BRITISH STANDARD

Design for manufacture, assembly, disassembly and end-of-life processing (MADE) –

Part 1: General concepts, process and requirements

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Contents

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 41 and a back cover.

Foreword

Publishing information

This part of BS 8887 was published by BSI and came into effect on 31 October 2006. It was prepared by Technical Committee TDW/4, *Technical product specification – Methodology, presentation and verification*, in response to an original proposal from BSI Programme Manager Geoff Gonella. A list of organizations represented on this committee can be obtained on request to its secretary.

Relationship with other publications

The function of BS 8887 is to provide context for the preparation of technical product specifications in accordance with GPS principles. However, it is not the intention that BS 8887 is a “stand-alone” standard since it is part of a triumvirate of TPR (Technical Product Realization) standards comprising BS 8888 and BS 8889. The relationship of these three standards to each other is explained in Annex D.

It is intended that subsequent parts of this British Standard will address specific requirements for various types of engineering manufacture, for example mechanical; hydraulic; electronic; chemical.

It should be noted that BSI does make educational/training aids available in this field and is currently planning a major education/training initiative which, it is expected, will lead to a programme of competency assessment and certification.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is “shall”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Introduction

This British Standard is introduced at a time of considerable change in the nature and presentation of technical documents prepared as part of technical product specifications. It is structured so as to provide the designer with a framework within which the selection, preparation and presentation of appropriate documentation to facilitate the efficient transfer of the design concept into and beyond the manufacturing environment can be undertaken. It is appropriate to all types of manufacture and has the primary purpose of identifying and specifying the use of ISO Standards relevant to the design for manufacture route.

Support for the design of technical products, by standards, is currently deficient in that there are no British Standards focusing on how the designer ought to set about the task of preparing their conceptualizations for manufacture. The nearest would seem to be the withdrawn PD 6470:1981, *The management of design for economic production*, which is now somewhat dated in terms of its scope and content. The current BS 7000 series deals with the broader concepts of design management and BS 7373-1 and BS 7373-2 address product specification but all stop short of providing for the preparation of the actual documentation for manufacturing, assembly, disassembly and end-of-life processing (MADE).

Technical designers do not just require a broad understanding of those things which influence manufacture, such as materials, the nature and capability of available manufacturing facilities, the implications of out-sourcing, product safety, eco-considerations and the needs of European and International markets. Designers also need to be able to express the design requirements with precision and without ambiguity, in a manner that is understandable and accessible in a broad range of manufacturing situations, possibly remote from the immediate location of the design facility. It is unlikely that this can be achieved through the use of purely National Standards and therefore cognizance of International Standards is essential.

In view of this, and to facilitate the use of such standards, this specification requires the use of BS 8888, *Technical product specification* (TPS). The primary function of BS 8888 is to provide a comprehensive list of International Standards relevant to TPS and BS 8888:2006, Annex A and BS 8888:2006, Annex B identify cross-references, by standard number linking them back to the part of the main text that relates them to appropriate stages of the design definition process and contains the specific requirement for their application.

The complexity of products is generally on the increase, with a higher emphasis on cost control and improved time to market. In addition, today's social model, with the mobility of labour and attendant problems of knowledge and skill retention, brings new pressures for completeness of specification. One result of the simultaneous impact of these phenomena on today's business model, is an increasing need for the development of a specification system ensuring a methodical (rather than intuitive) approach to the preparation of technical product specifications.

This part of BS 8887 addresses the design task, irrespective of whether the designer works for a manufacturer, a design company, or is freelance. It is expected that it will, therefore, be of considerable interest to a wide range of businesses and be applicable to a broad range of product types. Businesses experiencing the need for a more precise approach to design specification, and established designers/design companies who might be seeking a benchmark for design competency might also find this standard of considerable assistance.

It is not the function of this part of BS 8887 or of BS 8888, to teach the designer how to design nor to seek to restrain the creative process. Rather, it provides a methodology for ordering the output of that process in a manner that maximizes the possibility of the most efficient, cost effective transfer of the design concept to realization. It is intended to be beneficial for the designer to take account of the requirements of BS 8887-1 in the formulation of their ideas, but the function of BS 8887-1 in conjunction with that of BS 8888, is to provide for precise, comprehensive, unambiguous specification capable of fully informing manufacturing, assembly, disassembly and end-of-life processing.

There are several stages to the manufacture of a product. In the early years of design, designers traditionally applied the principles of design for manufacture to the production of the individual piece parts which together make up the product. This was the approach adopted by publications such as PD 6470 last published in 1975. Phrases like "design for producability" were used at this time. More recently designers realized this was too limiting and the approach then adopted was that there were two stages to the manufacture of a product; the production of the individual parts followed by their assembly together, hence creating the product. Design for manufacture was then applied to these two stages. Typical of this approach was the work of Boothroyd et al. [1]. Their recommendation was that design for manufacture might be equally applied to the assembly stage as to the production of the individual parts and they coined the term design for manufacture and assembly (DFMA). However, during the last several decades, two major developments have occurred, which mean that design for manufacture needs to be considered beyond these two stages.

Firstly, the importance of product quality and customer satisfaction meant that the customer needed to be included. Hence, designers used phrases like design for the customer (DFC). Secondly, environmental pressures produced new legislation; with the result that end-of-life processing is to be considered at the *ab initio* design stage. This legislation has forced manufacturers to take responsibility for a product when the customer has finished with it.

Thus, to complete the whole life cycle, disassembly stages have to be added, consisting of, not only the actual disassembly of the product, but also the treatment of each and every one of the individual parts through re-cycling, re-use or disposal including the possibility of material separation for materials recovery or disposal purposes. Environmentalists have coined terms like design for the environment (DFE), design for recycling and design for reprocessing (DFR). Yet others considered that design for the environment ought to pervade the whole life cycle and terms like life cycle design (LCD) or design for the life cycle (DFLC) are used. This approach has been supported by policy initiatives, fiscal incentives and some legislation, which have variously encouraged or required environment-related elements of product composition, energy consumption and energy sourcing. More recently, the term DFX is used to refer to all these techniques since each is relevant in their own right. It is considered that all the DFX terms are limiting since they each force a focus at a particular point at one stage of design. Furthermore, they represent an acronym rash. A holistic view is taken in this standard and hence, for convenience, the generic term design for manufacture (DFM) is used throughout.

1 Scope

This part of BS 8887 specifies requirements for the preparation, content and structure of design output and the preparation of related technical product documentation for the manufacture, assembly, disassembly and end-of-life processing (MADE) of products. It identifies and describes methodologies and conventions appropriate to the preparation of documentation, in whatever form, intended to transfer a design concept to manufacture, including the determination of required accuracy and tolerances for verification purposes. It also provides guidance on the application of principles and techniques to assist the designer in the preparation of unambiguous instructions, commensurate with the perceived complexity, role and life of the intended product.

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.

NOTE Requirements to modify any design and therefore its specification could arise as a result of experience in manufacture and use but the provision of design improvement occurring subsequent to the issue of the first sealed design brief is outside the scope of this British Standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 8888:2006, *Technical product documentation (TPS) – Specification*

BS EN 1050, *Safety of machinery – Principles for risk assessment*

BS EN 20286-1, *ISO system of limits and fits – Part 1: Bases of tolerances, deviations and fits* [ISO 286-1]

BS EN ISO 1043 (all parts), *Plastics – Symbols and abbreviated terms*

BS EN ISO 11469, *Plastics – Generic identification and marking of plastics products*

BS EN ISO 14040, *Environmental management – Life cycle assessment – Principles and framework*

BS EN ISO 14041, *Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis*

DD ISO/TS 17450-1, *Geometrical product specifications (GPS) – General concepts – Part 1: Model for geometrical specification and verification*

DD ISO/TS 17450-2, *Geometrical product specifications (GPS) – General concepts – Part 2: Basic tenets, specifications, operators and uncertainties*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this British Standard the terms and definitions given in BS 8888 and the following apply.

3.1.1 manufacture
production of piece parts

3.1.2 processing
transformation of material or component, or materials or components in combination, from one physical or chemical configuration or state to another

3.1.3 assembly
bringing together of piece parts in a functional relationship

3.1.4 demanufacture
disassembly of the product, and the reuse, reprocessing or disposal of piece parts

3.1.5 recycle
action of reprocessing a material, component or piece part which has previously been processed for inclusion in a product

3.1.6 renewable
replenishable naturally at source at a rate at least the same as consumption

NOTE This can apply to materials and energy.

3.2 Abbreviations

DFE	Design For the Environment
DFELP	Design For End-of-life Processing
DFLC	Design For the Life Cycle (or LCD: Life Cycle Design)
DFM	Design For Manufacture
DFMA	Design For Manufacture and Assembly
DFR	Design For Recycling (or reprocessing)
DFX	all the “design for” approaches
LCA	Life Cycle Analysis
MADE	Manufacture, Assembly, Disassembly, and End-of-life processing
TPD	Technical Product Document
TPS	Technical Product Specification

4 Design process

For the purposes of this standard, design for manufacture shall be considered to include the following in addition to the fundamental requirements for product use:

