Design for Manufacture and Sustainability in New Product Development

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Abstract

Design for manufacture is well recognised by industry and is about optimising design to aid production. Today there is a significant and growing trend of recognising what happens to a product once its user phase has finished. Post-consumer processes are now an important consideration during the *ab-initio* stages of design. Rather than a focus limited to design for manufacture or (more recently) design for assembly now the pressure is on for post consumer design. Companies need to do this because legislative pressures are increasing and consumers are becoming ever more aware of, and concerned about, environmental issues. End-of-life processing and design for the environment are therefore areas of growing of interest.

This conference paper investigates with industry practitioners their experiences regarding for both the environmental and economic advantages of product life-cycle planning. Legislative pressures and consumer awareness are driving businesses to develop sustainable product design strategies (Jones et al, 2001 p. 27). Changes within the law, to protect our environment, cause companies to pay attention as they begin to affect profitability. The first British Standard to address design for end-of-life processing, and therefore support industry, is BS 8887-1. Over 60 UK manufacturing and design companies that had bought BS 8887-1 contributed to this by being interviewed or providing a written response. The research investigated multiple aspects of sustainable design in practice however, in this conference paper the focus is its application within the design process.

1.0 Introduction

Engineers need to have an understanding of production methods, but not all processes are relevant to all materials, situations or components. Therefore it is also necessary to have an understanding of how processes influence products and systems. Traditionally, design for manufacture is about optimising design to aid production. Today there is a significant and growing trend of recognising what happens to a product once its use phase has finished. Post-consumer processes are now an important consideration during the *ab-initio* stages of design. In the past, the focus was limited to design for manufacture, and later design for assembly. The buzzwords were ‘design for manufacture and assembly’. Now the pressure is on for post consumer design. Companies need to do this because legislative pressures are increasing and consumers are becoming ever more aware of, and concerned about, environmental issues. End-of-life processing and design for the environment are therefore areas of growing of interest.

If material is recycled and reused by a manufacturer then money may be saved as less virgin material will have to be bought. Material from post consumer products should cycle back in the system within ten years or so. If a product, or part of a product, has to go into landfill then it has a negative value associated with it, as someone will have to pay for that disposal. These considerations must be factored into the initial product design as they alter the costing over the whole product life-cycle. For manufacturers required to take back their products at end-of-life, these issues will directly affect their profitability.

European legislation is becoming progressively more demanding with regards to waste electrical and electronic equipment, end-of-life automotive vehicles and the disposal of hazardous substances. As a result manufacturers have had to develop strategies to deal with their products once the end user has finished with them. They have had to choose between various options, and find the most appropriate solutions that fit with their business model.

The constraints of end-of-life processing techniques should be accounted for in the early design phase. Such consideration would assist companies to make this reprocessing activity more profitable by recovering the added value inherent within the viable components of used products, in addition to high quality materials recycling. Constraints and standards are something that a designer needs to know about before beginning to develop a new component or product. For example, to design a moulded plastic part, it is necessary to incorporate draft angles within the design so that it can be ejected easily from the mould. Failure to incorporate the appropriate draft angle could result in a higher cost or greater difficulty to manufacture. The limitations of selected production processes, and the requirement for the optimisation of products for ease of assembly, influence the design decisions made. A substantial industry has built up around design for manufacture, and libraries have sizeable collections on the subject. Perhaps most notable among these works are the writings of Boothroyd and Dewhurst (1994) who are referenced within BS 8887-1. Additionally, Design for end-of-life Processing should now form part of these constraints. Designers have been aware of production issues for many years. However, design for disassembly and end-of-life processing are not so well established or understood. There is a need for practical advice and information about the implications of design decisions and material choices.

2.0 Design for manufacture Standards

The focus of this paper is to investigate the use of sustainable design standards in the product development process. In the UK the main standard is the BS 8887-1 which has as its origins the PD 6470 (1975). This standard was entitled 'The Management of Design for Economic Production', and provided the basis of design for manufacture. It was a key part of the history of design in the UK. In the past the emphasis was on the manufacture of industrial piece parts, economically, without necessarily thinking about putting them together and certainly without thinking about how they would be taken apart and dealt with at the end-of-life.

