures and work instructions that cascade down from that, standards are cross-referenced.

AP asks why BS 8887-1 was purchased.

We were asked by one of the breweries, for who whom manufacture cellar cooling systems, to provide information about whole life costing and particularly end-of-life for the equipment that they were buying.

One of the brewery companies has had a very big environmental drive in the last 2-3 years. They have invested huge sums of money making the whole brewery end of the business extremely environmentally friendly. They are trying to roll that out into as many aspects of the business as possible. The brewery was keen to see information relating to equipment purchased for their tied public houses. I wasn't familiar with the standard at the time. The reason for purchasing BS 8887-1 initially was so that we could bring the reliability of a British Standard to the information that we were providing to our customer and to show them that rigour had been applied to the information gathered for them.

Having read BS 8887-1, we have tried to apply many of the concepts within it to everything else since. For example, we have product that has only been in high volume production for about six weeks. This has taken nearly a year to develop. The product is a package condensing unit. Some of the principles of BS 8887-1 were adopted into that, so the unit is now 98% recyclable. We try to use parts that can either be completely reused at the end of the unit's life, or if they cannot be reused then it will be possible for them to be recycled and used again in something else. In the refrigeration and air conditioning business that is not always difficult as a large proportion of the products are made out of metal. Unless something is done to contaminate the product then it will be largely recyclable.

I like the style in which BS 8887-1 has been written as it is more practical than some older standards. It is very much a how to guide. Reading through it there is some technical information and some maths but it is almost conversational when compared with older standards. BS 8887-1 is also easy to apply. The principles contained in it are easy to understand. It is not necessary to constantly refer to it. Other standards that we refer to regularly are very much more densely written, so it is impossible to retain all of that information mentally, and it is necessary to keep referring back to them. The title of BS 8887-1 *General Concepts* sums this up – this is exactly what is in this standard.

The company is fortunate in bringing green concepts into the design process because it manages the whole process in-house, and nothing gets designed for us outside. This starts with a development process normally driven by the sales and marketing department. It will be a requirement for a product that they feel will address a niche in the market, or it will be something specifically requested by a customer. If it is thought to have enough potential to warrant development, work will commence.

The identified opportunity will be developed into an engineering specification. For this, elements of BS 8888 will be used. This will move forwards through various modeling stages to prototyping, then a production engineering phase and field trials. Assuming that all the issues have been addressed validation work will be done before the product is moved into production.

We have control over the product development process with the exception that electronics is usually designed by a contractor. For this, a design specification is written. Developing board and components layouts is a specialist function that we don't have the time or resource to undertake and so this work is subcontracted. Most of the other development work is done in-house. This enables us to bring concepts from within BS 8887-1 into the design process right at the beginning.

BS 8887-1 was ordered to provide a customer with reliable information about end-of-life reprocessing. We are a subscriber to BSI. Following a word search, BS 8887-1 was suggested by the system as an appropriate document. I was not aware of the standard before being prompted to look for this information by the customer.

AP asks if there was anything in the standard that conflicts with functional design requirements.

I don't like the tone of the *Industrial Design* section within BS 8887-1. It is a little bit patronizing, particularly with regard to the way in which reference to industrial design was made. The process outlined indicates that a company would almost certainly need to go elsewhere to find good industrial design input. This does not seem to be in keeping with the rest of the document. On a practical level I don't think there are any real clashes. There is a feel to that part of the document, and later on, that there is an assumption that a company will not have the required skill set in-house and that it will have to be found elsewhere. I don't think that this is generally true, and it is definitely not true for the products we make. We operate at a fairly low level of technology in light to medium engineering of electro-mechanical products with a little electronics. The use of advanced electronics is very limited. Three or four of the products in the range might have PLCs [Programmable Logic Controllers] built into them. We are not working with any particularly cutting edge technologies. The design activity is concerned with bringing different disciplines together in different ways.

We are not working in the retail product, or consumer product, design sector so the design of equipment is far less aesthetically critical. Design must first meet functional requirements and aesthetics secondly. We have moved away from an architectural / industrial approach to design. This is largely to do with health and safety issues i.e. removing sharp corners and reducing mass. Ergonomics and aesthetics does not have to be particularly considered, unlike with consumer products. It is quite easy to apply many of the ideas from BS 8887-1 as the company's design process is relatively straightforward. I have not found clashes with regard to functional requirements and those of the standard.

AP asks about the influence of RoHS.

Both RoHS and WEEE were addressed well before becoming involved with BS 8887-1. We do not have any issues with WEEE as the legislation is at present, because we do not make any consumer products at all. Steps have been taken to meet obligations under RoHS. This was addressed as part of the company's Health and Safety obligations. We were under no obligation to take back product at end-of-life. If consumer products were manufactured, under WEEE it would be necessary to show some method of recovering end-of-life product, but not for commercial product.

AP asks about the company's products' end-of-life.

