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An Investigation into Standards in Sustainable Design and Manufacture

Alexander V. C. Plant, David Harrison,
Brian Griffiths and Busayawan Lam
School of Engineering & Design,
Brunel University, Cleveland Road
Uxbridge, Middlesex, UB8 3PH
United Kingdom
Phone: +44 (0) 1895 276080
E-mail: Alexander.Plant@brunel.ac.uk

Abstract
This paper reports upon the application of standards to reduce the negative environmental impacts of manufacturing through product lifecycle planning and closed loop production. By eliminating waste and retaining the energy embodied within materials and components, manufacturing can become more sustainable from both ecological and financial perspectives. Energy consumption and the associated carbon pollution can thus be minimised. Environmental Management System implementation is also considered.

Introduction
In 2006, British Standards Institute published BS 8887-1 entitled 'Design for Manufacture, Assembly, Disassembly and End-of-life processing' (MADE). The standard represents a progression from the earlier PD 6470 (1975) 'The Management of Design for Economic Production'. Perhaps most importantly, advice on how to enhance designs for end-of-life processing was added (Griffiths 2008 p. 23). End-of-life processes will play a significant and increasing role in an era of materials scarcity and will support our national and global progress towards low carbon economies. Increasing the levels of recycling and remanufacturing to recover the energy invested through virgin material processing will lead to more sustainable industry and reduce CO_2 emissions (ASME 2009).

Through an analysis of the Standard Industrial Classification codes of firms that had ordered BS 8887-1, it was found that the largest single division within the customer base consisted of companies engaged in the manufacture of electrical and electronic products (Plant et al. 2009 p. 162). These customers form the basis of this study. The companies were contacted and interviews were arranged with appropriate members of the design or engineering staff. Care was taken to ensure that all data protection and ethical requirements were met. By selecting firms from related industries it was anticipated that common themes might become apparent.

Aims and Objectives
The primary purpose for this research was to investigate the practicalities of implementing BS 8887-1, with particular consideration of design for disassembly and end-of-life processes. The goal was to learn about the issues faced by designers and manufacturers that apply sustainable design principles.

The ISO 14000 Environmental Management System promotes continual improvement through the reduction of unnecessary consumption and waste, while BS 8887 facilitates efficient product manufacture and reprocessing. These two standards each address different aspects of the same goal of increasing prosperity while minimising environmental damage and resource depletion. Given this commonality of purpose, the influences of both standards were of interest.

Interview Technique
The interviews were a combination of face-to-face meetings and telephone discussions. These were semi-structured rather than prescriptive. Thus they were consistent, while allowing flexibility to explore ideas more widely. Themes for discussions were prepared in advance.

Data Analysis

Recorded conversations and hand-written notes were transcribed and the text was 'coded' in QSR NVivo qualitative data analysis software [see Bazeley 2007]. In the coding process, text or 'data' was arranged thematically at 'nodes'. This broke the continuity of the transcripts but enabled the efficient comparison of statements and opinions. There were generally high levels of agreement amongst the participants. Selected elements of the data are presented below in a précised form with supporting quotes.

Discussion

Motivation for Sustainable Industry

Interest in sustainability is generated by a combination of compulsory legislation, customer preference and employees who take on the role of 'environmental champion'. It was frequently said that customers today are asking more questions about the environmental performance of products they are considering buying. Customer preference is a major stimulus for progress towards sustainability.

> *"Market demand drives new product development."*

> *"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 end of life is a long way off."*

BS 8887-1 is a good fit with 'best practice'. Planning for the whole lifecycle, especially efficient production and end-of-life management, is considered an essential part of this.

> *"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."*

Most of the companies within the study made products for industrial applications. These often had exceptionally long service lives. Durability and maintainability were high priorities. A direct benefit for designing for disassembly and maintainability was that equipment could be repaired more efficiently. Working parts from broken products were used for repair and refurbishment work. Despite a preference for maintainability, practical requirements sometimes made this difficult.

> *"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 we 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..."*

MADE in new Product Development

For some companies, design for the environment was a new area whereas for others BS 8887-1 fell in line with existing initiatives.

> *"Our philosophy has been to reduce waste and reduce variants and those good things the standard talks about."*

BS 8887-1 takes a holistic approach, minimising the costs associated with manufacture and assembly, while maximising the value of end-of-life products. The content and layout is logical, purposeful and unambiguous. It is neither too specific nor too general; it gives guidance without being overly prescriptive and is very approachable.

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

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

Product function and cost is of primary importance. Material choices are optimised for service rather than for recycling. Where possible materials are selected that can be recycled within the engineering system. Biodegradable materials are rarely used except for packaging. Older designs are updated in light of these end-of-life reprocessing requirements.

> *"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."*

BS 8887-1 was considered as a whole but not necessarily applied in its entirety as it is voluntary. Commonly the standard had been ordered for inclusion within company libraries with a view to applying it to future projects.

Most of the product developers spoke of a long term commitment to sustainable design and manufacture. In some instances this went back over a decade. All agreed that sustainable design practices were becoming ever more important in their businesses because of tightening regulations, consumer pressure and a sense of corporate responsibility generated internally.

Once a standard has been studied by a designer or engineer, it will have a long term influence. However, the rate at which new design projects are initiated has slowed with the recent economic decline.