The British Standards Institution (BSI) committee concerned with Technical Product Realization is designated TDW/4 and has many sub-committees addressing a broad remit. The one concerned with design is the fifth committee TDW/4/-/5. When the TDW/4/-/5 committee that wrote PD 6470 was re-established, it was decided to take a holistic view. The new standard was given an equal emphasis on each stage of the product life-cycle. This included assembly and what happens after use. The result is BS 8887 'Design for Manufacture, Assembly, Disassembly and End-of-life processing (MADE)'. As BS 8887-1 (2006) is 'Part 1' of the series, it is the entry standard or foundation from which others follow. The MADE acronym represents the four stages of piece part manufacture, assembling them together and how in some way at the end-of-life they will be taken to pieces and dealt with in an appropriate manner. It provides a focus or emphasis for the committee during the continuing development of the series.

BS 8887 did not start as a sustainable design standard. It is concerned with the documentation produced by designers to manufacture things. The standard was originally developed to support the manufacturing side of production. It was intended to be used by manufacturers to help with the interpretation of design output into physical products. However, it is also necessary to consider product-life-cycle planning. This necessity led to the inclusion of eco-design, disassembly and end-of-life considerations within the standard. It has continued to grow since then. The committee has spent a good deal of time looking at end-of-life processing. Far less time has been devoted to manufacturing and assembly, which is what they originally set out to do. This is probably because these areas are already better understood and less contentious. BS 8887 is a highly authoritative source of information that supports designers in the emergent industrial trend towards more sustainable production. There is a need for end-of-life processing and product life-cycle planning standards plus additional specific standards to expand the series which are directly applicable to specific industries and product groups.

3.0 Research Method

Industry practitioners were approached who are active in new product design for the purpose of gaining insights into the application of BS 887-1 with a focus on sustainability. Organizations that had previously bought BS 8887-1, and some other interested parties, were invited to contribute to this research and responses were obtained from 62 companies. Insights were obtained from these interviews and communications with managers with responsibility for design and development including Production, Quality and Design Managers. The majority of the meetings were recorded and extensive notes were written from these. Where recording was not permitted, hand written notes were used and subsequently typed. The documents were each forwarded to those involved to assure the accuracy of interpretation. The study was limited to UK organisations and averaged 45 minutes of contact.

Related information within the meeting notes was clustered using NVivo, qualitative data analysis software package (Bazeley, 2007). Selected subject areas within the data have been summarized. The people involved and their organizations have not been identified to preserve anonymity. Ideas presented here are supported with references to, and quotes from, published sources. The unreferenced italicized quotations were spoken by various participants.

4.0 Research Findings

A synthesis of the comments and observations made during the field research is given here. Initially the overall production approach is discussed and then each of the key product development processes are reviewed.

4.1 Open Loop and Closed Loop Production Approaches

During the conventional product life-cycle, materials move through a system comprised of the following stages: Extraction, Production, Distribution, Consumption and finally Disposal which is an "open loop" approach. This is called the materials economy and is represented in *Figure 1*. It is a linear system and we live on a finite planet that can not support such a system indefinitely (Leonard, 2005). "Unsustainable consumption and production patterns in the developed world have led to the increased generation of waste over many decades" [Staikos & Rahimifard 2007 p602].

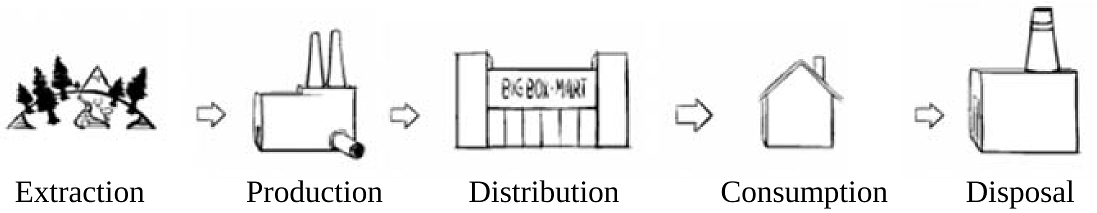

Figure 1: Conventional Production - *Leonard, 2005*

Extraction, or natural resource exploitation, is a major limit to the economy as we are running out of resources. “In 2003, humanity’s footprint exceeded the Earth’s capacity by over 25 percent” (Global Footprint Network, 2007). A demand for bio-capacity greater than the available global supply is considered unsustainable as more resources are being consumed than can be regenerated (Frey et al, 2006 p. 201). “In the past three decades, one-third of the planet’s resources, its ‘natural wealth,’ has been consumed” (Hawken et al, 1999 p. 4). This was recognized in an interview with a company making high tech equipment manufacturer:

> *“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.”*

The entails that product designers should consider not only the production and transformation processes, assembly and technical aspects of manufacture, but also the consumption of water, energy, the origins of raw materials, as well as the types of residues generated and their destiny (Platcheck et al, 2007 p. 81). This was verbalized by an R&D manager responsible for new product development:

> *“In the Research and Development 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.”*

Eco-design refers to design approaches that minimise environmental impacts, reduce production costs and gives companies a competitive differential in the market (Platcheck et al, 2007 p. 85). Closed loop production is an approach that embraces this and imitates the natural world. About 60% of products are no longer in use six months after they are purchased (Howarth, 2004 p. 13). Closed loop production has obvious environmental benefits and can deliver significant cost savings. End-of-life products become the ‘technical nutrients’ necessary for manufacture. There is no ‘away’ into which we can throw things any more (McDonough & Braungart, 2002). 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 2.

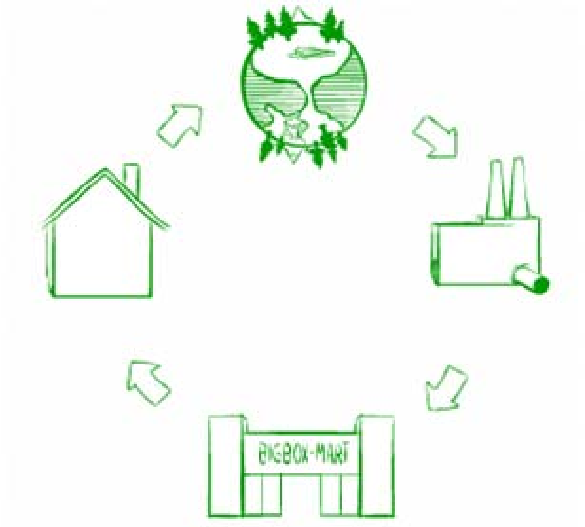

Figure 2: Closed Loop Production - *Leonard, (2005)*

Every day, markets give more emphasis to sustainable development because the capacity for raw materials extraction from nature is becoming exhausted in an accelerated rhythm (Platcheck et al, 2007 p. 85). This was discussed by a leading authority on civil engineering 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 organisations 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!'"*

This illustrates that even if end-of-life product does not have an immediate financial value, there can be other advantages to taking it back. The other advantages of closed loop systems were acknowledged by a railway engineering manager responsible for 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 to know what needs to be improved. The value of returned product is in determining the reason for failure."*

The recognition of the value of a design standard advocating sustainability was articulated by a knowledgeable BS 8887-1 user, a specialist consultancy in closed loop production. They were 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 our selves, 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 managed 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, thus 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 quantify the financial gains from closed loop production although the client concerned has increased its profitability and market reputation having adopted and implemented this strategy. From this we have a firm industry example that the product development process detailed in BS 8887-1 implicitly supports closed loop production. It further emphasizes that, for a standard to encourage sustainability in the development process, it needs design and management requirements for such closed loop systems to be seeded throughout. This has been achieved within BS887-1.

4.2 Design and Development Process

The research results will be analyzed in terms of each of the key product development processes. The 'Design Activity Model' shown in *Figure 3* is a typical design sequence.