The implication is that they make their own arrangements to have products reused or disposed of. This is part of the reason why some customers have asked us to consider design for end-of-life. They understand that it is their responsibility, but they want it to be made as easy as possible. They would not want many tons of a particular type of plastic that cannot be used again and has to go into landfill. Customers would rather not have foams used within their products that have foaming gases within them that cannot simply be burned or thrown away. Whilst they are responsible, they want us to make that job as easy as possible. A customer will calculate the cost of disposal at the end-of-life and they are passing that back. The retail customer does not have that leverage; they are not in a position to negotiate the price of the product they are buying, with regard to what happens at the end-of-life. Whereas the organizations that we sell to do have that leverage and hence the emphasis within the law.

A customer will calculate that the cost of disposal might be £100 and demand that this is deducted from the sale price. A package condensing unit probably would cost £50-60 to dispose of. This reverse calculation may make only a small difference to the overall cost of each individual product, but when in the business of selling many hundreds of units of a particular piece of equipment, this soon becomes significant and worth considering. Customers have accepted that they will have to do this work and that it will be a cost they will incur, so they try to pass that back to the manufacturer. The WEEE regulations take a different approach to protect the people who don't have that leverage.

AP asks about design for disassembly.

If a company can do design for disassembly so that it is very simple and straightforward to remove non-valuable parts and leave perhaps 300 kg of stainless steel, this would be equivalent to a very good discount for the customer as the stainless steel is highly saleable. Our products only contain small amounts of stainless steel although they are primarily metal construction and all metal is recyclable for a price.

We offer, although not many people take up the offer at present, an informal system where if a customer wants to bring or send back end-of-life equipment it will be correctly disposed of. There is no charge for this because through the returns system, a quantity of copper will be received and this can be sold. There is normally enough value in this to warrant providing the service free of charge.

AP asks about the capture of refrigerator gases.

The gases are recycled. If the cooling gas were CO_2, this could probably be released but these systems are not currently built. All the refrigerants currently used are HFCs [Hydrofluorocarbons]. These cannot be vented under the F-Gas [Fluorinated greenhouse Gases] directive. Most of the refrigerants used today are fluorinated vapors. The current exception to that is hydrocarbon refrigerant e.g. propane and butane. These have been used in domestic fridges and CO_2 is becoming increasingly popular.

CO_2 has very low global warming potential in spite of being the cause of the problem. Relative to 404a, a very popular refrigerant at the moment in the UK, CO_2 has 400 times less global warming effect mass for mass. The problem is that CO_2 is not a very good refrigerant. It is extremely difficult to work with. It is also inefficient, and so a CO_2 fridge will require more energy input to run. CO_2 is a problematic fluid. Loose in the atmosphere CO_2 is far less damaging than 404a.

The difficulties of working with CO_2 have resulted in the company not producing CO_2 products because it is horribly inefficient. This is because of the associated physics. A standard CO_2 fridge will have many workarounds to control pressure and temperature in various parts of the system. All these result in energy losses and cause inefficiencies. With CO_2 it is necessary to put in far more energy than with an equivalent system using 404a.

The other problem is with the high or condensing side of a CO_2 system, as the pressures are very much higher. Super heated steam systems operate at around 200 bar, whereas fridges operate at 10 bar typically. Working with higher pressures is unfamiliar to fridge engineers and the equipment must be suitably robust. Even today it is difficult to obtain some of the components necessary to build CO_2 systems, especially for smaller scale units. The positive benefit is that if it escapes to atmosphere CO_2 does less harm. The company point of view is to continue to champion the development of systems that are better at containing the refrigerant. As many joints as possible are eliminated because these have the potential to leak.

We also do all that we can to educate end users. The problem is that no matter how well we make a system, in the long run, its gas tightness and lack of leaking is down to maintenance. The irony is that many of the supermarkets are now keen to see that the company has ISO 14001 accreditation. They ask many environmentally oriented questions about how the company will deliver products and what the products offer with regard to energy saving and alternative refrigerants but they are the worst culprit for loss of refrigerant because they maintain the systems so badly. In some respects this is almost forgivable as a superstore will have twenty or thirty compressors, many hundreds of meters of pipe work connecting the compressor packs to the display cases and multiple evaporator sections, all of which have the potential to leak.

Commonly part of the system will be in a plant room or on the roof, located remotely from the shop floor. One of the things that supermarkets hate to do is to use floor space for equipment when that space could otherwise be used for selling from. If equipment can go on the roof then that is where it will go. The potential for leaks is enormous. There will be small leaks all over these systems and the effort required to find and fix those leaks just doesn't show them an economic return. Instead they just keep topping the system up with more refrigerant.

Hundreds and hundreds of equivalent tons of CO_2 go up into the sky because these leaks are too difficult and expensive to find. This is very sad because it is all about maintenance. If they took their responsibility seriously, and this is where the F-Gas directive is relevant. The new regulations, for the first time, place a legal responsibility on the end user. There has been legislation put in place for manufacturers, and most of the affected companies have responded responsibly but there wasn't any emphasis on the end user. This has only recently been recognized as a huge part of the problem. Legally now, because of the F-Gas directive, regulations have gone into law under the Environmental Protection Act [EPA]. An end user now, depending on the size of the installed system, must regularly carry out leak checks. When a leak is found it must be repaired and not knowingly left. Something must be done immediately to stop it. This is difficult to police and I couldn't say how often this actually happens. Unfortunately there are no Government inspectors checking that this is being done.

