DESIGN 1ST

Design Process

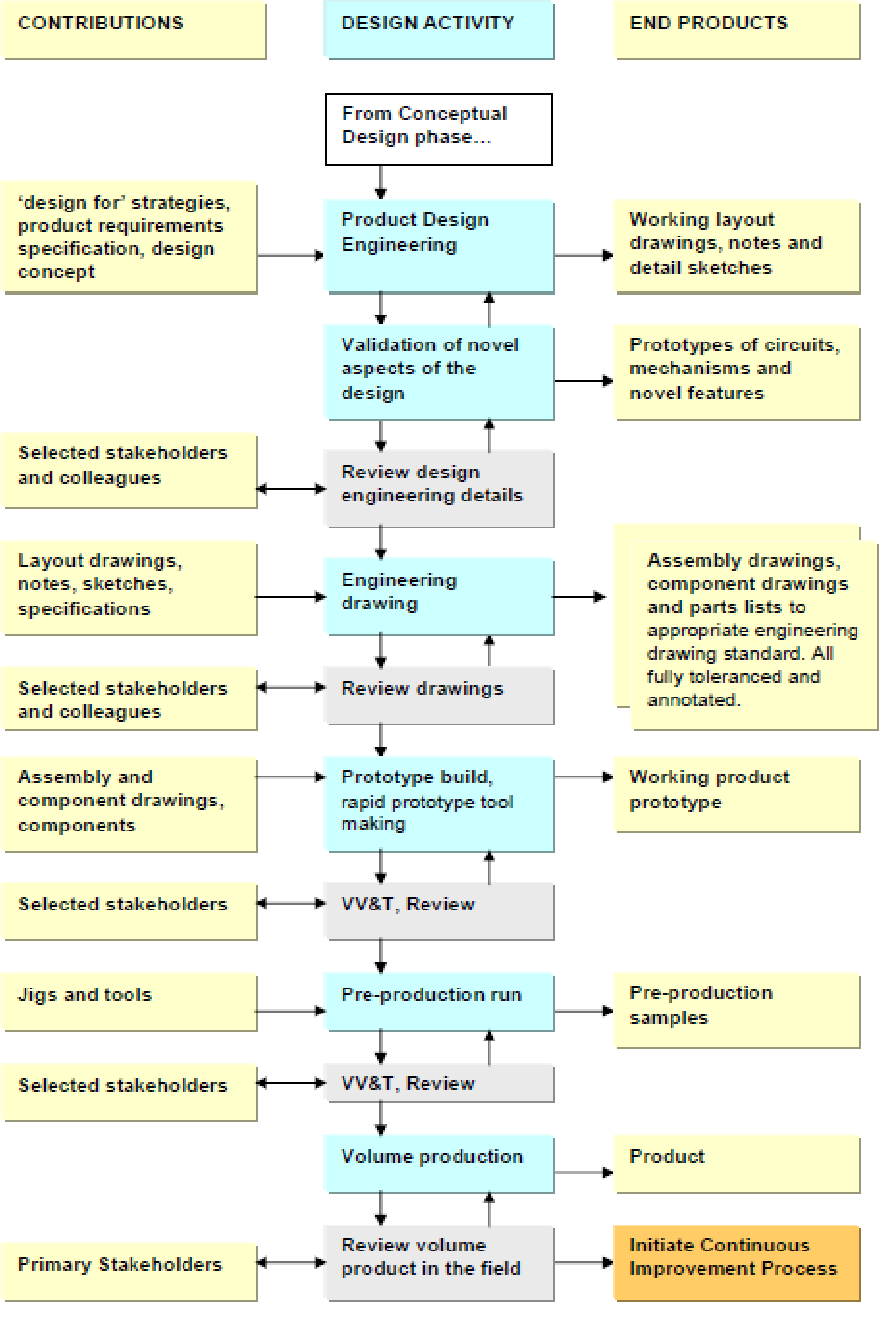
Design Engineering

Author: Andrew Taylor BSc MA FRSA - Art and Engineering in Product Design

Design Process: Design Engineering

- Process flow chart
- Engineering sketches and layout drawings
- Component validation
- Engineering drawing standards
- Prototypes, validation and testing
- Volume production
- Continuous improvement

Design Engineering and Manufacture



Author: Andrew Taylor BSc MA FRSA - [Art and Engineering in Product Design]

Product Design Engineering

With the product concept agreed upon, the process of translating ideas and visual forms into a usable product begins with Product Design Engineering. That is, the critical application of engineering skills to the design concept so as to create a manufacturable product that meets the requirements of the Product Design Specification and addresses the relevant ‘design for’ strategies. Shoddy or unreliable products are invariably the result of lack of thoroughness in Design Engineering.