Design for Assembly, Disassembly and Recycling

High-volume manufacture necessitates that products are designed for ease of assembly. Snap fits are very helpful from this perspective as they reduce assembly costs, and avoid having fixings within the waste at end-of-life. Screws are problematic because they require time and equipment to use; glue is generally best avoided but can be convenient in some instances. New products have been designed for assembly without glue or heat staving and with a preference for not using fixings or metal inserts in plastic mouldings. Heat staving involves softening and deforming the top of a plastic location pin that is used to fix a PCB or other part in its housing. This makes the product difficult to disassemble and so is best avoided.

> *"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."*

Particular consideration is given to reducing parts count and design for disassembly. This often led to cost reductions. There was unanimous 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 within new product development. Once a design goes into production it becomes expensive to make changes.

Design for disassembly was already an established part of the product development procedure for several of the companies that bought 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. Other firms had reviewed their design process in light of BS 8887-1. The standard refers to brainstorming, quality function deployment, failure mode and effect analysis, and value engineering etc. Many of these techniques were commonly used and so did not necessitate major strategy changes.

End-of-life planning presents new challenges and it was often this content that generated the greatest interest. Flow diagrams, check lists and worksheets were commonly used throughout the design process, these referred to relevant standards at the appropriate stage. In some cases BS 8887-1 has become one of those reference standards. Product design and development was often very procedural.

One company produced an excellent example of a product housing highly optimised for production and maintenance. Snap fits were used for speed and efficiency in assembly but the mouldings also incorporated redundant screw bosses and screw location features. If products with snap fits are disassembled, the clips are often weakened or broken. By providing the option to use screws, the potential in-service life was extended with negligible extra cost.

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. The ability to precisely identify material grades helps to ensure that they are placed in the correct recycling stream, 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."*

> *"All of our materials are the same grade: LM6. The recycling marks, and in some cases the grade mark, are moulded onto the products."*

Functionality was of primary importance for all of the products discussed. This resulted in material choices and designs being optimised for service rather than for recycling. For example, copper bus bars are plated to prevent oxidation and to help maintain good electrical contacts. This makes the material more difficult to recycle. Pure copper is necessary for high power applications. Impurities would cause hot spots that could result in a fire, so secondary copper is not used.

> *"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."*

Management Systems and MADE

The ISO 14001 Environmental Management System was a common interest as most of the firms had this accreditation or were working towards it. All but one of them had ISO 9001 Quality Management System accreditation already. ISO 14001 was seen as being relatively straightforward to integrate into ISO 9001 in a unified continuous improvement system. Continuous environmental improvement was seeded throughout business policy manuals. It was suggested that perhaps BS 8887-1 could be incorporated by referencing it from within management 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."*

Practical work on recycling, sustainability and green supply chain management were implemented in advance of their being made a requirement of the system. Good environmental practices were also beneficial for staff morale and cohesive employee relations. Having ISO 14001 accreditation is seen as almost essential in attracting new business. Both ISO 9001 and ISO 14001 were often insisted upon by clients.

> *"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... I don't think it [design for the environment] is generally a cost, but it is sometimes perceived that way."*

One firm identified heating buildings as their biggest environmental impact. Installing insulation was both good for the environment as it saved energy, and good for the company as it saved money. In this instance, product associated impacts were thought to be secondary. Another firm focused on recycling and reduced their waste going into landfill by 85% in the last year and a half.

Legislation, Sustainability and MADE

When a customer commissions the design and production of a new item, for example a sub-assembly or fixture, they will usually specify requirements. Increasingly these include compliance with various pieces of environmental legislation and standards relevant to the particular country in which the final product is to be sold.

Both the Waste Electrical and Electronic Equipment (WEEE) directive and the Restriction of Hazardous Substances (RoHS) regulations were said to add to costs but BS 8887-1 has cost saving benefits. These were mainly associated with optimising designs for production and design for disassembly.

> *"Obviously being in the electronics industry we are affected by the EUP Directives [Energy Using Products] as well as WEEE and RoHS. It actually ties in quite well with that."*

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 driven by a desire to be environmentally friendly and anticipate

the future tightening of legislation. Most electronics components on the market are now RoHS compliant, so it is both convenient and a good sales advantage to claim compliance.

One of the engineers in the study was an authority on lead-free soldering. He said the RoHS regulations were good for the environment insofar as if end-of-life products did go into landfill there would be no lead to leech into the water table. However the amount of energy needed to melt the solder increases by about 30%. It is an alloy of tin, copper and silver, and is more expensive than the lead based version. Depending on how the energy is generated, more CO_2 may be released. The higher temperature will also be needed to melt the solder from the board in re-processing.

Conclusions

The findings of the study so far include the following:

- Compliance with legislation was a primary motive for developing cleaner design strategies. Strong environmental credentials are also considered advantageous to business relationships, especially having ISO 14001 accreditation.

- All of the interviewees spoke of the importance of designing and manufacturing correctly functioning and economically competitive products, however environmental concerns were seen to be of increasing importance.

- Design for the environment is an important aspect of all new product development work. Incremental environmental performance efficiency gains are continually being made.

- Manufacturing costs are sometimes reduced as a result of applying BS 8887-1. Design for disassembly contributes to efficient product assembly.

- Most of the companies in the study had ISO 9001 accreditation and were concerned that any new standard, initiative or process should fit within its framework.

- Pursuing sustainable design can present contradictions and challenges in determining the best approach.

Further Work

A wider investigation will follow this pilot study. Enterprises from the varied industrial sectors represented within the BS 8887-1 customer base will be invited to contribute. Their experiences on the journey towards sustainably will reported upon, and inform the continuing development of the BS 8887 series.

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