AP asks about product maintenance.

The maintenance engineers are a mixture with some employed by the company and some external contractors. With regard to static refrigeration, the type used in supermarkets, they almost always have a sub-contractor. They will generally employ a building services maintenance company rather than a specific refrigeration maintenance organization. Our involvement largely ends once the equipment has been sold to whoever the installing contractor is. Equipment is rarely sold directly to the supermarkets. They will employ a prime contractor to oversee an installation project. The prime contractor will purchase the equipment on behalf of the supermarket and arrange for it to be installed. It is common practice, but not in every instance, that the installer is awarded the maintenance contract for the system for at least the first year. Money tends to be made in that part of the contract. Supermarkets have a very close relationship with the maintenance engineers and tend to use the same people repeatedly. These are quite large national organizations that provide on-site teams wherever these installations are fitted. The industry is self regulated and has self-structured.

The supermarkets are always looking for the lowest bidding contractor. Depending on the size of the system, at least once a year, a joint by joint inspection should be carried out. There are a number of ways of doing this. Probably the most effective way, bearing in mind that this check is done while the system is operating, is to use soapy water. The downside is that this is time consuming. The benefit is that even very small leaks can be pin-pointed. What tends to happen is that electronic detectors are used. These are less accurate with regard to finding the exact location of leaks but they are quicker. The devices are electronic sniffers that detect the presence of a leak. Companies that do this really well, and there are some that are conscientious, will do this in stages. They might also have a static, permanently installed leak detection system. In a relatively enclosed area like the plant room, there will be a detector on the wall so that if there is a buildup of refrigerant in the room the device will bring up an alarm.

At a more precise level sniffing can be used by following the system around with a detector. The major offenders are usually mechanical joints or places where there is significant vibration or a particularly aggressive environment e.g. near the compressor. Joints on the compressor are at high risk. Visually it is often possible to see where refrigerant is leaking from because there will also be a trace of oil.

The next level is to test every single joint. This is extremely difficult in practice because at least half of the pipe work in a standard system will be covered with insulation. Pipe work will be insulated to prevent condensation dripping and possibly damaging goods beneath. Removing the insulation to test for leaks is hugely difficult. When dealing with hundreds of meters of pipe work that does not get done. The majority of interconnecting pipe work is made with as few joints as possible and all of these will be braised. A properly made braised joint is unlikely to fail. One of our latest products was made in a similar way, without mechanical joints, and instead used braising. Once the tubes are in place with proper allowance for expansion and vibration, the braised joints should be good for the life of the equipment.

AP refers to the product mentioned earlier that was 98% recyclable.

A new product has just been introduced. This is the first completely new design, rather than a partial redesign, into which the concepts of BS 8887-1 have been adopted. There were a number of reasons for us to start the process. At the top of the list was ease of manufacture.

We found that many of the processes and practices that BS 8887-1 encourages fitted-in well with our production engineering philosophy. Usually, the easier you make something to build, the easier it is to disassemble. There will be fewer parts, fewer fastenings and the mass of certain parts will be reduced. The reliability and recyclability has also been looked at, for example the company has moved away from using PVC coated sheet metal used for the cabinets, to organically coated steel. This is much simpler to recycle at the end-of-life.

AP asks about the difficulty with the PVC coating.

The PVC can be burned off but the released gases must be treated. The fumes created by burning PVC are noxious. The newer coating is entirely non-toxic when it is burned off. The steel is purchased in the pre-coated form. My understanding from the steel supplier was that the plastic coated metal could be recycled but that the process was more complex than it needs to be. The fumes that the PVC gives off are well known to be horribly toxic and so they have to be specially dealt with. Recycling companies cannot just let the fumes from the furnaces go up.

We have not yet moved away entirely from PVC coated cable insulation. This is partly to do with availability and partly to do with cost. Non PVC cables are still very expensive but they do exist. We started to use 'Low Smoke and Fume' cable which is non PVC. One of the first incentives for low smoke and fume was that if there were ever to be a fire in situ with PVC, then the insulation would burn off the cables, and anybody near the product would be badly affected. This change was not so much about recycling but has the same effect at end-of-life as well. This type of cable is horrendously expensive in comparison to the cost of conventional cable. It is six or seven times the price.

The only time that low smoke and fume has been used was when it was specifically requested by the end user. Being able to say that we don't use PVC cable in this, but the price has gone up by £10, would be of no interest the customer. They wouldn't even want to pay £10 more 'why would I care, a fire won't happen to me'.

The product designed with the BS 8887-1 was not designed to account for every requirement; however, the design process was informed by it.

AP talks about BS 8887 design handbook.

BS 8887-1 is readable and usable on a practical level when compared with other standards. Normally standards can be a little bit impenetrable. They are highly technical documents by their nature. In the past, guides have been useful. We have a guide for BS 378 *Refrigerating Systems and Heat Pumps*. This is one of the standards that support the Pressure Equipment Directive. This is a four part standard. Part 2 and 3 are extremely detailed and very densely written documents. All the information they provide is very important. We do not have a choice; we have to work to this as there is a piece of legislation that supports it. The guide makes it much more accessible and is a starting point that might actually get referred to as it is written in such a way that some of it might stick in your mind. This is quite helpful. Yes, I think a guide would be good and I think it would extend the use of the standard and the employment of the standard into design.