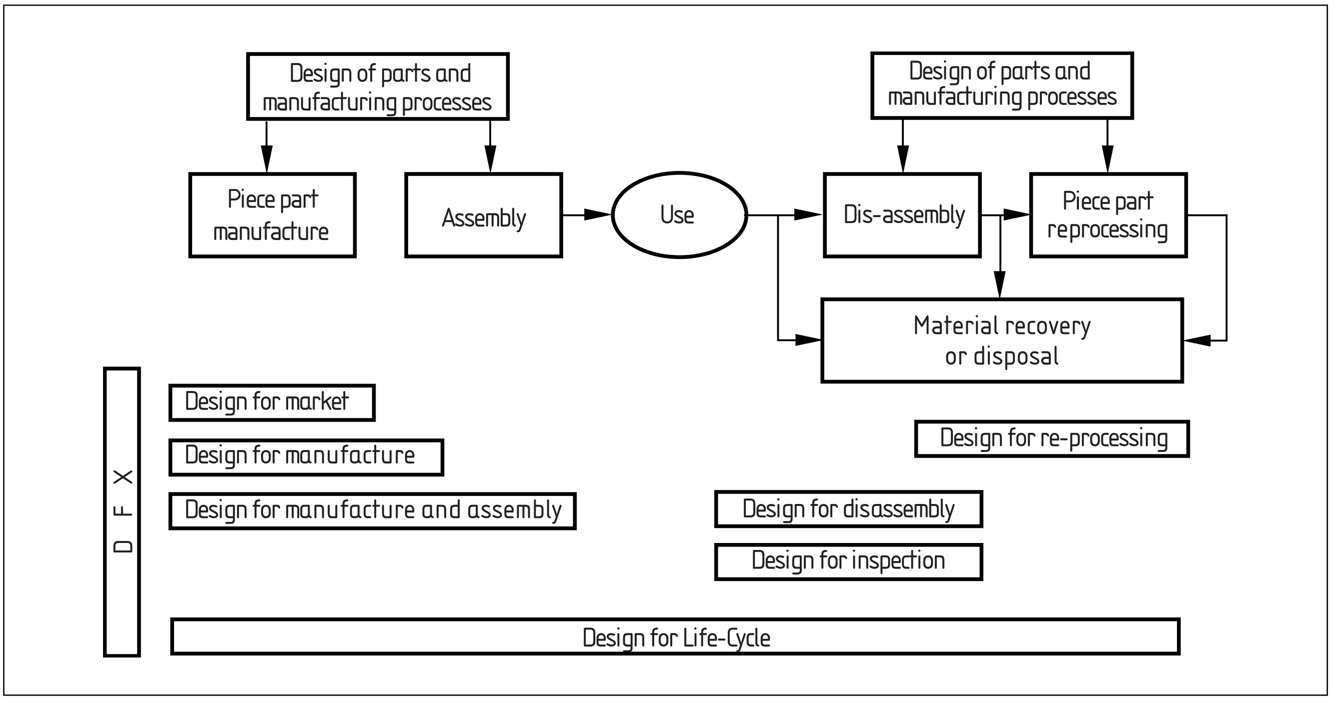
- part production;
- assembly;
- disassembly;
- materials recovery/disposal and part reprocessing.

NOTE 1 It is recommended that PD ISO/TR 14062 is taken into account. Although PD ISO/TR 14062 was drafted for environmental managers rather than designers and engineers, it provides a very useful reference document for users of BS 8887-1.

These design process stages are shown schematically in Figure 1. Design for manufacture considerations shall be applied to each of these five stages.

NOTE 2 The sequence of events implied by the order of the clauses in this British Standard should not be taken as absolute since the process is iterative. In practice many stages are revisited, perhaps many times, throughout the overall activity. This applies particularly to the design improvement element that by its very nature, influences and informs every activity.

Figure 1 **The stages in the life of a product and the various DFX terms**



5 Design brief

NOTE 1 The process by which a design brief is prepared varies with the size of the organization undertaking the project and the nature and relative size of the project itself. However, the process should be as consultative as possible in order to obtain the input of all disciplines likely to be involved in the ultimate realization of the resulting design concept, at the earliest practicable stage.

NOTE 2 The detail of any given design brief varies from project to project with specific elements varying significantly in their level of importance within the brief and indeed, not appearing at all in some instances. Table 1 is presented in the form of a check-list of subjects to be considered as potential elements of a design brief that may be included, as appropriate. This list is not necessarily exhaustive for any particular project and the format is provided by way of example only although it might be of assistance to users.

The design brief shall collate the set of requirements and limits, which identify and define a perceived market need, the satisfaction of which requires specific design input. These are common to all product areas and the design brief shall include the following, which are further expanded in Table 1.

- Establishment of market need including target selling price and required time to market.
- Determination of technical feasibility (with particular reference to available and possible manufacturing/verification facilities).
- Assessment of serviceability.
- Consideration of end-of-life implications.

Each of the elements identified in Table 1 shall be given positive consideration, even if it is subsequently set aside as having no relevance to the project, since parties involved in the preparation of the brief are advised not to make assumptions about the relevance of particular aspects.

Table 1 **Parameters for consideration in the preparation of a design brief**

Market need [A)]	**Technical feasibility**	**Serviceability** [A)]	**Life cycle** [A)]
Market sensitivity Sales potential Competition Opportunities Aesthetics Price [A)] Potential for on-going development Impact on company image Performance Potential benefits of sale as a function rather than a product Confidentiality Time scale [A)] Quantity required Inclusive design	Material *(suitability and performance)* Currently available processes Potentially available processes Health and safety Design verification Process conformance testing Function verification Risk assessment Milestones [A)]	Level (e.g. module/ component) within a product Ease and practicality of access to relevant level Required tools (cost and availability) Health and safety Skills requirement Return to use processes Upgradability Spare stock implications	Materials *(minimization, surface area, density, recyclability, recycled content, renewability)* Manufacturing processes *(materials/energy consumption, pollution, toxicity)* Product operation *(energy sources and systems [renewable, low carbon], energy consumption)* Life cycle assessment Legal constraints Whole life costs *(production, use, end-of-life)* Health and safety Recovery (materials) Recycling (materials/energy) Recovery (energy) Reuse Ease and practicality of disassembly

Method of presentation of the final design concept, for approval

[A)] These items shall appear in every design brief.

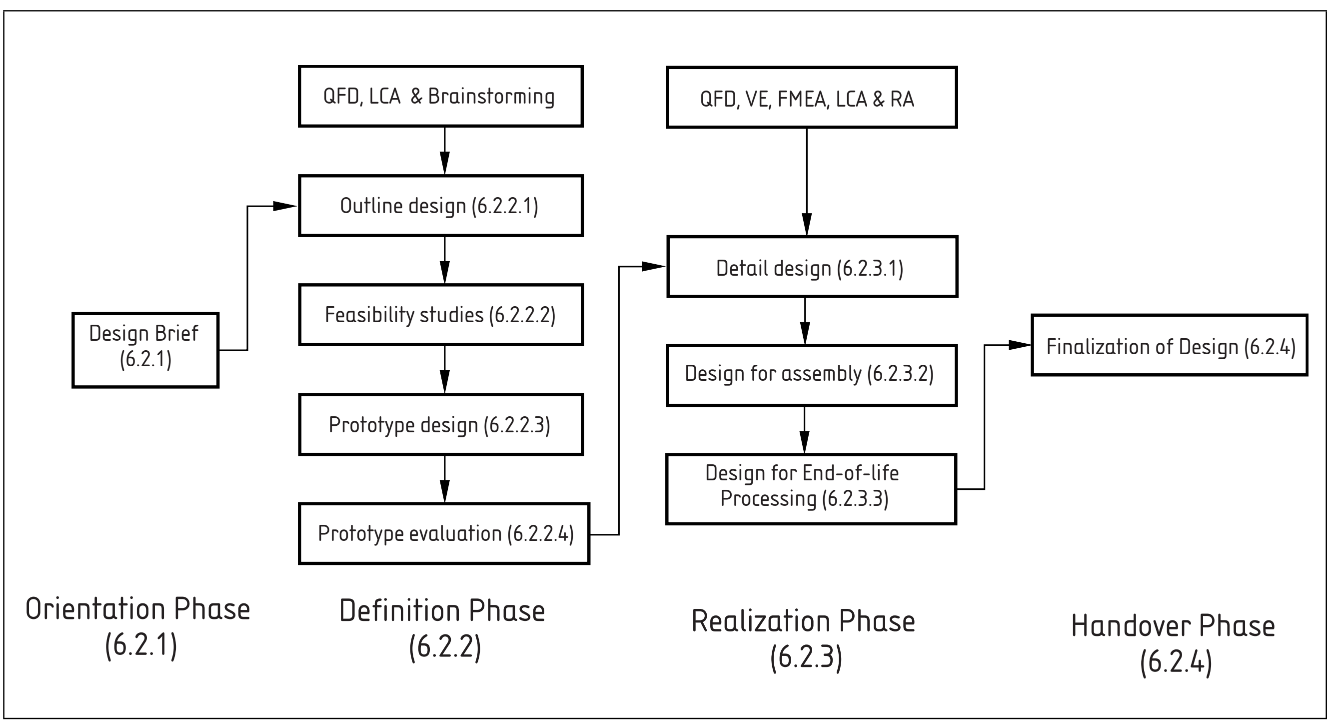
6 Design methodologies

6.1 General

The best practice sequence of events for design shall be in accordance with **6.2** and Figure 2, which set out the totality of possible methodologies/phases that can be beneficially applied throughout the design definition process. Figure 2 represents this best practice sequence graphically and provides cross-reference to the specific techniques that are applicable to any particular phase.

*NOTE 1 For any specific entity engaged in design for manufacture the inclusion of any particular phase, as a clearly defined step, is influenced by the circumstances of application and particularly by the size of the entity concerned, the complexity of the design project and the anticipated production run length/volume. However, the whole sequence of events should be conceptually applied in every situation even though particular phases might then be set aside as being inappropriate or merged to simplify their application. The phases for detailed design (**6.2.3.1**), design for assembly (**6.2.3.2**) and life cycle consideration (**6.2.3.3**) are considered to be of sufficient complexity and significance as to require elaboration in Clause **9**, Clause **10** and Clause **11** respectively.*

Figure 2 **Application of specific techniques showing best practice sequence of design methodologies**



NOTE 2 There are many established techniques that can assist in the design process and some of these are given in Annex A.

6.2 Best practice sequence of events

6.2.1 Orientation phase (consideration of marketing brief/design brief)

A design project shall be commenced by consideration of the marketing brief, melded into a design brief by a team assembled for the purpose (MADE design team). This team shall contain competent representatives of the critical disciplines which have ownership of the product from design inception to the end of its life. These disciplines shall include, but are not necessarily limited to the following.

- Sales/marketing.
- R&D/design.
- Manufacture.
- Quality assurance.
- Customer service.
- Take-back facilitation.
- Health and safety.
- Environment.

NOTE Representation for more than one discipline may be undertaken by any individual team member provided that their competence in the disciplines represented is confirmed as adequate by the management responsible for the project.

The output of this consideration process shall be a document containing an agreed detailed design brief, in accordance with BS 8888:2006, Clause **5**; targets for the various sections of the brief; and an allocation of the work needed to convert the brief into an outline design. The brief shall be forwarded to the management responsible for the project for decision as to continuation.

6.2.2 Definition phase

6.2.2.1 Outline design

During the outline design stage team members shall convert the design brief into an outline design for their allocated sections, taking into account the agreed design targets.

The outline design stage shall conclude with preparation of a set of outline design technical product documents, indicating where the design can be considered hard (relies on re-use of existing designs, or is based on work already tested) or soft (requires validation before proceeding to prototype stage). These technical product documents shall be reviewed by the team for the necessity and sufficiency of feasibility studies.