The usual ‘design for’ strategies are:

- Design for People (Human Factors)
- Design for Quality and Safety (the adoption of appropriate standards).
- Design for minimizing environmental impact
- Design for Product Survivability (‘braving the elements’)
- Design for Manufacture
- Design for Reliability
- Design for Maintainability

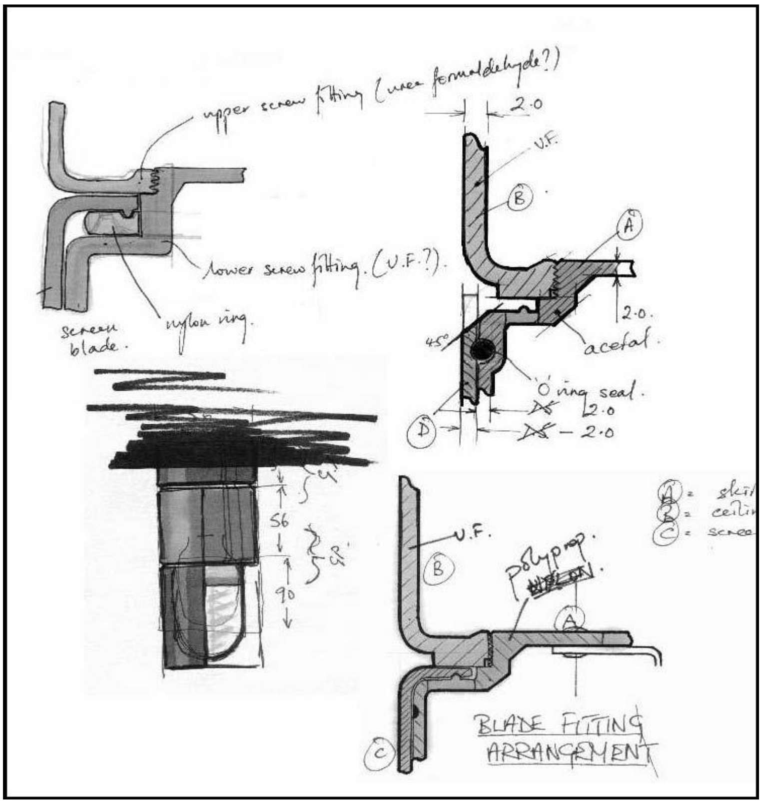
‘Design for’ strategies often contain contradictions, and minor compromises can be expected in almost every product. Professional design engineering calls for effective management of these contradictions and compromises. Note that the principal requirement during this phase is that of product **function**. To reduce the risk of functional failure, it is usual for novel concepts to be prototyped and tested before manufacture. Product concepts having a high level of functionality present a particularly high risk of failure.

For more on ‘design for’ strategies, see the booklet ‘Design Directions’.

The ‘design for’ activity is underpinned by the more traditional engineering skills set, covering electrical/mechanical design, component sourcing, materials selection and materials processing. The most commonly encountered materials and their associated forming processes are described elsewhere in the *design-bites* series. Mechanical and electrical engineering, however, are covered only to the extent that they impact directly on the product designer, there being a wealth of material already published in these areas.

The principal medium for design engineering is the working layout drawing, supplemented by working sketches. A **Working Layout Drawing** is a dimensionally accurate pencil outline drawing (or CAD multi-layer drawing), showing all the product components superimposed in their relative positions, and is used to visualize component relationships in 3D space. Dimensions, notes and drawing formats are absent. Although critical to the design process, the working layout drawing is not used for presentation or manufacture. It serves as the starting point when drafting component drawings, and an early version of the working layout drawing is often used as an underlay when drawing the product GA. This ensures that the necessary components can be fitted within the external envelope of the product and gives confidence that the form described by the GA can be realized in production, although minor editing of the form is to be expected as the design progresses.