One of the things that we are trying to do, but it is at an early stage, is to re-visit the whole product design process in line with ISO 9001. Early in the design process we are using the house of quality [HoQ] system. Some of the things in BS 8887-1 sit well in that.

AP asks about HoQ.

The house of quality is made up of several quadrants. In one box 'wants' will be listed.

These will probably be the requirements that the customer has specifically asked for. There might be half a dozen specific requirements. Each requirement will then be considered and matched with a means of delivery. What the customer would really like to happen is then considered alongside things we want to do with regard to production. In the middle section there is a matrix that cross references wants with what we believe will be deliverables. The 'roof' shows where there is a relationship between these things. For example, a common customer requirement is that the equipment, e.g. a condensing unit, has a small physical footprint. We know that it is important to keep the noise down. One of the ways to do this is to use large, slow fans. This might have a relationship with the requirement for a small footprint. A large fan might not need a large footprint if it were a tall unit. So there might be a positive relationship between these two requirements and they would be cross referenced. This boils down to a set of outputs that are prioritized to help understand the things to focus on and those that can be achieved with relative ease or difficulty. This will be given a grading as to how hard it will be to deliver these relationships. Building in MADE at the beginning of the process, as a given requirement, means that the principles of the standard are thought about at the start of the design process. This results in the house of quality giving very clearly focused, but broadly understood, outputs.

It could even be taken to a further degree by building on the process by linking that general idea to the fundamentals in house of quality to help understand where some of the environmental priorities will lie. The initial take on a subject might start out being very different from the finished product.

It is taken as read that at some point in time the customer is going to have to dispose of the equipment. Nothing we make is going to survive forever. Someone is going to have to deal with it. If it is us, and we are offering to do that, we want to make it as easy as we possibly can.

The company endeavours to make it as easy as possible to dispose of the product regardless of who has to deal with it. If we are to deal with end-of-life products, we will want to reduce the burden as much as possible. Also, we want to reduce the leverage of the customer. Making the customer aware of the value of the unit, when it comes to disposal is interesting, but not something that we have done yet. We want it to be as simple as possible for the customer to dispose of end-of-life equipment. We do not want issues of disposability to be a barrier to sale… When dealing with people like the breweries and supermarkets, there is an accountant somewhere who's taking every pound a prisoner. It is certainly something that is worth taking account of right at the beginning. It is a truism that time spent at the beginning of the development project is the best place to do it. It can have a very long gestation period, but the more time spent at the front end of the project, the money saved at the back end is multiplied by a factor of ten.

AP asks about where standards are used in the design process.

Standards are used in design and engineering. We have a group of half a dozen engineers. This is a broad disciplined team. The process is in line with the house of quality although this has not been used for very long. Prior to the introduction of house of quality a similar process was used.

At the conceptual stage the technical specification is drawn up for the product. This is put together with input from the sales and marketing department and production engineering. There is no point in planning to build something that the company cannot produce. A clear fixed picture of the specification is developed so there will be certainty about what it is that we are supposed to be delivering. The project will then move to ‘Specific Design’. At this stage it will be fleshed out exactly how the product will be delivered. It is at this point especially that standards become applicable. All the basic health and safety requirements will be applied, all the products will be built to the Machinery Directive and the Low Voltage Directive, Pressure Equipment Directive and now BS 8887-1, or whatever is appropriate

We try to apply the principles of BS 8888. This is largely about how information is presented. The design process is all in-house. There are one or two manufacturing processes that the company tries to hedge its bets on. We like to produce information so that it can be disseminated to other partners if the company is unable to meet all of its production requirements. We have only one turret punch on site, so the factory’s ability to cut metal is limited to the maximum throughput of that machine.

We … have invested significantly in new equipment. Much of this was related to changes in, or additions to, existing production processes within the factory. We try to be very flexible and operate within a market niche centered on the UK. Not much is exported. Our market niche is concerned with making smaller volumes of more bespoke equipment than our competition.

AP talks about British standards versus ISO standards.

Most of the standards are harmonized… All the equipment leaves the factory with a CE [Conformité Européenne] mark on it, if this is appropriate. Alternatively a certificate of conformity will be supplied with it. There is no issue with only using BS and ISO standards.

AP asks about the requirements for CE marking.

This depends on the level of the product in relation to various different Health and Safety standards. The company is competent to build equipment under the Machinery Directive. This is all self-assessed. We must be able to prove on demand that this work has been done. The CE system, at least for our products, centers around the concept of the 'technical file'. For everything we make it will be possible to assemble the required contents of a technical file. The standard requires that on demand the company must be able to prove that they have done all the things that they say they have done to prove that the equipment is safe. We are always able to do this. For serial product the technical file generally grows out of the development process. This will be quite a thick development file.

Serial products are those that are made the same over and over again, as opposed to bespoke, one off items, or very small batch production products. Serial product is made hopefully the same every time. It is the catalogue product. We have a range of transport refrigeration products, cellar cooling products and a new package condensing unit. There are a range of models that are made over and over again.