The output of the outline design stage shall be *either*, a set of outline technical product documents plus an agreed set of feasibility study briefs, with costs and allocation of work required to proceed to first prototype, *or* a conclusion that the design brief cannot be adequately met with current technology at an acceptable cost.

6.2.2.2 Feasibility studies

Team members shall complete agreed studies and prepare reports of the results. From the results of the studies the set of outline design technical product documents shall be completed. The team shall review this set of documents against the design brief and recommend action.

The output of the feasibility study stage shall be *either*, a set of approved outline design technical product documents sufficient to proceed to detailed prototype design conforming to BS 8888:2006, Clause **6**, or a conclusion that the design brief cannot be adequately met with current technology at an acceptable cost. Management responsible for the project shall then decide whether to continue with or abandon the project.

6.2.2.3 Prototype design

MADE design team members with relevant competence or their directly nominated alternates shall continue the design work to produce a first working prototype of the product.

The output of the prototype design stage shall be a working prototype either real or virtual, not necessarily physically representative of the final product, and a set of detailed design technical product documents used to construct it, which shall conform to BS 8888:2006, Clause **6** and/or BS 8888:2006, Clause **22** and having specific regard to BS 8888:2006, Clause **19**, BS 8888:2006, Clause **20** and BS 8888:2006, Clause **21**.

6.2.2.4 Prototype evaluation and feedback

MADE design team members with relevant competence or their directly nominated alternates shall evaluate the prototype and the technical product documents against the design brief and report on work required to completely fulfil that brief.

The output of the prototype evaluation stage shall be a decision by management responsible for the project, as to whether to abandon, re-assess or continue the project. If the decision is made to continue a *sealed design brief* capable of fully informing the remainder of the design process shall be completed.

6.2.3 Realization phase

6.2.3.1 Detail design

When the main design intent has been fully agreed and the sealed design brief issued, a detailed analysis of the possible options for fulfilling its requirements shall be carried out, including determination of any new tooling required.

*NOTE See Clause **9** for further information.*

6.2.3.2 Lifecycle considerations, including end-of-life processing

Requirements with regard to end-of-life processing shall be prepared in accordance with Clause **11** and Annex C. Statement as to the nature and extent to which lifecycle considerations, including end-of-life processing, have been addressed shall be incorporated in the technical product specification taking account of **13.3**.

*NOTE 1 End-of-life processing is a relatively recent introduction to the design definition process. Manufacturers in certain fields are required to take control of the recovery, disassembly, recycling and disposal for their products at the end of their useful life. See Clause **11** for further information on end-of-life processing.*

NOTE 2 It is recognized that specific action with regard to lifecycle considerations are not required for all products. For example, many end-of-life processing issues are introducible to standard waste recovery/processing streams without special action or following simple separation of components. In requiring a lifecycle considerations statement for compliance with this standard it is accepted that for such products the statement may be to the effect that "no special action with respect to lifecycle environmental impact is considered necessary".

6.2.3.3 Design for assembly and disassembly

Although much of the proposed expenditure is likely to have been committed, at the end of the detail design phase consideration shall be given to specific requirements for efficient assembly and disassembly of products, in particular to the minimization of the parts count for any given assembly.

*NOTE See Clause **10** for further information.*

6.2.3.4 Risk assessment

Where risk assessment (**A.6**) is undertaken, it shall be in accordance with: BS EN ISO 14040 and BS EN ISO 14041 where there are environmental implications; and BS EN 1050 where there are safety implications.

NOTE Guidance on risk management is also given in BS IEC 62198, and BS 8444-3.

6.2.4 Handover phase (finalization of design, approval and sealing of technical product documents)

Following completion of the manufacturing prototype stage, marketing shall lead the project into the product launch stage, during which all technical product documents shall be reviewed for completeness. Verification of these technical product documents shall be completed during initial manufacture, and shall include checking whether the documents conform to the appropriate sections of BS 8888, particularly BS 8888:2006, Clause **19** and BS 8888:2006, Clause **20** for tolerancing, and BS 8888:2006, Clause **21** for display components. As each technical product document is completed, it shall be deemed to have received final approval, and be transferred to the document controlled store. Once a technical product document has been stored in the document vault the relevant designer shall be released from the project.

The output of the finalization stage shall be approval for continued manufacture.

7 Cost considerations

7.1 General

The design brief includes the target price for the product in accordance with Clause **5**. The designer shall ensure that the overall product cost is consistent with the target price derived from the design brief, P_t, allowing for any required contribution, as shown in the following equation:

$$P_t + P_c = [(C_{dev} + C_{mkt})/Q_{at}] + C_{mat} + C_{ma} + C_{de}$$

where:

P_c is that portion of the selling price contributing to the manufacturer's overhead cost and the required profit;

C_{dev} is the cost of developing the product (for total anticipated quantity);

C_{mkt} is the cost to market (including direct sales, delivery etc.) (for total quantity);

C_{mat} is the cost of materials, components, etc. (per unit);

C_{ma} is the cost of manufacturing and assembly (per unit);

C_{de} is the cost of disassembly and end-of-life processing (per unit);

Q_{at} is the anticipated total quantity of the product.

NOTE 1 It is often necessary to make trade-offs between technical needs and commercial needs, typically between unit cost vs. unit features and development costs vs. development timescales. If trade-offs have to be made, this should be done as early as possible in the costing process.

*NOTE 2 Although operating costs have necessarily to be considered by the designer (see Clause **11**) they do not constitute part of the calculation.*

7.2 Development costs (C_{dev})

The cost of the product development project shall be estimated taking into account the following constituent costs.

a) Project planning and estimating effort.

b) Project management effort.

c) Patent agent research and patent related costs.

d) Effort in finalizing the design brief (see Clause **5**).

e) Effort in using the design tools (see Clause **6**).

f) Concept phase effort (see **6.2.2**).

g) Realization phase effort (see **6.2.3**).

h) Technical documentation effort (see **6.2.4**) (including user documentation).

i) Industrial design effort (see Clause **8**).

j) Detail design effort (see Clause **9**).

k) Design verification effort (see Clause **12**).

l) Prototype hardware build (materials and man-hours).

m) Hire of specialist equipment for development/ testing and/or test house fees.

n) Overheads for facilities needed (where these need to be explicitly accounted).

o) Software development.

p) Software testing.

q) Regulatory compliance testing (where relevant).

r) Independent product evaluation or involvement of a Notified Body.

s) Packaging design and development.

Estimation of the cost of individual tranches of work, or sub-programmes, shall be undertaken by the staff responsible for those areas. Estimates shall be based as far as practicable on actual data gathered from similar previous development work.

NOTE 1 The resources required (i.e. number of staff) is dictated by development timescales, which might have a limit stated in the design brief. Alternatively the development timescale should be established by working back from the deadline by which the product is to be launched in order to capture the desired market share, making allowance for the time required for manufacture and distribution etc.

NOTE 2 The designer should consider options for reducing development costs, for example through variety reduction, simulation, rationalizing and standardizing commonly used components (such as fasteners), use of off-the-shelf mechanical hardware, subassemblies, electronics, software etc.

7.3 Marketing, sales and support costs (C_{mkt})

The costs of taking the product to market shall be estimated taking account of the following.

a) Product launch (one-off).

b) Marketing costs, including publicity in the press, promotional expenses, direct advertising.

c) Fees to agents.

d) Discounts to distributors.

e) Sales.

f) Export (including exchange rate variability).

g) Distribution.

h) After sales support.

i) Staff training.

j) Warranty.

7.4 Materials costs (C_{mat})

The costs of materials required to make the product shall be determined and typically comprise the costs of:

a) electronic/electrical components;

b) mechanical components;

c) structural items such as housing/frame/chassis/etc.;

d) bought-in subassemblies and assemblies;

e) raw materials;

f) special processing of parts, for example painting, plating, passivation;

g) consumable materials necessary for assembly/processing;

h) packaging materials;

i) unit based licences, for example software, patents.

NOTE Parts costs can be heavily dependent on the quantity purchased. One or more purchasing specialists should be involved in establishing best prices for the items listed.

7.5 Manufacturing, assembly, disassembly, end-of-life processing costs

7.5.1 Manufacturing and assembly costs (C_{ma})

The manufacturing and assembly costs shall be estimated taking into account the following.

a) Piece part manufacture.

b) Piece part inspection/test.

c) Assembly and associated processes.

d) Sub-assembly and assembly testing.

e) System integration.

f) Product/system testing, functional and safety.

g) Specialist equipment.

h) Subcontractors packing and storage.

NOTE The non-recurring costs of making production tooling, jigs and fixtures, test harnesses, test equipment etc., should also be included if these have not be taken account of as part of the development.

7.5.2 Disassembly and end-of-life processing costs (C_{de})

End-of-life processing costs (if any element of these is borne by the manufacturer) shall be estimated taking account of the following.

a) Transport and collection.

b) Disassembly.

c) Disposal of harmful or toxic components (e.g. batteries).

d) Reprocessing or re-cycling parts.

e) Other disposal costs.

8 Industrial design

Industrial design shall be considered as part of the design process of a product.

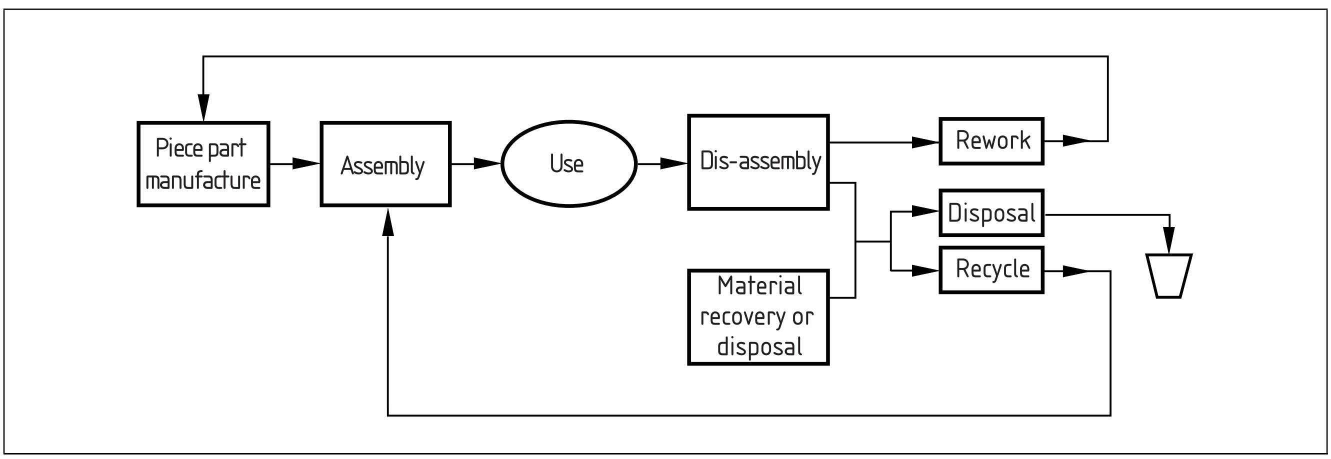
NOTE Information and recommendations regarding industrial design are given in Annex B.