Fine details can be explored using **Working sketches**. Sketches like those shown below may be created at any time during the design and drafting process to explore alternatives for engineering detail and assembly. They are not used for manufacture.



Engineering Validation

Novel engineering solutions or untried combinations of components should be validated prior to the start of engineering drawing. The validation will normally involve R&D, software, systems, electrical or mechanical engineering, the design engineer, the validation and test facility, and, with components becoming increasingly process dependent, the production engineer. The activity must be thorough since significant investment will be made on the strength of the technical solution used. It is not uncommon for a novel technical solution to be in development and refinement for several years before being deemed robust enough to be deployed as part of a capital or mass-market product.

Engineering Drawing

Engineering drawings define all physical aspects of the product, removing ambiguity and setting the program of work for manufacture. Engineering Drawings have legal status, and must be produced to the appropriate national or international standards. Most standards bodies offer guidance on engineering drawing standards, usually in the form of manuals, which contain relevant extracts from the drawing standards themselves. Examples include:

(W) ISO Standards Handbook: Technical Drawing, ed 4, 2002.
(US) ANSI Drafting Manual (with references to ASME 14.100, 2004).
(UK) BS 8888: 2004, Technical Product Specification (TPS) with references to all relevant EN and ISO standards. BSI provides convenient access to these referenced standards via 4 kits:

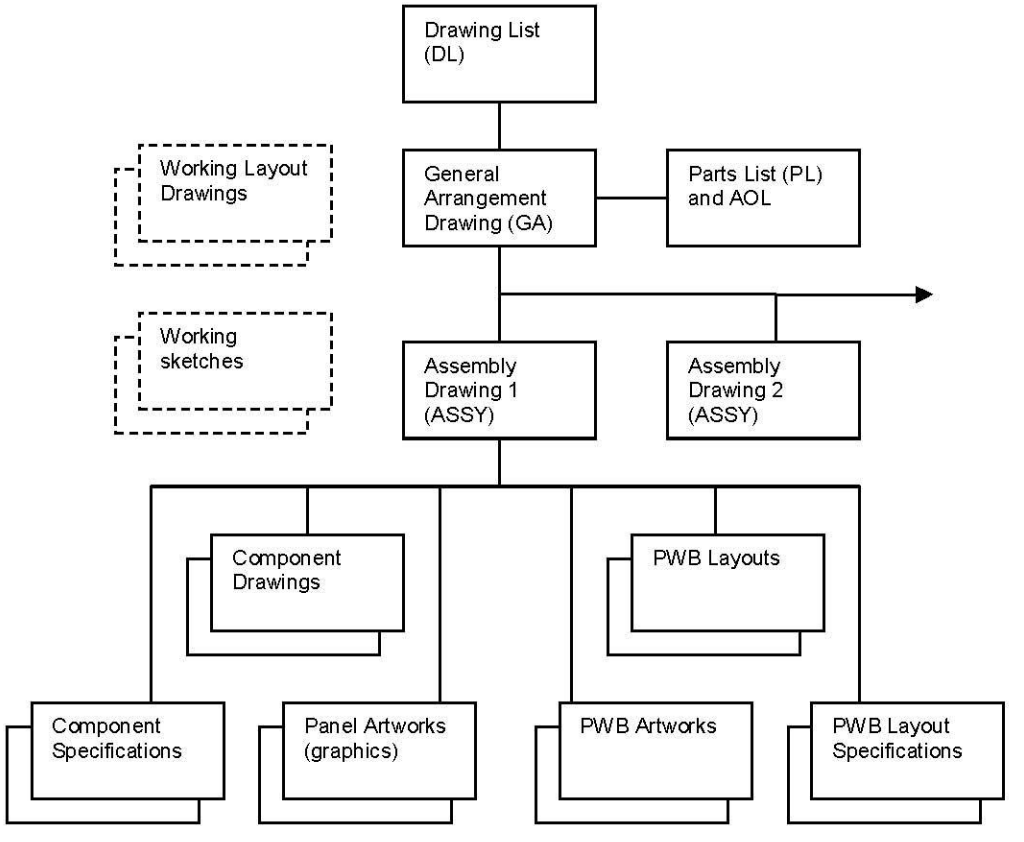
1. General principles kit
2. Tolerancing and dimensioning kit
3. Computer aided engineering kit
4. Design Management kit