The other side of the business that has always given us a market edge is the ability to build one-offs or at least low volumes of equipment to a specific customer's standard. In the factory at any time, there will be a piece of equipment in build for which there will only ever be one-off. These are made for specific customers. It is surprising the number of customers requiring this level of service. [A smaller supermarket chain] very rarely orders two products that are the same. They have quite a high level of engineering expertise within their business. If they are looking at the refurbishment of a store, they will ask for a very specific piece of equipment to match their requirements rather than ordering multiple units of a general design and making them fit. This is different from the approach taken by [a major supermarket chain] where they use only three different sizes of packs. These packs are identical other than their sizes. These are integrated to suit their requirements. [A major supermarket chain] would rather have a simple and relatively flexible design of unit all made the same. [A smaller supermarket chain] will telephone with their order and describe exactly what they want including shape, size, parts fitted and the store to which it is to be delivered and the required delivery date.

When the size or magnitude of the projects are compared, it is easy to see why they do what they do. Proportionally to the number of stores, and the number of people employed [a major supermarket chain] has a very low level of in-house engineering expertise. One or two engineers will be responsible for refrigeration design for all of their stores. [The smaller supermarket chain] is not run nationally... So, for example, we might be speaking with the Norwich or Norfolk division. They will have their own fridge engineer. He may be responsible for as few as forty or fifty stores so proportionally they will have more in-house input. They feel that in the long run it is more competitive for them, or more cost effective, to tailor the engineering. They don't have features they do not need in a particular store. They get exactly what they do need. They are planned on a store by store basis with a much higher level of input from their in-house engineers.

If the two engineers from [a major supermarket chain] were asked to put an equivalent level of detail into each store refurbishment they had planned for the next eighteen months, they could not do it as there are just not enough hours in the day.

AP asks about Product Service Systems (PSS).

We used to offer, but it has fallen out of favor, a leasing system for the cellar cooling product. This was aimed at the non-managed public houses. Much of our business was with the chains. However, there was also another aspect with the smaller market sector where the public houses are privately owned. The person paying for the cellar cooler will be the licensee of the property. These customers are usually looking for budget products as they have less money to spend generally. They are usually less concerned about payback in the way that a brewer would be. We did offer a leasing system for that product for a time. This had mixed success. Few people saw a real benefit financially. It is not something that the market sector sees as a benefit.

We build equipment for a leasing firm specializing in re-locatable cold stores. They will lease a complete cold store with our fridge fitted. This has been a very profitable business for them over the last few years. Only this year have they seen a depression in the growth of that market place. One of the things that drove their market for a long time, and this is why there has been a drop this year, it was a very effective way of using money when money was expensive to borrow to capitalize something like a cold store. Leasing was a really attractive option.

Some of their major customers are food processing companies. The system gives them greater flexibility. They might hire a cold store to run a trial manufacturing process for a new product. If this works out well then the cold store will probably just stay in situ. If it doesn't work, they just off-hire the cold store and move on to something else. From speaking with them, and working with them for a long time, I know of a large food processing company where this frequently happens. [A major frozen food supplier] might launch a new vegetable product packaged differently, presented differently and put on a trial manufacturing line. This will be run for approximately six months and if it works out well then the whole thing will be absorbed into the main business. Very often the leased cold store will remain on site indefinitely. The leasing company loves this as the long term contracts are highly profitable for them. If the people … where these new products are usually tried do not adopt the new frozen vegetable product, they will stop manufacturing it and the cold store will be returned.

AP talks BS 8887 training.

E-training is used within the design department for keeping the staff up to date with CAD. Like any other CAD product, is regularly updated. Frequently this has major new upgrades included in each stage for the CAD draughtsman to learn. They do not have to, but the company's approach is that if the originator of the software has gone to the trouble of developing the product and building in new and more effective ways of doing things, then it is incumbent upon the draughtsman to learn how to use them especially as the company has to pay a subscription. It is in their interest to always be able to make the best possible use of the product offered to them.

The draughtsman in the design team are already familiar with e-training and I think that a BS 8887-1 e-training tool would be quickly accepted. We had looked at using e-training more broadly to give staff essential health and safety and environmental awareness. There are a couple of companies that offer programs that can be bought into to give on-line access. These systems have built-in quizzes. The software records who has looked that the material, and then requires that a test is completed to demonstrate that the user has absorbed at least some of the information.

We have only run trials so far. More leadership from those higher up within the company will be necessary for e-training to be adopted more widely. Many people within our organization are not familiar with using this type of system or technique and would need a little help in using it. However, among the engineers, e-training would be readily adopted. They would have no fear of using it and it would work well.

AP talks about concepts generation techniques.

We use group brainstorming. One of the strengths within the business is having no specialists in the design team. The team comprises two or three engineers, myself included, who have broad electrical experience, two very experienced mechanical designers and another two with more knowledge of refrigeration. Generally they all have a fairly broad church of background with regard to design and engineering. There is always the risk of designing by committee. Usually a development project will be given to a lead engineer or project owner with regard to the design development. They tend to choose two or three people to help them with the process. As we have a very flat management structure and are not enormous, a design meeting can called on anybody thought likely to be able to make a contribution. This tends to be a face-to-face around the table brainstorming.