9 Detail design

When the main design intent is fully agreed, the detail design stage of the design process shall begin.

NOTE 1 This is the final stage whereby the detailed design work locks the final design. Any changes made after this are expensive. It is the last stage before the tooling is manufactured and thus, inherent within the detail design decisions are decisions concerning the manufacturing processes and the tooling to be used for manufacture as well as the costs of assembly and then after use, the disassembly and the parts re-processing. The re-processing can be one of three things: disposal, rework or recycling. This is illustrated in Figure 3 which has been developed from Figure 1.

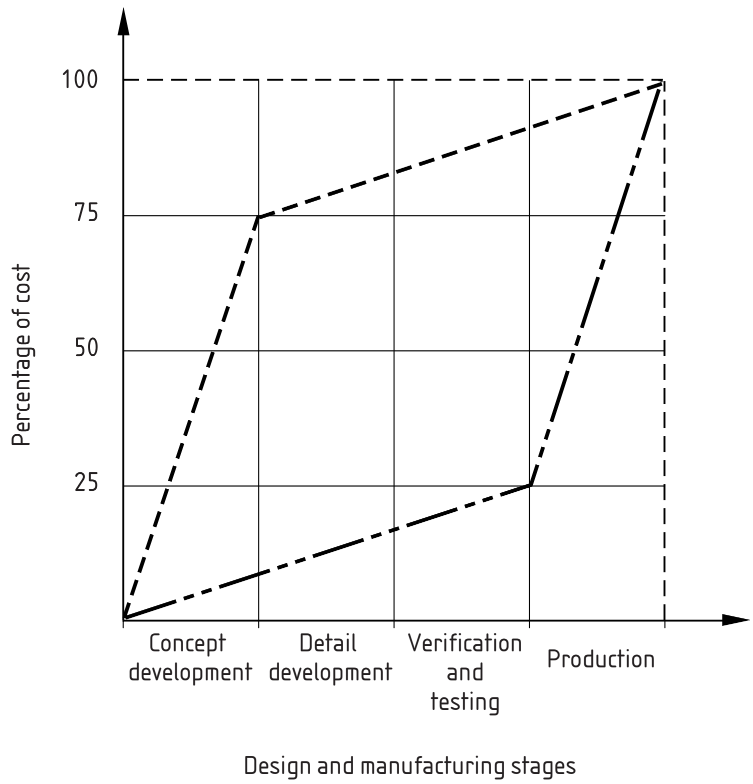
Figure 3 **The stages in the life of a product, including the three routes of part end-of-life processing**



NOTE 2 The locked in costs when the detailed design of each part is finalized depend on which of the three routes for part end-of-life processing. The ideal situation is when a part can be re-cycled since this is straight part re-use. There is no further part cost, only the cost of disassembly and subsequent re-assembly. The next most expensive is when the part has to be refurbished in some way or other because the part cannot be immediately re-used but requires some reworking. This would typically mean some reprocessing to allow for the degradation that occurred during use. A typical example of rework would be re-plating and grinding to compensate for wear. Recycling involves the disassembly and/or deformation of the product, and further processing so that the materials can be fed into the production of a new product. It incurs machinery, energy, storage and transport costs. The most expensive way of dealing with a part at the end of the product's life is to simply discard it but this incurs a disposal cost.

NOTE 3 Estimates vary but generally at the end of the detailed design stage, the costs incurred are 15% to 25% of the overall cost to market yet, as a result of these decisions, the committed costs are 75% to 85% of that figure. This is shown in Figure 4.

Figure 4 **Costs over the life of product design showing the difference between the incurred costs and the committed costs**



Key

Committed cost

Incurred cost

Concurrent engineering extends the concept development and shortens the detail and testing stages.

NOTE This figure should be considered as illustration only. Whilst a plot of committed costs will probably be more or less linear, that of incurred costs is more likely to be a series of curves with varied slopes influenced by the nature of the products under consideration.

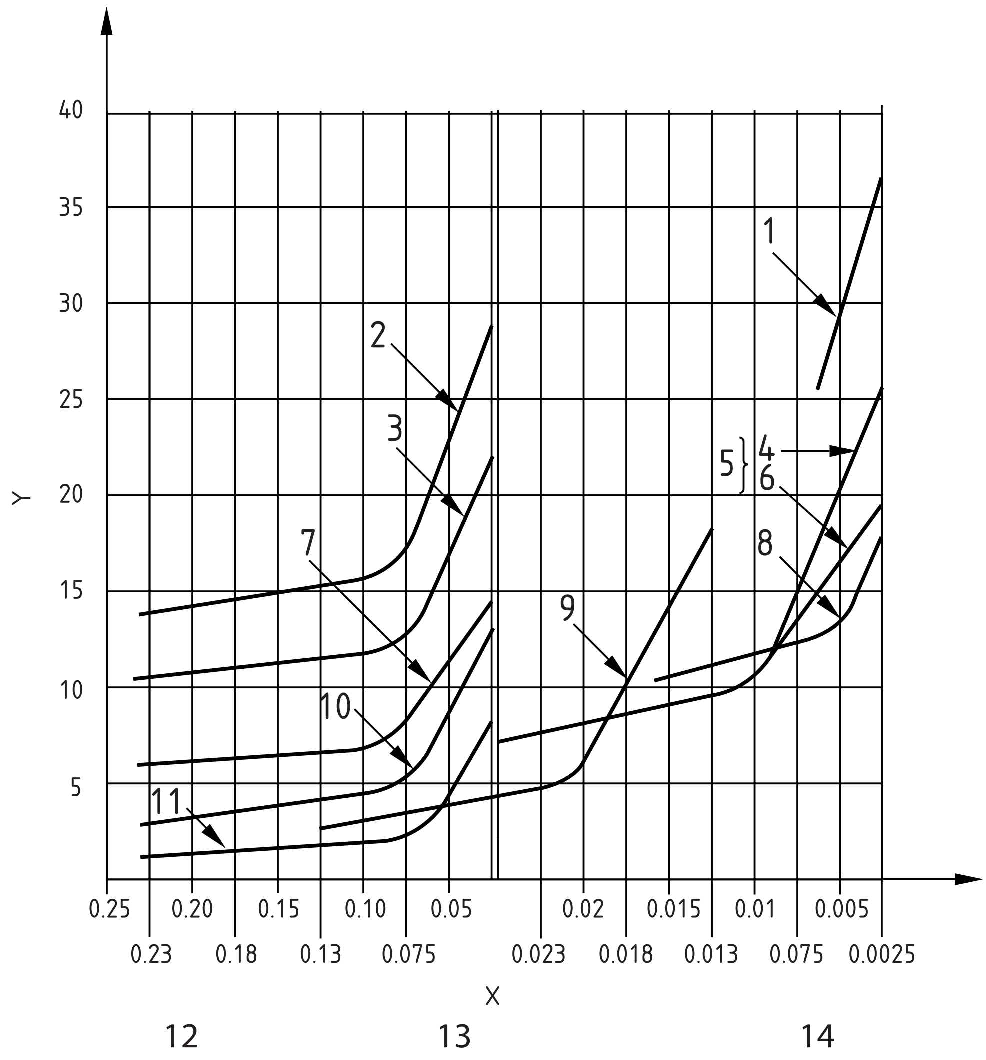
The detail design stage shall specify and define each and every one of the piece-parts, which together make up the final assembled product. This includes the physical geometry, the material, the tolerances, the geometrical tolerances, the surface finishes and the methods of manufacture.

Tolerancing of linear and angular dimensions shall be in accordance with BS 8888:2006, Clause **19**. Tolerances shall be specified in accordance with the IT grades given in BS EN 20286-1, whereby numbers and letters are used to specify tolerance bands.

NOTE 4 In general, the tighter a tolerance is, the more expensive it is to achieve (see Figure 5).

However, the use of geometrical dimensioning and tolerancing as specified in BS 8888 will be found to mitigate this negative effect, as a result of targeting the tighter tolerances to those features of characteristics critical to the correct functioning of the piece part.

Figure 5 **Example of cost versus process**



Key

X Tolerance in mm
Y Relative costs
1 Hand lapping
2 Shaping
3 Planing
4 Internal
5 Grinding
6 External
7 Horizontal borer
8 Honing
9 Lathe
10 Milling
11 Turret (capstan)
12 Low
13 Accuracy
14 High

Geometrical tolerancing shall be in accordance with BS 8888:2006, Clause **20**, which specifies geometric forms for single features like straightness, flatness and cylindricity and for features that are related like position, parallelism and concentricity.

NOTE 5 As with tolerancing in general, the tighter a geometrical tolerance is, the more expensive it is to achieve.

Tolerancing of surfaces shall be in accordance with BS 8888:2006, Clause **21**, which defines how two-dimensional surface finish requirements are to be specified.

NOTE 6 As with tolerancing in general, the finer surface finishes are the more expensive to achieve. Comprehensive requirements for the specification and assessment of three-dimensional surface finish are in preparation in the ISO/TS 25178 series of Technical Specifications. It is expected that these will be available for public comment by the beginning of 2007 and published by the end of that year.

The detail design stage shall result in the specification of standard components that need to be purchased, taking into account the lead times involved. Standard parts and features shall be in accordance with BS 8888:2006, Clause **18**, which gives details of methods of defining standard components like fasteners, springs, gears, roller bearings, seals etc.

The output from the detail design stage shall be the technical product documentation (TPD), see BS 8888:2006, Clause **3**. This TPD is the controlling documentation which specifies all the piece-parts and hence the product itself. It also includes the process plans for and quality assurance manufacture.