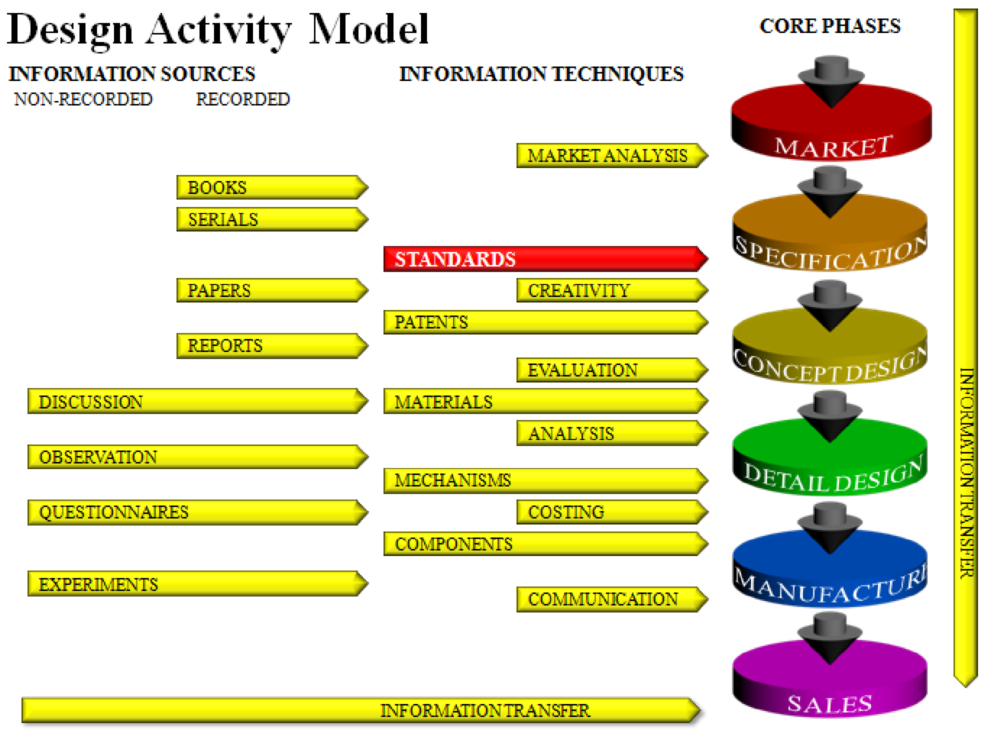

Figure 3: Design Activity Model - *Adapted from Rhodes and Smith, (1987) in Pugh, (1990)*

New product development 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. Visibility of green issues can be apparent at this stage as the quote from a designer in an electrical parts firm indicates:

> *"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 within 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."*

In the second stage, a product *Specification* detailing design and engineering requirements is created detailing the desired attributes. These would have been established through market research such as questioners and target user group observation as indicated in an interview with an automotive parts company:

> *"Others engaged in new product design 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".*

Relevant standards and legislation to be complied with are stipulated in the specification. For manufactures supplying to industry, these are often specified by their customers as highlighted in an interview with a marine engineering specialist 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 for the creation of *Concept Drawings* and models. The most promising of these are verified with the client or members of the target market audience before moving forward to *Detailed Design*. Existing standards often have regulatory compliance mandates which it can be argued distract attention from voluntary requirements set out within the design process standard as reported below:

> *"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."*

This emphasizes the focus at the detailed design stage. The chosen concept is optimized for the selected production process and piece parts assembly. The appearance, function and features of the product 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 and proof of principle testing.

The design output then drives the *Manufacturing* activity. Production engineers are limited in how much they can improve a product by the position that they occupy within the development process. This is true in general and from an environmental perspective as described below by a Quality Consultant:

> *"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 on 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 last stage is that of commercialization i.e. *Sales* and product use. 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 i.e. the research highlights that sustainable production starts with design as summarized below:

> *"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 challenge of sustainable design is in part capturing in writing information pertinent to all user requirements and product attributes as discussed by a boiler engineer:

> *"One of the parts of BS8887-1 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: Design Brief, Table 1 on page 6 of BS 8887-1. 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."*

The representation of the design process in *Figure 3* illustrates information transfer down 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 in light of experience with previous iterations as highlighted by a 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. Such 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 salesmen and service engineers and visit end users. Comments from the various concerned parties are then addressed in the design of future products.”

The challenge of information transfer can be problematic for those working in the earlier stages of product development and expensive as the comment below indicates. This was representative of the interviewees opinions on this:

“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 feed back 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.”

This concludes the synthesis of comments relating to the key stages of the design process and the implications of using the BS 8887-1 standard. We next examine the design process as detailed in the standard itself.