We have a tendency to do brainstorming on paper. I have worked within teams where nothing is written down other than on Post-it notes. The benefit of a Post-it note is that they can be moved around inside the process. They might start off in a place that was originally thought to be appropriate, but end up somewhere entirely different. If ideas can be relocated, that would be an intuitive way forward because it would fit with a more organic brainstorming design committee format. You can shuffle stuff around very easily, until happy with the layout and then capture it. It wouldn't be everybody's cup of tea, but depends on how the design process works and the nature of the company's product.

It can be frustrating that once the design process has started and an accurate technical specification has been arrived at, the design requirements may change following the first iteration of a product. Very often other demands will grow out of that. One of the things that the company suffers from is the people who work in the sales department and many of the customers are ignorant of the engineering possibilities. A customer may request a list of features. The company will then build the specification and turn that into a real product. The initial feedback from that first iteration will probably be, and frequently does spark the reaction in the customer; ‘Oh I didn’t know you could do that. If you can do that then I want this.’ Almost immediately the specification has to alter. Design tends to be a fairly organic process and it needs to remain flexible right up to the prototyping stage. Frequently there will be changes, sometimes fundamental changes, in the components of a specification right up to the point where the first production prototypes are built. Even beyond that, and after validation, which generally involves field trials with customers. Often there will be feedback from that because there were unforeseen issues. Sometimes it is thought the design process is complete, but on referring to a standard it is realized that something has been forgotten that is really important and should have been done.

End of interview, thank you etc.

Appendix 6: **Presentation Slides from 2010 Sustainable Design Lectures**

Design for Sustainability and the Environment

BS 8887-1 Design for Manufacture, Assembly, Disassembly and End-of-life Processing

Alexander V. C. Plant

Postgraduate Researcher

Supervisors: Professor David J. Harrison
Reverend Dr. Brian J. Griffiths

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Design for Sustainability and the Environment

What is a Standard?

It is a “document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context”

http://www.bsigroup.com/en/Standards-and-Publications/About-standards/Glossary
date accessed 19/06/09

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Design for Sustainability and the Environment

BSI Leads the Way

World's first National Standards Body (NSB) and was founded in 1901

Founder member of the International Organization for Standardization (ISO) in 1947

The most popular standard in the world, ISO 9001 Quality Management System, began as BS 5750. It is now used by over 670,000 organisations in 154 countries.

The second most popular global standard, ISO 14001 Environmental Management System began as BS 7750, it is used in over 90,000 organizations in 127 countries.

Other leading international standards that started as British standards are:

ITC - BS 7799 which became ISO 27000 - Information Security Management System
ITC - BS 15000 which became ISO 20000 - IT Service Management
Service - BS 8600 which became ISO 10000 - System of SI Units

http://www.bsi-global.com/en/Standards-and-Publications/About-BSI-British-Standards/
date accessed 19/06/09

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Design for Sustainability and the Environment

Linear Production and Disposal

Extraction Production Distribution Consumption Disposal

www.storyofstuff.com date accessed 19/06/09

THE STORY OF STUFF WITH ANNIE LEONARD

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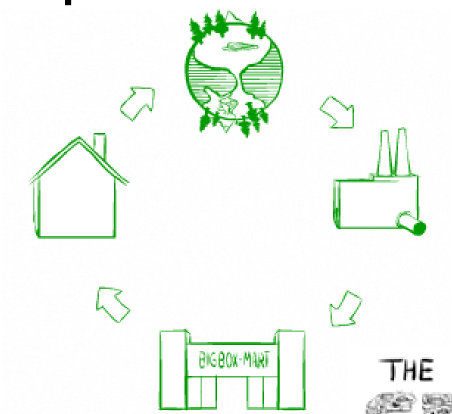
Design for Sustainability and the Environment

Closed-Loop Production



www.storyofstuff.com date accessed 19/06/09

THE STORY OF STUFF WITH ANNIE LEONARD

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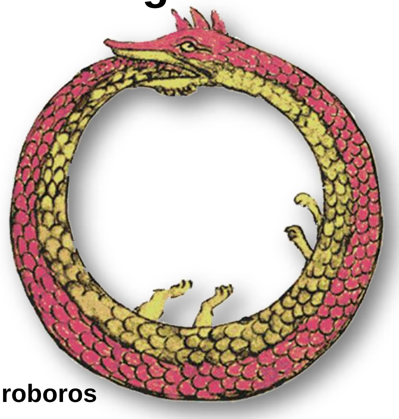
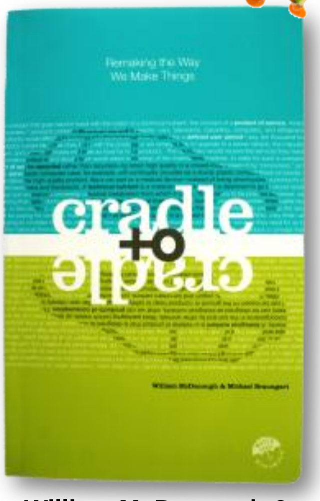
Imitating Nature