NOTE 7 The internationally agreed set of standards concerning the geometry of a work-piece or part is described as the Geometrical Product Specifications*. BS 8888 provides a route map through the relevant set of standards. This approach addresses the requirements for dimensioning, tolerancing and surface definition from a geometrical perspective. All ISO standards relating to mechanical design operate under this system. Its application ensures that specifications can be targeted to ensure relevant performance without redundancy, hence with minimum cost, whilst providing not only functionality but also safety, dependability and interchangeability.*

10 Requirements for assembly

10.1 General

The first stage in the application of design for manufacture shall be the minimization of the part count.

NOTE 1 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. There are various techniques available to the designer which may be employed to minimize the part count. The most widely used is the one proposed by Boothroyd et al. [1]. However, this technique was proposed before the disassembly and end-of-life processing stages became important. This clause is an adaptation of the Boothroyd and Dewhurst technique.

NOTE 2 The technique of reducing the number of assembly operations and calculating the assembly efficiency surrounds five basic questions which attempt to determine whether a part is absolutely necessary. If it is not then in theory the part can be either removed or amalgamated. When these questions are applied to all parts, the various answers lead to a minimum part count. This provides a baseline from which other calculations can be made.

For each part in the assembly, answers to the following questions shall be determined.

a) During operation, does the part move relative to other parts already assembled?

b) Is it necessary that the part be of a different material from other parts already assembled?

c) Is it necessary that the part be separable from all other parts for inspection, maintenance or adjustment?

d) Is it necessary that the part be separable for end-of-life disposal?

e) Is it necessary that the part be separable for end-of-life part processing?

For any part, if the answer to all the five questions is "no", that part shall be a candidate for elimination. The designer shall then decide, in accordance with all other design constraints, whether that part can be removed or amalgamated. This produces an initial design from which assembly times shall be determined, in accordance with the mode of assembly to be used (manual or machine).

NOTE 3 Using standard data, handling and insertion times can be estimated for each of the individual parts to give the total assembly time.

The various designs shall then be compared and the most appropriate design selected. An appropriate method for comparing design efficiencies, D_e, with the average manual assembly time per operation of three seconds shall be given by the following equation, see Boothroyd et al. [1].

$$D_e = \frac{[3*N_{min}]}{T_{ass}}$$

where:

N_{min} is the theoretical minimum number of parts;

T_{ass} is the estimated time to assemble the selected design.

10.2 Parts in the assembly

The following shall be taken into account for each part in an assembly:

a) tolerances;

b) geometrical tolerancing;

c) surface finish.

Mating parts in the assembly require further consideration as follows.

- At the parts manufacture stage, the principles of tolerancing are applied to the dimensioning of the parts making up the product assembly. No part shall be manufactured without a tolerance because nothing can be made to an exact size, there is always variability and that variability shall be stated explicitly or implicitly. Tolerances shall be specified in accordance with the IT grades given in BS EN 20286-1, in which numbers and letters are used to specify a tolerance band which is related to size. Therefore tolerances of mating parts shall be considered when reviewing the assembly of the product.

NOTE 1 BS 8888:2006, Clause 19 gives details of the tolerancing of linear and angular dimensions.

- At the parts manufacture stage, the principles of geometrical tolerancing are applied to the shape and form of the parts making up the product assembly. Geometric forms are defined using geometrical tolerancing in accordance with BS 8888:2006, Clause **20** which specifies geometric forms for single features like straightness, flatness and cylindricity and for features that are related like position, parallelism and concentricity. Geometrical tolerances of mating parts shall be considered when reviewing the assembly of the product.
- The surface finish of mating parts shall be considered since surface finish can influence assembly and cost.

*NOTE 2 Details of the assessment and specification of two-dimensional surface finish are defined in BS 8888:2006, Clause **21** as is the way in which surface finish requirements are to be indicated on engineering drawings. Comprehensive requirements for the specification and assessment of three-dimensional surface finish are in preparation in the ISO/TS 25178 series of Technical Specifications. It is expected that these will be available for public comment by the beginning of 2007 and published by the end of that year.*

10.3 Ease of assembly

The design of each individual part shall be considered with respect to its ease of assembly into the sub-assembly or product.

NOTE Many publications give part and product design recommendations and these should be followed in an analysis. Further information is given in Boothroyd et al. [1]; Nof et al. [2]; Jovane et al. [3]; Otto and Wood [4]; and Ulrich and Eppinger [5].

The following aspects shall be included in the consideration of manual assembly.

a) Maximizing reliability of each assembly operation through the use of chamfers, avoidance of sharp corners and the use of generous tolerances.

b) Aid individual part-orientation through either the use of symmetry or the use of significant asymmetry.

c) Use of cone or oval fasteners to aid assembly and the avoidance of rolled threads which hinder assembly.

d) Use the principles of modularity so that assemblies and sub-assemblies can be built and tested independently.

e) Use lower cost mechanical fastenings rather than high cost ones like rivets and screws.

f) Avoid the use of fasteners/fastening systems which mitigate against disassembly for end-of-life processing.

g) The use of permanent joining methods e.g. welding or adhesives, provided that the parts to be joined can be recovered through the same method or process.

h) Employ fool-proof techniques such that parts can only be assembled one way.

i) Use techniques such that if a part is mis-assembled, subsequent parts cannot be assembled.

j) Do not use procedures where the field of assembly view is restricted.

k) Avoid holding parts to maintain their position during their assembly or during subsequent part assembly.

In addition the following aspects shall be included in the consideration of machine assembly.

1) Use the principle of building onto a base part which is the equivalent of a jig or fixture.
2) Make the base part the heaviest part.
3) Ensure the base part has features to locate it readily in a stable position.
4) Build the assembly from the base part vertically upwards in a layered (pancake) fashion.
5) Avoid the use of parts which tangle, nest, shingle or jam in feeder systems.
6) Design for vertical additive assembly of parts.
7) Make parts self-locating if they are not secured immediately after insertion.

10.4 Ease of disassembly

The design of each individual part shall be considered with respect to its ease of disassembly into the sub-assembly or product. The aspects given in **C.5** shall be included in the consideration of disassembly.

11 Life cycle considerations

In order to minimize environmental impact throughout the life cycle, product design shall address the issues relating to the environmental impact of the product, namely:

a) materials and components sourcing;

b) manufacturing processes;

c) product use and maintenance;

d) demanufacturing processes;

e) costs, savings and income.

The output from this process shall be a set of documents which identify the extent to which life cycle impact has been addressed, the methods used and the reasons for subsequent design decisions.

NOTE Annex C provides a checklist of issues that should be considered in relation to life cycle.

12 Requirements for verification

Verification principles, relevant to the complexity and intended function of the workpiece shall be considered and incorporated in the specification as part of the design stage such that when the verification stage is reached, the workpieces can be verified with respect to correct function and not solely that they are dimensionally correct *per se*. It is strongly recommended that the requirements of BS 8889, *Technical product verification – Inspection of size, form and surface texture in relation to function* [1] be considered for application in all cases but these requirements shall be applied for all workpieces manufactured to a specification incorporating GPS principles. Where metrological verification is appropriate it shall be made in accordance with DD ISO/TS 17450-1 and DD ISO/TS 17450-2.

NOTE 1 It has been suggested that there are twelve different definitions of size for non-ideal features, see Figure 6. Only those definitions of size which are associated with the intended function, are correct. If incorrect associations are made, the part might agree with a specification but could under-perform or be over specified. For example, if a shaft is required to engage and rotate in a bearing, it has to enter the bearing along a length appropriate to its operation. Thus, over the engagement length the appropriate verification method would be the minimum inscribed size *of the bearing and the* maximum inscribed size *of the shaft.*

To prove the correctness of the verification element, the detailed design of the piece-parts, components or assemblies, as defined by the Technical Product Specification (see BS 8888:2006, Clause **3**), shall be passed to an appropriate manufacturing facility for trial processing. When the initial physical piece-parts, components or assemblies manufactured in accordance with that specification are received by the design body or other designated organization, they shall be assessed to establish whether/if they meet the specification. This applies, irrespective of their state, e.g. prototype, refurbished, initial.

The verification process employed to prove the verification element of the specification shall be undertaken firstly in accordance with any verification specific guidance or instruction provided as part of the specification, supplemented by additional verification procedures as judged appropriate by the verification team.

NOTE 2 The relevant standards should be consulted for verification methods relating to products of other disciplines.

[1] BS 8889 was in development at the time of publication.

NOTE 3 The concept of GPS verification is that the physical realization of the design, inherently consisting of non-ideal features, is related to the ideal model of the specification via association of operation/s. DD ISO/TS 17450-1 defines "association" as an "operation used to fit ideal feature(s) to non-ideal feature(s) according to a criterion". The manufactured physical piece-part or component consists of surfaces which together define features. The word "real" is preferred to the word "physical". BS EN ISO 14660-1 defines the "real surface of a workpiece" as a "set of features which physically exist and separate the entire workpiece from the surrounding medium". Association assures that the most appropriate and correct verification methods are matched to functional requirements, thus saving time and money. This needs to take into account uncertainty in manufacture as well as verification [2]. This is critical because the association methods have to be selected correctly to ensure the specification is tested unambiguously for the functional performance to be assured.

The output from the verification stage shall be a set of documents which define the verification process to be applied in confirming the acceptability of future production, including pertinent decision criteria and confirmation that the design has been proved to be fit for purpose, according to the product specification, during the proving process.