The more commonly used drafting-related standards referenced by BS 8888 are:

Standards	Scope
BS 8888: 2004	**Technical Product Specification (TPS)**
BS EN ISO 5457	Drawing sheet sizes
BS ISO 128	Technical drawings -Lines
BS EN ISO 3098	Technical product documentation -Lettering
BS EN ISO 7200	Title blocks
BS EN ISO 6433, BS ISO 7573	Item references and parts lists
BS EN ISO 5455	Technical drawings: scales
BS ISO 129, BS ISO 10578, BS ISO 10579	Technical drawings -Dimensioning
BS ISO 406	Technical drawings -Tolerancing
BS EN ISO 14660	Geometrical Product Specifications (GPS) – geometrical features
BS ISO 1101, BS ISO 5459, BS ISO 2692	Geometric tolerancing, and maximum metal principle
BS EN 22768, ISO 2768	Linear and geometric tolerances (default values)
BS EN ISO 1302	Indication of surface textures
BS EN 22553	Welding, brazing, and soldering symbols
BS EN ISO 2162	Technical product documentation -springs
BS EN ISO 2203	Technical drawings – gears
BS EN ISO 8826	Technical drawings – roller bearings
BS EN ISO 6413	Technical drawings – splines and serrations
BS EN ISO 9222	Technical drawings – seals
BS EN ISO 5845-1	Simplified representation of fasteners
ISO 286, BS EN 20286	Limits and fits (holes and shafts)

A typical set of engineering drawing documents for the manufacture of a complex product might be arranged as follows:

The **Drawing List** identifies all the documents appearing in the engineering drawing package (including itself), irrespective of storage medium, and is effectively the index of all drawings required to make the product. The **Parts List** identifies every piece of hardware in the product, down to the last nut and bolt. On complex products, each assembly drawing has an associated parts list. Long-lead items may be identified on an Advance Order List (AOL), which is used by the purchasing department and identifies those items in the parts list having unusually long delivery times.



The **General Arrangement (GA) Drawing** is the 'top level' true drawing of the set, showing the fully assembled and finished product (*see earlier paragraph on General Arrangement Drawings*). An **Assembly Drawing** is a drawing showing how parts are brought together to create an assembly or 'module', and shows manufactured components, off-the-shelf components, fasteners, electrical components and wiring etc. Large and complicated assemblies may contain sub-assemblies, although the naming convention for drawings makes no distinction between an assembly and a sub-assembly – both drawings are described as assembly drawings. Every component shown on the assembly drawing must have an identified component manufacturing drawing, be identified as a particular stock item (a screw for example), or, in the case of an uncommon off-the-shelf item, have an associated specification sheet. In the above diagram, components below each assembly drawing have been arranged into two groups, namely PWBs (electronic printed wiring boards) and general mechanical or structural components. **Component Drawings** are fully dimensioned and toleranced manufacturing drawings, showing materials, processes, form, dimensions and finishes. Where an off-the-shelf component is to be used, and where performance of this component is critical, for example in military or aerospace products, a Source Control Drawing is sometimes created, which forms part of a binding contract with the supplier and prevents unannounced changes being made to the delivered component. **Component Specifications** are usually data sheets or drawings carrying the important dimensional and performance details of off-the-shelf components such as electronic components, cabinets, motors or displays. **Artworks** are large scale, precise, graphic design masters used to create either panel graphics (printed logos, panel legend, labels or rating plates) or PWB (printed wiring board) track layouts.

Metric drawing sheet sizes are given in the Miscellaneous Design Data section.

Prototype Build

With all components and novel technical solutions validated, and the first draft engineering drawings completed, proving of the product concept continues with the Prototype Build, where one or two fully working products are constructed by hand. Since hand fabrication cannot faithfully recreate the appearance or physical properties of volume manufactured parts, the degree of realism required in each part, and the specific tests to be undertaken, must be established before prototype build begins.