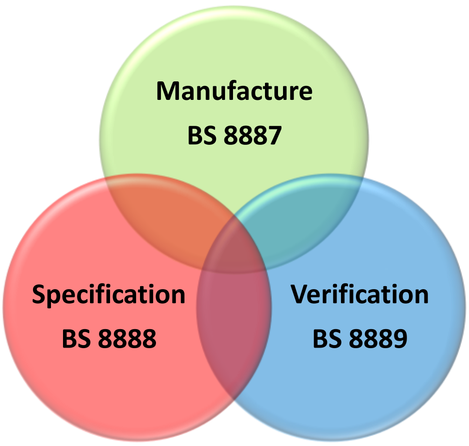


Ouroboros
Drawing by Theodoros Pelecanos (1478)



William McDonough &
Michal Brangart

Technical Product Realisation Triumvirate



Design for Sustainability and the Environment

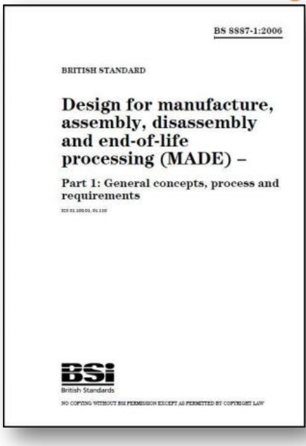
BS 8887-1

Manufacture

Assembly

Disassembly

End-of-life Processing


BS 8887-1:2006

BRITISH STANDARD

Design for manufacture, assembly, disassembly and end-of-life processing (MADE) –

Part 1: General concepts, process and requirements

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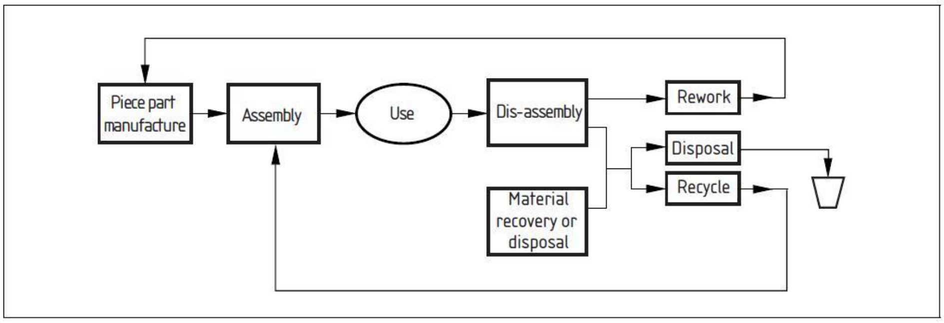
Design for Sustainability and the Environment

BS 8887 Product Lifecycle

Figure 3 **The stages in the life of a product, including the three routes of part end-of-life processing**



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BS 8887-1 (2006) Annex C *Life cycle considerations*

Materials and components sourcing

Design for Sustainability and the Environment

NOTE: In some fields legislation is either in place or emerging which requires that high priority is given to life cycle considerations. Such legislation includes the Eco-design Requirements for Energy-using Products Directive, the Waste Electrical and Electronic Equipment Directive, the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations and the End-of-Life Vehicles (Producer Responsibility) Regulations.

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Materials and components sourcing

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C.2a) Use materials which are as ubiquitous and abundant as possible.

Celia

All too often the glitzy world of contemporary design feeds off a limited palette of seductive technological materials. It takes the vision of the Campana Brothers to realize exciting tactile and aesthetic pleasures from humbler man-made materials. The Celia range uses the ubiquitous strandboard found on building sites the world over for temporary, disposable screens or shuttering. In the strandboard, nature is roughly thrown together and bonded with glue, heat and pressure. The Celia sideboard reminds us of the precious and unique nature of these resources and lends a quiet dignity to the material. Modest and non-elitist, this furniture hints at a quality that all members of society could aspire to and afford.

Fernando and Humberto Campana	305
Campana Studio, Brazil Habitart, Brazil	305
Strandboard	
• Single material • Renewable materials • Recyclable materials	325 325 324

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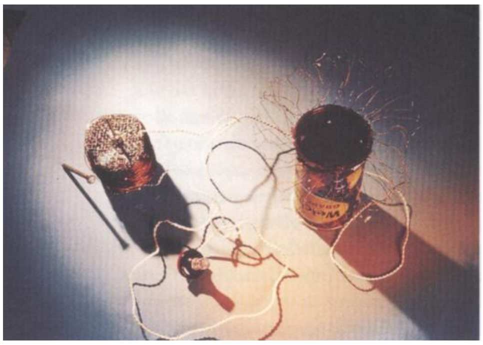
C.2b) Use materials and components which are as local in origin as possible.



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C.2c) Use less dense (lighter) materials, unless density contributes to lower energy or materials requirements of the product in use which outweigh the additional energy and material embodied in the product. Construction products and products requiring toughness are good examples of where this might apply.