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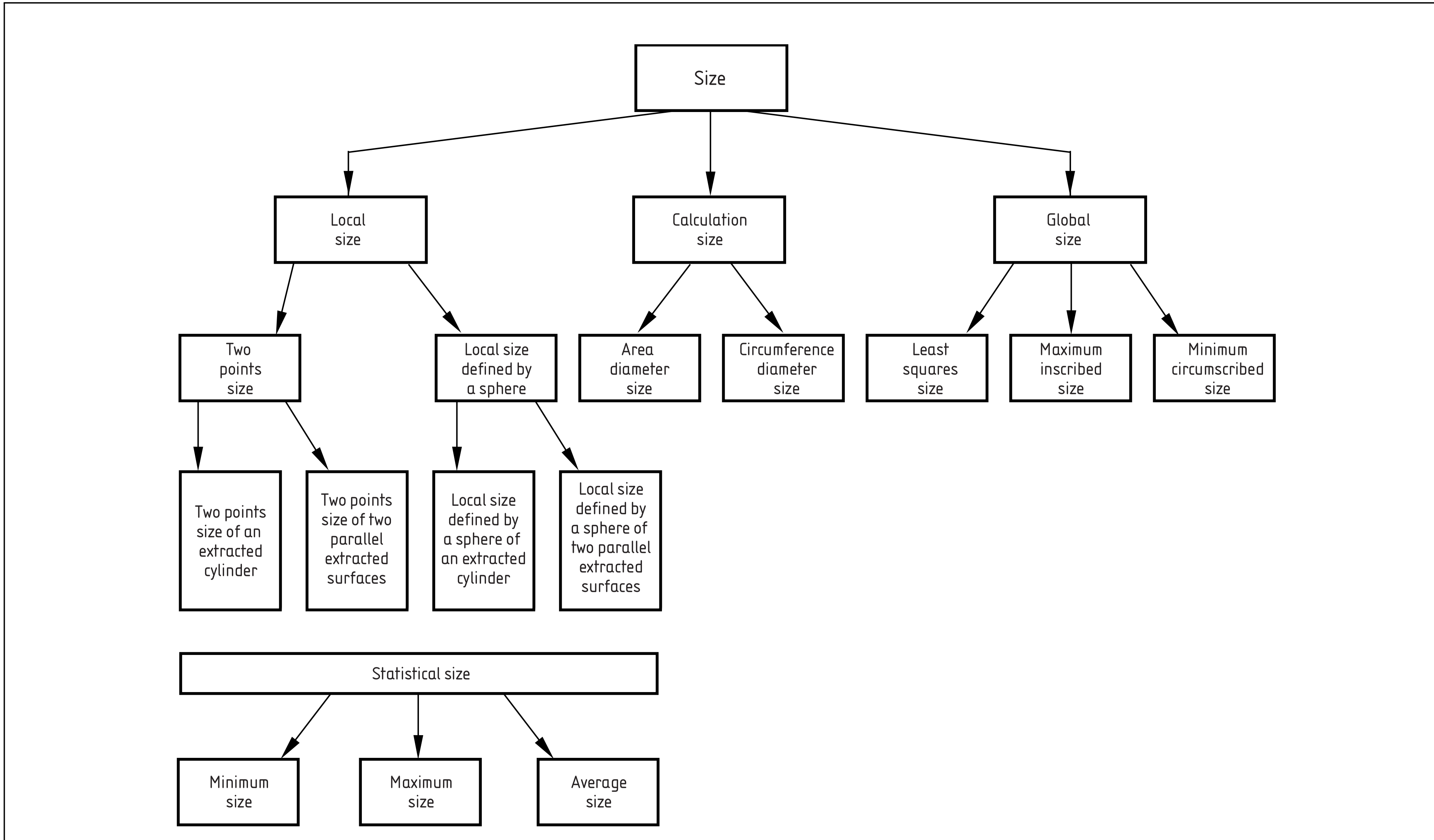
[2] ISO documents relating to uncertainty in manufacture and verification are in preparation but are currently in the early stages of drafting.

Figure 6 **Concept diagram showing the twelve different definitions of size**



13 Documentation

13.1 Design documentation

Documentation of the design shall be prepared, maintained, and archived so that the information is available for reference, maintenance and future development of the product. In the event of any query over the safety or integrity of the product, the design route and calculations are available, and any accusation of poor design or negligence can be investigated. The documentation produced shall be maintained and ultimately archived. Design documentation shall include the following.

a) The design brief.

b) Specifications.

c) Design drawings.

d) Intellectual property rights implications (patents etc.).

e) Schematics (electrical, electronic, pneumatic, hydraulic etc.).

f) Software code.

g) Calculations.

h) Results of modelling.

i) Risk assessments.

j) Identity of legislative requirements.

k) Product life cycle assessment.

l) FMEA.

m) Minutes of design reviews.

n) Manufacturing drawings.

o) Items lists.

p) Instructions.

q) Test specifications.

r) Test results and acceptance criteria.

s) User instructions.

t) Maintenance instructions.

NOTE Also supporting information such as packaging design, marketing and sales material, and product brochures should be included. It is strongly recommended that records of the progress of the development project itself such as the project plan, the project team (who was responsible for doing what), minutes of meetings, project cost records, and acceptance or qualification of prototypes or pre-production models, user trials etc. also be retained. These records might be invaluable for support later in the product life cycle. The concept of strict liability means that when a manufacturer offers a product for public sale, they are representing that the product is suitable for its intended use. The documentation list can provide the evidence that this is the case and thus defend against litigation or any accusation of negligence in design.

13.2 Manufacturing documentation

Manufacturing documentation shall be prepared, maintained and robustly archived so that records are available of how the product is made. If traceability is required, information about particular batches of the product shall be kept.

Manufacturing documentation shall include the following.

a) Drawings.

b) Bills of material.

c) Purchasing information.

d) Manufacturing process documentation.

e) Assembly instructions.

f) Test specifications.

g) System integration procedures where relevant.

h) Drawings/specifications for test equipment and tooling.

Also, where applicable, copies of test certificates or certificates of conformity and traceability information on the materials used shall be kept. Production records that provide evidence of compliance to specification (including where applicable safety testing) for batches or individual products shall be kept.

13.3 End-of-life documentation

End-of-life documentation shall include the following:

- Identification of materials.
- Reception location for any take-back scheme.
- End-of-life processing instructions.

A method shall be implemented by which access to the end-of-life documentation can be maintained for the foreseeable life of the product.

NOTE Some of this information may be in the form of codes on the product itself.

Annex A (informative) Established techniques which assist with the design process and their correct use

*NOTE There are many creative design techniques of which those addressed in **A.1** to **A.6** are considered to be the most generally relevant.*

A.1 Brainstorming

Brainstorming is a well known technique used to stimulate the generation of ideas when trying to solve a specified design problem.

The technique is widely used at the concept design stage. It is a group activity where members of the group attempt to find a solution for a specific problem by generating ideas spontaneously.

A suggested approach to the use of brainstorming is as follows.

- Selection of group members; usually four to eight people. The group of people selected for a brainstorming session should be diverse, with one member being appointed as group leader.
- Statement of the design problem to be solved.

  NOTE The initial problem might need to be further sub-divided on analysis.
- Call for possible solutions to the problem.
- Analysis of solutions.
- Call for further solutions if initial solutions are considered to be unacceptable.
- Continuation of the process until an acceptable solution is found.

On completion of a brainstorming session the designer should have a clear view of possible solutions to a specific problem.

NOTE For further information see Cross [6], Kahn [7], Osborn [8] and Rawlinson [9].

A.2 Quality function deployment

Quality function deployment (QFD) is a product design philosophy that has been developed to ensure that the customer/end user needs drive the entire product design and manufacturing process in a company.

QFD is a team based activity and calls upon the expertise of marketing, design, manufacturing and other relevant people within a company, as well as external inputs.

The perceived benefits of QFD are that it is customer/end user driven, it reduces implementation time, it promotes teamwork and it provides documentation.

The stages or phases of QFD are as follows:

a) *Phase 1: Product planning*
The customer/end user's wants are translated into design requirements through an analysis matrix called the House of Quality.

b) *Phase 2: Part deployment or component planning*
Takes the critically important design requirements down to the level of part characteristics in a scaled-down House of Quality.

c) *Phase 3: Process planning*
Identifies key process operations that are related to the important part characteristics.

d) *Phase 4: Production planning*
Relates the key process operations to production requirements and results in prototype construction and production start up.

The use of QFD aims to ensure that products brought to market fulfil, as far as possible, the needs of the customer/end user.

NOTE Further information on QFD is given in Baxter [10], Booker et al. [11], Cross [6], Inwood and Hammond [12], Kahn [7] and Pugh [13].

A.3 Value engineering

Value engineering (VE) is a well established technique used in product design and manufacture, it is concerned with the evaluation of design and manufacturing criteria for new products. Value is measured in terms of quality, performance and reliability at an acceptable price.

The technique is applied at the design stage to assess a complete product, sub-assembly or individual component. It is concerned with improving the value and reducing the total cost of a well-designed product without compromising the design specification, and is most effective when undertaken as a team based activity. The technique and philosophy of value engineering is based on simple concepts. Normally there are six steps to be followed systematically when carrying out a value engineering exercise.

The steps to be followed are as follows.

- Selection of the product, sub-assembly or component for investigation.
- Information: assembly of all relevant facts about the product/sub-assembly/component.
- Analysis of the functions of the product/sub-assembly/component to rank in order of priority and assign as accurately as possible the costs attributable to each function.
- Speculation on ways of improving poor value items giving due consideration to new materials and manufacturing processes.
- Evaluation of detailed information on performance, cost and availability of alternative materials, and the costs of manufacturing criteria.
- Implementation of solutions generated through appropriate documentation.

On completion of a value engineering exercise the designer should have established a sound design based on the requirements of quality, performance and reliability at an acceptable price.

NOTE Value analysis (VA) is a very similar technique which follows the same sequence but is applied to an existing product, with the objective of producing the same or improved value at reduced cost. VA, and other techniques employed to assist with the improvement and/or cost reduction of products, are not specifically addressed in this British Standard which is focused entirely on processes and techniques necessary for the preparation of the initial, sealed design brief.

NOTE Further information on VE is given in Cross [6] and Younker [14]

A.4 Failure mode and effect analysis

Failure mode and effect analysis (FMEA) is a well established technique that has been developed to minimize the possibility of poorly designed and manufactured products coming to market. It can be used to assess the design and manufacture of complete products, sub-assemblies or individual components.

It is a technique applied to the design and manufacture of new products at the embodiment and manufacturing design stages and is most effective when undertaken as a team based activity. It relies on the interpretation of historical records of product failure collected over a reasonable period of time, this information generally being presented as statistical data. This data is used to identify possible weaknesses in similar products currently being designed.

An FMEA is carried out systematically, generally through a ten step sequence of events, with the information being presented in tabular form. The steps to be followed are as follows.

- Listing of parts under investigation.
- Statement of the function of the parts.
- Identification of possible failure mode(s).
- Statement(s) of the effect(s) of failure.
- Statement(s) of the cause(s) of failure.
- Specification of an occurrence ranking index.
- Specification of a detection ranking index.
- Determination of a risk priority number.
- Statement(s) of the action(s) to be taken and specification of its/their status.

On completion of an FMEA the designer should be able to identify areas of weakness in the proposed product design and take corrective action.

NOTE Further information on FMEA is given in Booker et al. [11] and Huang [15].