4.3 Review of the BS 8887-1 Design Process

Following the field research and the insights gained a closer examination of the BS 8887-1 standard is now made in order to ascertain the role the standard can play. The standard 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. Design for these stages is shown schematically in *Figure 4*. The right hand side of the diagram shows a closed loop system as the norm rather than the exception.

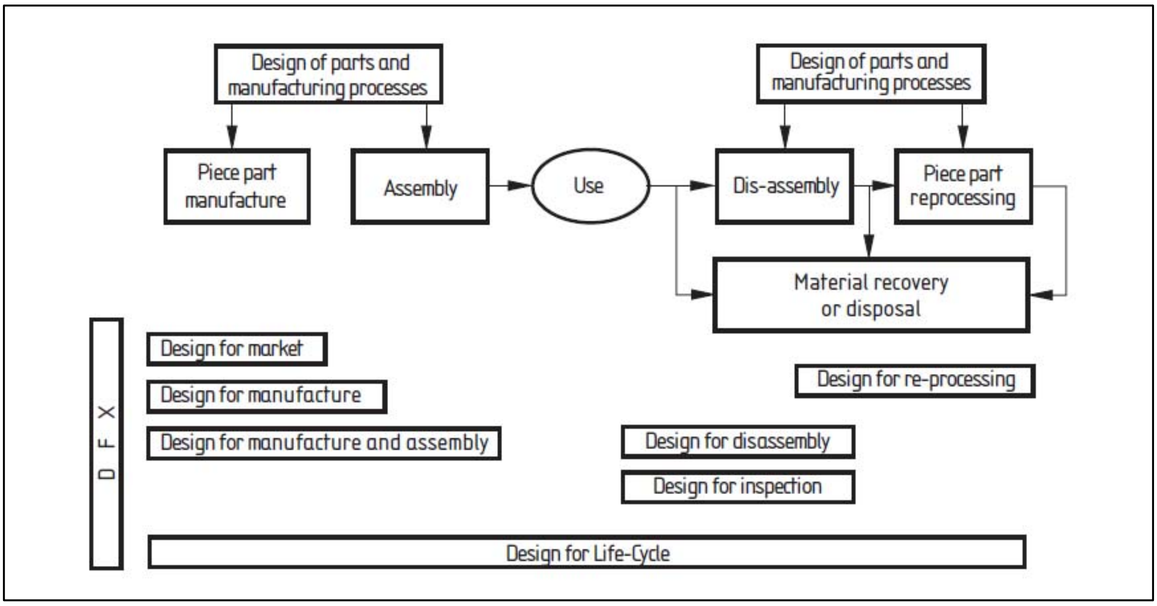

Figure 4: The Stages in the Life of a Product and the various DFX terms - *BS 8887-1 (2006)*

In Section 6.2 of the standard, a 'Best Practice Sequence of Events' for new product development 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 title within the standard. For 6.2.3.2 ‘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

The end-of-life processing is a new area for design managers and is starting to gain recognition, however, financial implications of adopting such processes can be an obstacle when the activity is not profitable as commented by the 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."*

From the perspective of a designer concerned with the environmental impact of products, this is especially useful as it can be directly applied to product development and appears as almost a check list. These 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.” 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. A comment that highlights that it is product dependent as to the extent of recycling as explained in an interview with a firm manufacturing disability aids:

> *“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 an interview with 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 another example from a railway 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.”*

The BS 8887-1 ‘Best practice sequence of events’ features several differences from the model shown in *Figure 3* but most notably now contains ‘Life-cycle considerations, including End-of-life Processing’ and ‘Design for Assembly and Disassembly.’ This latter requirement was sometimes unintentionally achieved through design for assembly:

> *“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.”*

However, there are differences between design for assembly and design for disassembly. Just because something is designed to be easy to put together, it 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 definitely not designed it for disassembly because they did not want their product to be taken apart for security reasons. They did not want competitors to disassemble and reverse engineer it. To prevent disassembly, the commercially sensitive technology was encased in resin. The laser company was small and highly innovative and led the way in their sector. Major competitors had been known to steal their ideas. Using the resin was a way to keep their ideas for longer.

It is widely recognized that it is in the early stages of product development where sustainability can be most effectively addressed. This is now discussed in the next section.