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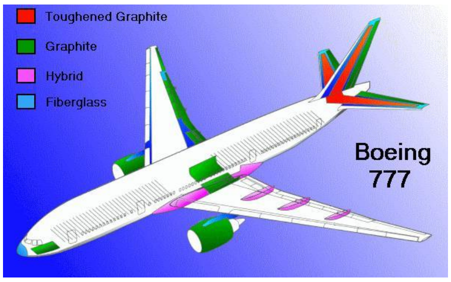
C.2c) Use less dense materials...



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C.2d) Use materials with low embodied energy (that is, the energy used to extract, harvest or gather them from source, process and transport to the manufacturing facility).

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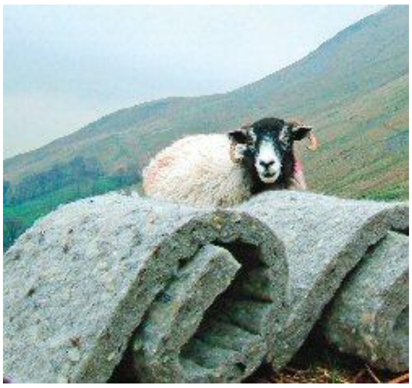
C.2d) Use materials with low embodied energy...



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C.2e) Maximize the use of materials which can be extracted, harvested or gathered from source with zero or minimal collateral material not intended for the product.

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C.2f) Use renewable materials.

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C.2g) Where certification schemes exist covering environmental stewardship of natural resources, such as that of the Forestry Stewardship Council, use materials approved under an appropriate scheme and Chain of Custody from plantation/forest to immediate supplier.

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C.2g) ...environmental stewardship

FSC
100%
From well-managed forests
Cert no. TT-COC-1110
www.fsc.org
© 1996 Forest Stewardship Council

BSI REGISTERED
UKAS 003

ISO 14001 EMS

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C.2h) Reuse fit for purpose components and piece parts.

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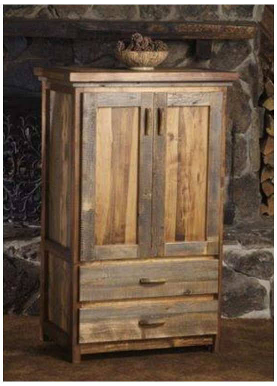
C.2i) Use 100% reclaimed for reuse materials.



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C.2j) Use recycled fit for purpose components and piece parts.

A Kodak employee inspects inbound cameras at the firm's primary recycling facility in Rochester, New York. Vibrating tables sort the cameras by model.

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C.2k) Use 100% recycled or part recycled materials.

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C.2l) Use recyclable materials which allow optimization of quality, energy, waste and emissions in the recycling process.

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C.2m) Use recyclable materials and components for which collection for recycling is well established for the product customer group (commercial, household), or which customers can recycle on site or easily despatch for recycling.

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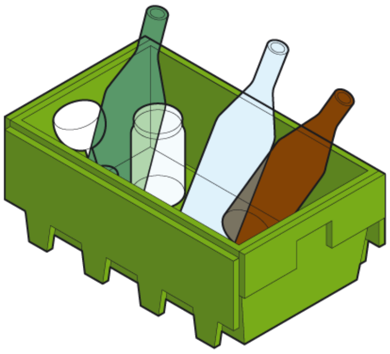
C.2m) Use recyclable materials...



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C.2n) Use recyclable materials and components for which there is a prospect of collections being established.

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C.2o) Avoid pigmented plastics (for easier recycling) where possible.

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C.2p) Use chemical additives (including metals) which are environmentally and physiologically benign.

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BS 8887-1 Annex C Life cycle considerations

C.3 Manufacturing processes

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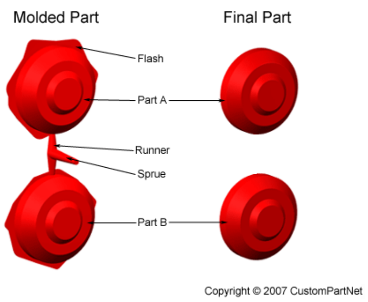
C.3a) Maximize capture and reuse of materials arising as waste during process (aim for zero waste residue from process).



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C.4 Product use

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C.4b) Consider any environmental, customer or commercial benefits of providing the utility of the product to the customer without the sale of the product and whether there are design implications.

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C.4e) Maximize the potential for upgrading and serviceability of the product.

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C.5 Demanufacturing processes

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C.5a) Avoid mixing as far as possible of component and piece part materials which reduce the efficiency of recycling, e.g. Metal inserts in plastic parts.

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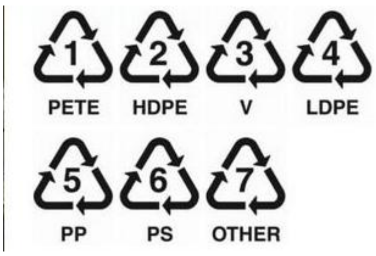
C.5a) Select materials with similar component life to match design life of assembly.

C.5d) Code or otherwise identify parts to facilitate recycling and audit trails to production data. For plastic parts above 50 g, mark in accordance with BS EN ISO 1043 and BS EN ISO 11469.



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Thank you

Questions?

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