A.5 End-of-life consideration

End-of-life consideration (ELC) is part of the broader concept of Life Cycle Analysis, sometimes referred to as "cradle to grave" analysis, or more recently "cradle to cradle" analysis. Cradle to cradle expresses the idea that resources should be part of cyclical systems, so that the quality of processing at end-of-life is high enough or appropriate enough to feed into new high quality products. This in turn has implications for how materials are processed for first use.

This technique is used to investigate the negative impact of products on the environment, from which a relative weighting can be determined for the manufacture, transport, use and disposal of the product. Further development of the product can then be focused on those stages identified as having greatest negative impact on the environment.

The technique relies on accurate data concerning the level of negative impact to the environment being obtained for each stage in the product's life cycle.

A life cycle analysis has three distinct phases. These phases are as follows:

a) *Phase 1*
Description of the product's life cycle: identification of inputs, transformations and outputs for each stage in the life cycle.

b) *Phase 2*
Analysis of each stage in the product's life cycle: identification of the basic purpose of each stage in the life cycle with measures of cost and value being apportioned.

c) *Phase 3*
Identification of opportunities for improvement: possible environmental or general improvements in the design of the product.

The following five criteria are the main ones used as a basis for life cycle assessment.

- Sources and system of energy used.
- Emissions to air.
- Emissions to water.
- Level of toxicity of materials used.
- Level of scarce material used.

NOTE *This list is not necessarily exhaustive. See Figure 1 and Figure 2.*

On completion of a life cycle analysis/assessment the designer should be aware of the product's impact on the environment (materials, energy, chemicals, water use and biodiversity), and the opportunities for product improvement with respect to costs, customer value, manufacturing efficiency and ease of transport.

NOTE *Further information on ELC is given in Ciambrone [16], EMAS [17], Huang [15], Hundal [18], Lewis and Gertsakis [19] and Molina et al. [20].*

A.6 Risk assessment

Risk assessment is the process whereby potential failure is quantified. It is used to provide answers to the following questions.

a) What can go wrong within the system manufacturing the product, the product and the impact of the environment in which the product is likely to be used (including misuse)?

b) How likely is the failure to happen?

c) What is likely to be caused by the failure as a consequence?

Risk assessment is partially mathematical in nature and involves both probability and consequences. Designing against risk (uncertainty) is used to avoid or eliminate causes of failure, detect and control failure early and reduce the impact or consequences of failures.

Risk assessment is a fundamental part of FMEA and can be part of QFD.

On completion of a risk assessment the designer should have a better understanding of the likelihood and significance of failure of components or products and be in a position to take, or not take, design actions to ensure that the intended product meets all reasonable requirements in the perceived conditions of use.

NOTE Further information on risk assessment is given in Modarres [21], Smith [22] and Wang [23].

Annex B (informative) Industrial design

B.1 Purpose of industrial design

Industrial design is an aspect of product development whereby style and ergonomic aspects can be designed-in without affecting the basic design so far developed, but which can enhance ease of use and the appearance, thereby improving the saleability of the product and the image of the brand name. If used to their full potential an industrial designer can have a far more influential role in the design process to produce wider benefits for both the product and the business/client.

It gives the product a competitive advantage through:

a) appearance/styling;

b) ergonomics;

c) ease of assembly/disassembly;

d) selection of materials for the application;

e) economic use of materials;

f) balancing investment to likely return;

g) guidance on methods of manufacture including tooling;

h) ease of use.

B.2 Circumstances where an industrial designer is/is not necessary

Most projects that involve a three dimensional product can benefit from an industrial design input. However, it is recognized that there is less scope for an industrial design input on some projects involving heavy industrial or civil plant or some aspects of military equipment, but even so there could still be a need for an ergonomic input.

B.3 When to call in the industrial designer

An industrial designer should be consulted as early as possible in the design process (ideally just after the product design specification has been established) if maximum benefits are to be gained and undue waste and cost minimized.

B.4 Choosing an industrial designer

When choosing an industrial designer the following are essential considerations to be taken into account.

a) A good track record/portfolio.

b) Experience appropriate to the clients/project needs.

c) An ability to establish a good working relationship with other members of the product development team.

d) The choice made from a shortlist of appropriate consultancies.

B.5 The industrial design brief

The design brief is a vital part of the design process and should be as clear and specific as possible, but may be subject to revision during the preliminary stages of the design process. Some of the revisions may result from the designer's involvement. The design brief should encompass more than just the instructions relating to what is expected from the actual design aspect. For maximum benefit to be derived from an industrial design input, the industrial designer should be briefed in the following:

a) the functionality of the product;

b) technical aspects such as environmental, safety and operational requirements;

c) market information (size and where etc.), marketing proposals such as projected sales;

d) budget constraints;

e) proposals and facilities for manufacture;

f) time to market;

g) the main competitors and where in the market they operate;

h) long term plans for the product and its development;

i) packaging requirements;

j) end-of-life disposal;

k) house style and appearance of existing product range.

B.6 Impact of the industrial design consultant

At design office level, consultants quite often meet resentment/opposition to their involvement in a project. It is important for the industrial designer to quickly establish a good working relationship with the product development team through mutual respect and understanding. As the work progresses the value of the designers input and breadth of experience becomes more evident and a firmer, more lasting relationship evolves.

The benefits and hence the greatest impact on the product as a whole come from a design bases on the consultants leadership, experience and the broadness of the design brief.

B.7 Presentation of design work

The importance of a proper presentation by the industrial designer to the client cannot be over-stressed. Only the designer knows the full implications and reasons behind the design as presented and is able to provide an explanation as to why this approach was taken. There might be a number of "what if" questions that arise and need to be discussed and could lead to changes in the design. This is a vital and valuable part of the interactive design process. With the introduction of CAD and internet mailing there is a danger that clients might want to see the designer's work without the full presentation process, this should be resisted. It can and has led to complete mis-understanding of the designer's intentions.

B.8 Evaluation and approval of the design

Evaluation and approval decisions benefit enormously from a good interactive presentation. This enables detailed discussions covering not just the products design in terms of functionality and its complete aesthetic attributes, but also material selection, methods of manufacture, assembly/disassembly, maintenance, packaging requirements, marketing and the products eventual disposal. It can be an iterative process before final approval is reached on the design and sanction for its manufacture to proceed is given.

B.9 Dimensions and tolerances

Unless specific instructions are given in the brief regarding its physical size and layout, the overall size and configuration of the product evolves as the design progresses. Important contributors to its physical dimensions are manufacturing and assembly considerations and material selection. Tolerances should be as open as possible, unnecessarily tight tolerances can significantly increase product costs. They can also limit the choice of materials and manufacturing processes.

B.10 Colour schemes and surface textures

Where there is no existing corporate style, a designer might recommend an appropriate colour scheme. Colour could be used to simply reinforce the general aesthetics of the product, in either a fashion sense or as part of its function. It can also be used to create an apparent image of reduction or increase in size.

Similarly, texture can be used to provide a smooth glossy finish or a matt or rough surface depending on need. Again such surface finish might be for appearance purposes or as part of its function or operational use.

In both these areas the designer is fully acquainted with surface coatings and methods of applying or achieving the desired effect.

B.11 Product graphics and symbols

Product graphics and symbols should be located as close as possible to the product attribute or feature to which they apply and in a manner that avoids ambiguity as to which attribute or feature is depicted. Product graphics and symbols should also be clearly legible to the user. This is particularly important where safety and operational instructions are concerned.

NOTE Basic graphical symbols are covered in BS ISO 7000.

Annex C (informative) Life cycle considerations

C.1 General

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.

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 [24], the Waste Electrical and Electronic Equipment Directive [25], the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations [26] and the End-of-Life Vehicles (Producer Responsibility) Regulations [27].

Some of the recommendations might constrain the application of others, according to particular design features. This requires the judgement of the designer and/or relevant colleagues.

Issues concerning the transport of raw materials, and intermediate and final products, have not been addressed here as the factors involved are beyond the control or influence of the design function.

Whole life costing, where the value of future savings and income provided by a product to the customer is brought forward to today through discounting accounting, often shows that products with features which are more environmentally sound are less expensive.

C.2 Materials and components sourcing

In selecting materials and components the following should be considered.

a) Use materials which are as ubiquitous and abundant as possible.

b) Use materials and components which are as local in origin as possible.

c) 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.

d) 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).

e) 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.

f) Use renewable materials.

g) 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.

h) Reuse fit for purpose components and piece parts.

i) Use 100% reclaimed for reuse materials.

j) Use recycled fit for purpose components and piece parts.

k) Use 100% recycled or part recycled materials.

l) Use recyclable materials which allow optimization of quality, energy, waste and emissions in the recycling process.

m) 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.

n) Use recyclable materials and components for which there is a prospect of collections being established.

o) Avoid pigmented plastics (for easier recycling) where possible.

p) Use chemical additives (including metals) which are environmentally and physiologically benign.

q) Use chemical additives (including metals) which are less environmentally and/or physiologically toxic or polluting than the current additives for the product category.

C.3 Manufacturing processes

In specifying manufacturing processes, the following should be considered.

a) Materials

- Use net shape forming processes.
- Maximize precision of materials processing down to the smallest scale necessary for maximum material economy.
- Maximize capture and reuse of materials arising as waste during process (aim for zero waste residue from process).
- Minimize particulate emissions to air, land and water.
- Avoid materials which are/will be classified as hazardous as waste or at end-of-life.
- Pre-treat any unavoidable hazardous waste to reduce the hazardous nature.

b) Energy

- Consider alternative process technologies which are thermodynamically more efficient.
- Minimize energy input to chosen process.
- Maximize energy efficiency of chosen process.
- Maximize capture and use of waste process energy (both heat and power).

c) Water

- Minimize use of process water.
- Maximize capture and reuse of waste water, cleaned as necessary.

d) Chemicals

- Minimize emissions of toxins and pollutants to air, land and water.
- Avoid chemicals which are/will be classified as hazardous as waste or at end-of-life.

C.4 Product use

With respect to the impact of the product in use, the following should be considered.

a) Minimize energy and water requirements and maximize efficiency in the use of energy and water, other resources and any catalysts.

b) 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.

c) Incorporate sensors and information systems to provide feedback on product performance.

d) Incorporate sensors and information systems to provide feedback on the condition of materials and components.

e) Maximize the potential for upgrading and serviceability of the product.