Vacuum formed components can be produced using wooden formers (rather than the aluminum preferred for volume production), as can hand lay-up GRP parts. Deep drawn parts may have to be fabricated from smaller components. In some situations it may be wise to adopt the same fixing method as is required on the final product, especially where the fixing method is 'mission-critical', for example in adhesive bonded structural components for aircraft and racing car bodies. The process of prototyping electronic circuits is known as bread-boarding.

Component form and material	Possible approaches to prototyping	Issues
Off-the-shelf electrical parts	Use real examples	Ensure operating environment is appropriate. Cooling, physical mounting, power supply, RFI screening.
Off-the-shelf mechanical parts	Use real examples	Ensure operating environment is appropriate. Location and strength of mounting points, lubrication, sealing.
Fasteners	Use real examples when appropriate	Real fasteners will not give a representative performance unless the materials to be fastened match those to be used in the real product.
Machined solid metal	Machine from solid	
Cast solid metal	Cast, machine from solid metal, or simulate with plastic.	Sand casting and investment casting offer low cost routes. Die castings may be produced in low-cost aluminum or epoxy tools (with the lower melting point die casting alloys).
Sheet metal fabrications	Fabricate by hand	
Pressed or deep drawn sheet metal	Use super-plastic aluminum vac form, or welded / bonded fabrication	Deep drawn parts are difficult to simulate other than by using the real thing. Make allowance for the expected difference in performance when testing.
Plastic shells	Fabricate, vac-form, use stereo-lithography, NC machining, or low-cost injection molding methods.	Fabrication, stereo-lithography and NC machining are suitable where no specific thermal or mechanical properties need to be modeled. If more structural realism is required, adopt a low cost (aluminum or epoxy) tooling approach. The strength of fastening and mounting points may not be representative of the final form.
Cast or molded plastic solids	Cast in rubber or epoxy mould, use stereo-lithography, machine from solid, or use low-cost injection molding methods.	
Molded elastomers.	Use low-cost tooling with either the real elastomer or a thermoset urethane.	Depending upon application, the specific grade of elastomer used may be critical to performance.

The prototype payphone (right) is a hand lay-up GRP fabrication, fixed to an angle-section steel frame. The finish is spatter-textured gray gel coat. Loudspeaker grilles are black epoxy coated perforated mild steel. Pushbuttons are modified standard phone buttons, running in machined nylon guides, and fixed to a steel fascia plate which also supports the circuit board. The fascia graphics layer and the back panel labels are screen-printed self-adhesive PVC. Microphones, loudspeakers, displays, back-lights, status display, keypad, and card reader mechanism are all fully functional, and the instrument has been installed in a standard payphone booth.

Verification, Validation and Testing (VV&T)

Product testing often comes under the rather grand title ‘Verification, Validation and Testing’, or ‘VV&T’. Large companies may have in-house test facilities, but there are numerous independent test houses available to smaller companies on a sub-contract basis. Representatives from VV&T should have been given a watching brief from project inception. Now is the time for them to step forward. The VV&T team will:

- Take receipt of the prototypes.
- Gather relevant specifications and standards.
- Validate the standards (and versions) as being current.
- Validate the Product Design Specification and any engineering specifications.
- Verify that the proposed design meets the specifications in principle.
- Design a Test Specification, listing aspects to be tested and test criteria.
- Create a Test Schedule.
- Execute the tests.
- Document and report the test results.

Note that some aspects of the product may not be testable at prototype stage. If some parts of the prototype are fabricated rather than injection molded, or screwed rather than welded, then performing a drop test (impact test) on the prototype will not yield representative results. The drop test should be rescheduled to take place at preproduction stage. Your responsibility as a product designer is to respond to any concerns raised by the VV&T team and to revise any aspect of the design linked to product failure, before re-submitting the revised prototype for testing. The engineering drawings must be updated to reflect any revision. You should also support the VV&T team by firming up on any subjective areas of the design, and ensuring that these are fully described on the appropriate engineering drawings.

See also accelerated life testing under Design for Reliability.