4.4 BS 8887-1 Design Process and Early Stage Product Development

Under BS 8887-1, a ‘MADE team’ is required for the development of the design brief. This has competent representatives of critical disciplines including:

- Sales / Marketing
- R&D / Design
- Manufacture
- Quality Assurance
- Customer Service
- Take-back Facilitation
- Health and Safety
- Environment

Collaboration between representatives of various and diverse disciplines is not uncommon in commercial industrial design. Some quotes obtained 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 design for disassembly we could do that. It is well within our engineering capability."*

This early stage inclusion of people with expertise in product 'Take-back Facilitation' and 'Environment' within the MADE team, should greatly improve the end-of-life value of the product being planned. Sustainable product design needs to be integrated into the early stages of the new product development process (Jones et al, 2001 p. 27) as these decisions are crucial in determining a product's environmental impact (Tischner & Charter, 2001). 70-80% of a product's features, manufacturing methods and costs are determined during the early stages of the design process (Andreasen & Hein 1987; Cooper 2001). 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 designer's job is to translate a client brief into a product that can be manufactured and sold. Too often the brief is inherently unsustainable and the decisions that could make a really big difference are often taken at management level before designers are engaged in the project as commented by a technical product developer:

> *"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. In trying to comply with that... it's good to have the front end as well."*

Companies pursuing good design tend to have a strong management commitment to innovation and corporate responsibility (Greenwood, 2008 p. 29). "Enlightened management can address DfE as an opportunity for innovation and differentiation, rather than an unwelcome constraint. In this perspective, design for the environment is central to the design process, and early decision-making" (Holdway & Walker 2004 p.9).

Not all of the standard's users were motivated by its sustainable design content. The design for manufacture information had prompted the acquisition of the standard for a company reviewing and value analyzing their product range. In this instance the working method was to gather relevant reference information and review it together in detail. At the time of the interview the process was still at the information gathering stage. Having studied these, the participant intended to write a method or procedure for the company's product design review.

Standards are written by consensus; they could be regarded as statements of basic requirements to be exceeded.

> *"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."*

It can be argued that financial considerations still dominate decision making during the design process as the quote below from the construction specialist shows:

> *"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%."*

BS 8887-1 and Documentation

This is the subject of Section 13 within the standard which lists documentation requirements for design, manufacturing and end-of-life. Design documentation has to be prepared, maintained, and archived so that the information is available for reference, maintenance and future development. Similarly, manufacturing documentation has to be prepared, maintained and archived. End-of-life 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 be implemented by which access to the end-of-life documentation can be maintained for the foreseeable life of the product. In hindsight one interviewee commented:

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

documents, market, materials and through the whole range of recommended documentation."

Proper documentation and a full audit trail were also important to some environmentally aware commercial customers as indicated during an interview:

"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."

5.0 Synthesis of Results

The field research covered a broad range of product design and development issues both internal and external which affect the adoption of sustainable production. Further the data sample comprised few firms which are fully recognizing the closed loop approach which leads to greater sustainability. With regard to the key development processes (i.e. excluding manufacturing) a synthesis of the key themes is summarized in Table 1.

	Stage 1: Market	Stage 2: Specification	Stage 3: Concept Design	Stage 4: Detailed Design	Latter stages: Sales and Product Use
Role of BS 8887-1	Competitive comparisons Legislative requirement Customer preference	Enhance the established in-house design process End-of-life disassembly Materials selection for recycling	Criteria to be considered when selecting preferred design concept. Minimize materials	Criteria to be evaluated when optimizing chosen design.	Product information provision at sales stage. Learning from feedback from users

Table 1. Sustainability themes identified relating to key development processes

6.0 Conclusions

Sustainable design yields 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 inevitable transition through the development of lower impact products and into full closed loop production. This paper will aid in this subject by closing the gap between the academic literature and the organizational aspects highlighted by practitioners.

Interviews with industrial practitioners have revealed how BS 8887-1 is already being used within their established design process and is proving commercially advantageous. Key findings from the research were based around implementation rather than general acceptance of the need for changes. Implementation during the design process requires knowledge on the part of designers and support from management as well as extended scope of operations to include end-of-life product recovery. Further novel examples of how requirements of the standard have been, or could be, implemented will be discussed in the conference address supporting this paper.

7.0 References

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