C.5 Demanufacturing processes

Most materials used in industrial societies require mechanical operations to demanufacture and recycle them. The main environmental issues arising from this are the use of carbon-positive energy and emissions of toxins and pollutants from materials (as well as from combustion of fuel for machinery). The optimum approach to materials recycling involves the transformation of a material up or down in quality to a level suitable for use within a designated new product or class of product, through non-mechanical (microbial, biochemical, benign chemical) or energy efficient and zero carbon mechanical processes. Materials might have been chosen at earlier stages of the design process which enable this approach; otherwise the following checklist enables the energy and emissions impacts of demanufacturing and recycling to be minimized.

a) Materials, piece parts and components
   - Minimize non-biodegradable materials.
   - Use compatible materials (in for example chemical, electrolytic, polymer migration terms).
   - 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.
   - Maximize standardization of component variations.
   - Select materials with similar component life to match design life of assembly.
   - Avoid composite materials employing adhesives.
   - Group harmful materials in separate, accessible modules.
   - Avoid combining ageing and corrosive materials.
   - Minimize number of piece parts, either within the product or sub-assembly as designed, or by redesigning the product or sub-assembly, or by using different manufacturing methods which allow the product or sub-assembly to be made in fewer pieces or in one piece.

b) Joining
   - Minimize the number of fixings and fasteners and standardize the types and sizes.
   - Subject to security and safety considerations, use joining technologies and methods which enable easy separation of components and materials.

c) Coatings/finishing
   - Avoid secondary finishing such as painting, coating or plating.
   - Choose durable materials in preference to protective coatings.

d) Recycling

- Provide convenient access to valuable and reusable parts.
- Provide clear identification of replacement/repair modules.
- Protect sub-assemblies against soiling, corrosion and erosion.
- 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.
- Code or otherwise identify materials, including surface coatings and alloys, to facilitate recycling and audit trails to production data.
- Provide all information to assist recycling in documentation, whether in print or electronically.

NOTE Further information is given in Boothroyd et al. [1], Jovane et al. [3], Nof [2], Otto and Wood [4] and Ulrich and Eppinger [5].

C.6 Costs, savings and income

The design process should take into account all or some of the following costs, savings and income provided by a product to the customer.

a) Manufacturing costs.

b) Planned maintenance/overhaul.

c) Product operation, where the product is owned by the customer and where it is not, but it is the utility of the product which is being supplied.

d) Piece part upgrading, including any potential income from the return of parts to the supplier.

e) Recycling or disposal, including any income from the return of parts to the supplier.

f) Product or piece part replacement as part of ongoing customer relationship.

g) Fiscal benefits attached to the product, such as tax breaks, grants and incentives.

Annex D (informative) Technical product realization – The TPR concept

Having gained practical experience in the application of BS 8888 during the six years since its introduction in 2000, the BSI Technical Committee has also had the opportunity to address some of the misconceptions occasionally expressed by practising designers, engineers and metrologists. One of these, concerns the stage of manufacture at which BS 8888 ought to be implemented. There are, not infrequently, suggestions that since this British Standard gives requirements in a specification, it is the actual manufacturing stage that is most affected by its provisions. This is far from being a true picture.

The process of converting a concept to a correctly functioning product, relies on the cooperation of a sequence of disciplines (specification, manufacture and verification) that need to be coordinated if a viable outcome is to be achieved. The instrument best suited to achieving that coordination is a correctly formatted, unambiguously expressed technical product specification (TPS) and BS 8888 is the British Standard that specifies how that TPS can most effectively be prepared. BS 8888 does not set out to provide instruction on “how to design” but it does seek to provide for the orderly presentation of the output of the design process, in a manner capable of conveying the requirements of the product through the manufacturing and verification processes. A TPS prepared in accordance with BS 8888 therefore also carries briefing for the verification process most appropriate to the functional requirements of the product and can therefore be considered to govern the interface between both design and manufacture, and manufacture and verification.

Whilst it is true that manufacturing activity is strongly influenced by the specification produced in accordance with BS 8888, the only one of the three disciplines not actually referenced in the titles, is “manufacture”. Application of the standard actually impacts upon all the three disciplines of specification, manufacture and verification and the point of primary application is rather more at the interface between the disciplines. It is in an effort to convey this concept that TDW/4 has developed the term “Technical Product Realization (TPR)” defined as “system facilitating cooperation between mechanical engineering disciplines to effect conversion of a concept into correctly functioning workpieces or product, to time, to budget and with minimal rework/reject requirement”. Accordingly, none of BS 8887, BS 8888 or BS 8889 can be a stand-alone document since none tells the whole “story”, Indeed, during the preparation of the first edition of BS 8888 in 2000 it was always the intention that it would be supported by the related TPR aspects of manufacture and verification. Thus, there are three standards concerned with design for manufacture (BS 8887), technical product specification (BS 8888) and technical product verification (BS 8889). These three together can be termed the “TPR Triumvirate”. This British Standard is published for the first time, at the same time as the 2006 (3rd) edition of BS 8888 whilst BS 8889 is still in preparation but is expected to be published by the second quarter of 2007. There is obviously overlap in content between the three standards and this is shown schematically in Figure D.1. Here the three areas of design, manufacture and verification are represented by three circles. However, this is an over-simplification since the three are not of equal size and the overlaps are not the same. For example, it is estimated that there is some 60% overlap between specification and manufacture yet only 30% overlap between specification and verification. However, Figure D.1 merely shows the coverage between the triumvirate whereas their relationships and particularly the influence BS 8888 has on the whole is better shown by Figure D.2.

Figure D.1 **Coverage between the TPR triumvirate standards**

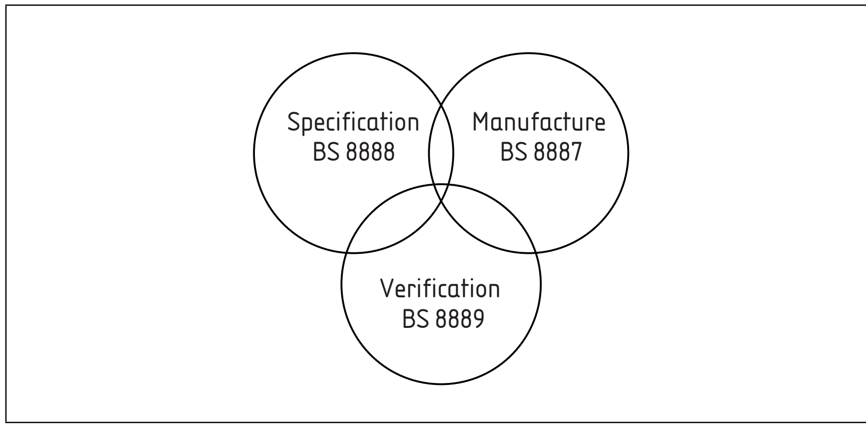
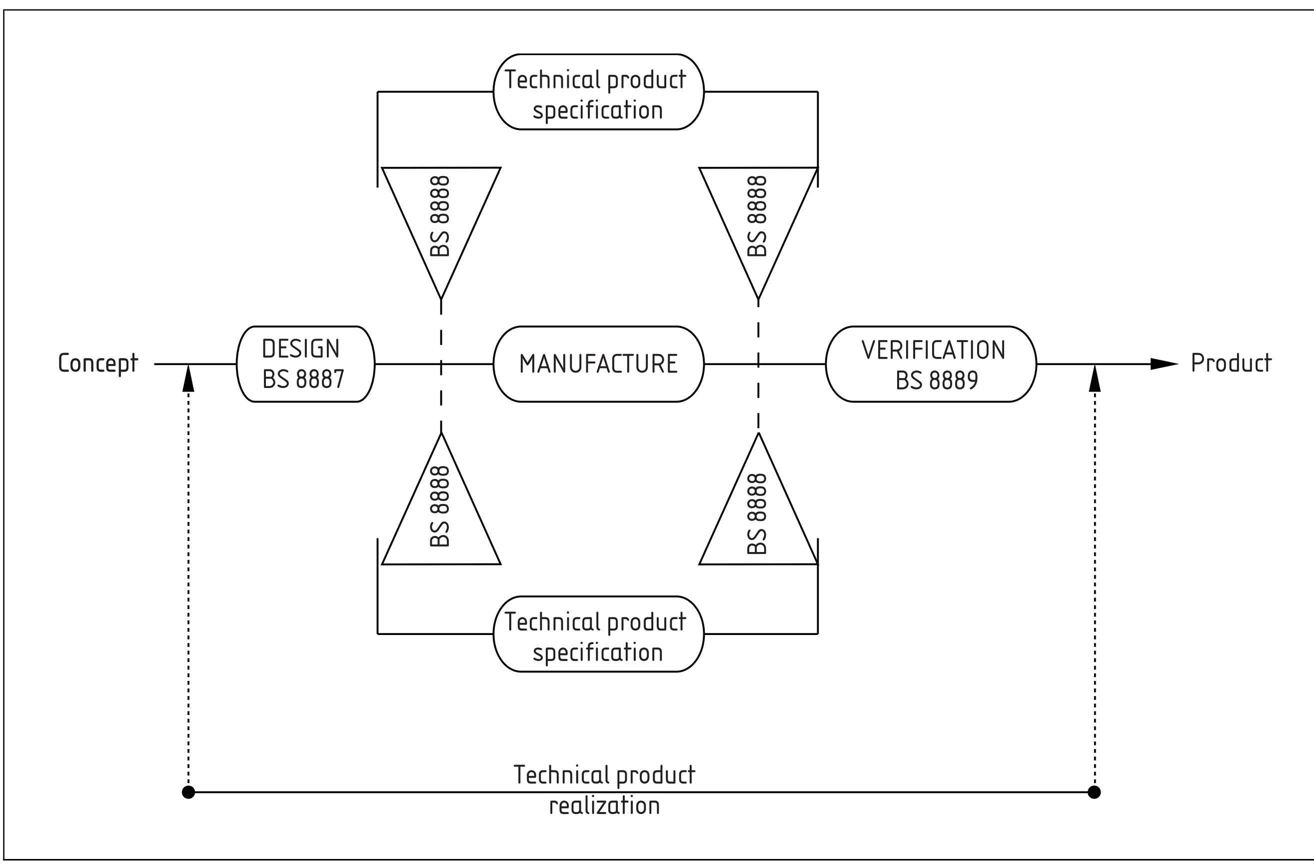


Figure D.2 **The dominant influence of BS 8888 in the relationship between BS 8887, BS 8888 and BS 8889**



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