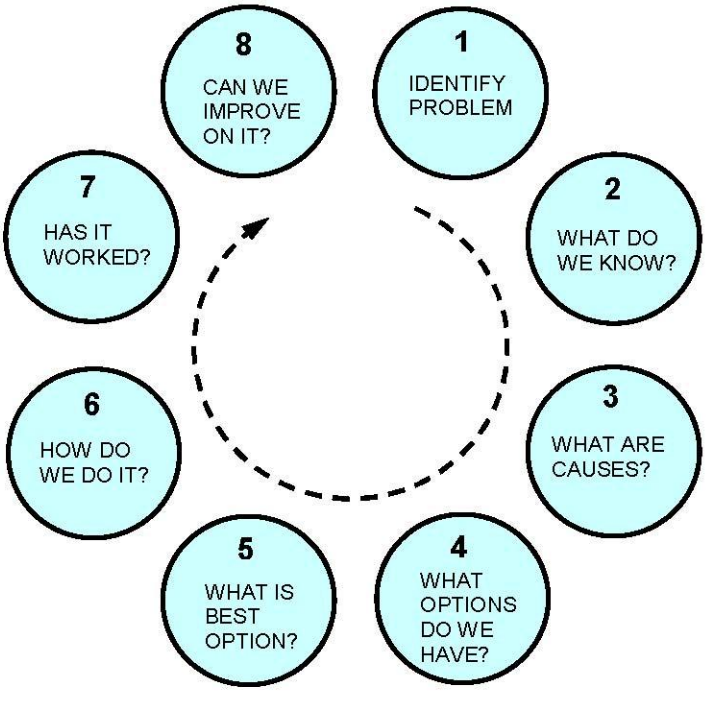
Pre-Production

The pre-production phase involves the creation of production schedules, the purchase of components and raw materials in suitable volume, the creation of jigs, fixtures and full specification hardened mold tools and press tools, and the establishment of assembly and finishing processes. A small batch of the product (say 20 examples) is run off using all the processes appropriate to volume production, and the resulting pre-production products are submitted to VV&T for test. This is the last chance to resolve any problems with the product or process before volume manufacture begins. Since an increasing number of products are dependent on tight control of the production process for their function, physical integrity and 'look & feel', designers should take a keen interest in both objective and subjective qualities of the preproduction samples, working closely with both production engineering and VV&T, and ensuring that any revisions are reflected in the drawings.

Volume Production

With the pre-production product samples tested, and any adjustments made to the product design or manufacturing processes, the design is 'frozen' and volume production can begin. It is usual to pay particular attention to the first batch of products emerging from the production line to ensure that the adjustments made during pre-production are having the desired effect on product quality. It is also valuable to take periodic samples from the line to ensure that the quality is holding up.

Continuous Improvement



Establishing a process of continuous improvement ('Kaizen' in Japan) brings benefits in terms of product quality and technical expertise. A company engaged in continuous improvement is always ahead of the game. A basic model for continuous improvement is shown above.

A vital though oft neglected aspect of continuous improvement is the gathering of product failure data from the field. Early product failures suggest a design or process problem and require immediate attention. There have been cases where prominent 'household name' manufacturers have been unwilling to fix problems appearing in early production examples because of the 'high cost of stopping the production line', with the result that shoddy product continued to be sent to market. It may seem obvious, but the buyers of such products did not buy the same brand again. Eventually these manufacturers were either taken over by more competent management, or went out of business.

For more on identifying early failures see Design for Reliability.

Developing a design concept through to production takes time. An all-too-common expectation among marketing functions in the West is that a consumer product should go from concept to volume production within one year, and designers frequently find themselves under pressure to meet such expectation. A look at the products coming from successful companies in both East and West shows the wisdom of investing more time in the design engineering phase, rather than rushing a product to market and bearing the high costs of remedial action.

LINKS and RESOURCES

Further information on engineering drawing and engineering standards can be found at:

(UK) http://www.roymech.co.uk/Useful_Tables/Drawing/Drawing.html which contains links to a wealth of relevant material and links. (US) The Drafting Zone: www.draftingzone.com (US) ADDA (American Design Drafting Association): www.adda.org

Engineering Design Methods, Nigel Cross, Wiley, 1989. Product Design & Development, Ulrich and Eppinger, McGraw-Hill / Irwin, 2003.

BS 7000: Guide to Managing Product Design.

Also see the section Generic Design Resources.

For General Design Tips and Resources, visit:

http://www.design1st.com/Design-Resource-Library/design-resource-center.html

Author: Andrew Taylor BSc MA FRSA - Art and Engineering in Product Design