

The Design Process

Man-made physical objects all come into existence through the creative application of technology. The creative process of engineering, turns abstract ideas into physical representations; be them products or systems. These products or systems have been produced to meet specific human needs.

Engineering Design

Generally, engineering designs can be considered as inventions, i.e. devices or systems that are created by human ingenuity and did not exist previously, or are improvements over existing devices or systems. Inventions, or designs, are the result of bringing together technologies to meet human needs or to solve problems. Design activity occurs over a period of time and requires an incremental (step-by-step) methodology.

It should be noted that design problems are usually more vaguely defined than analysis problems. Analysis problems have only one answer, whereas the solution to a design problem is a system having specified properties, i.e. the ability to meet a specific need; there may be many possible devices to meet the need.

Solving a design problem is usually an iterative process; as the solution to a design problem evolves, there may be continual refinement of the design. It may be the case that while implementing the solution to a design problem, the solution developed is found to be unsafe, too expensive, or will not work. Hence, design activity is cyclic or iterative in nature, whereas analysis problem solving is primarily sequential.

In order to solve a design problem effectively and efficiently, this requires a methodology or process. There are many recognised processes for design, but generally, they follow the application of a step-by-step problem-solving methodology involved in the design process.

The Design Process / Methodology

Design processes or methodologies are created to form a strategy to enable the design of technical systems. They describe plans of action to be linked into working steps and design phases formulated to achieve goals and to solve design problems. A typical example of these phases would begin with understanding and defining the customer needs. This would be formulated into a design specification of user requirements, along with any design constraints such as the cost of the end product or of a manufacturing process that has to be used. The design specification (or Product Design Specification, PDS) would be used to create a concept design. If the concept design is acceptable then detail drawings and instructions for manufacture are completed before the product is made.

There are numerous descriptive theories and models that have been developed to understand, describe and prescribe how the design process should be carried out. Many of which are procedural. The core sequential phases are mainly aimed at defining and understanding the customer needs and creating an abstract concept to suit these needs. This is in turn refined into detailed drawings and instructions for manufacture.

Below is a table that summarises three of these models;

Author	Strengths	Limitations
Pahl and Beitz (1996)	Procedural approach, with emphasis on concept design stage. Plan for functional involvement of humans before concept design stage.	Evaluation of human interaction with product was after concept design phase, which could prove costly and time consuming if re-design was required at this later stage.
British Standard BS7000 Part2 (2015)	Procedural approach based on Pahl and Beitz (1996). Stated that ergonomics was a performance necessity of a product.	No prescription of how ergonomics could be integrated into the design process.
French (1985)	Procedural approach focused on conceptual design.	No mention of analysing, designing or evaluating product for human user.

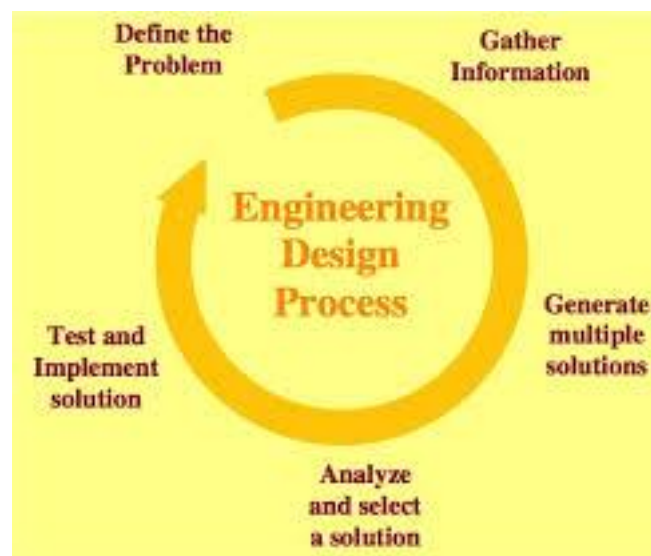
These three design models mentioned above are just a few of the proposed design models available to us. Others include; March (1984), Hubka et al (1988), Pugh (1990), Hales (1993), Andreasen and Hein (1987), and Keates and Clarkson (2001).

Essentially, there is a basic five-step process usually used in problem-solving, which works equally well for design problems. As mentioned previously, since design problems are usually defined more vaguely and have numerous correct answers, the process may require 'back-tracking' and iteration. These five general steps used for solving design problems are:

1. Define the problem
2. Gather relevant information
3. Generate multiple solutions
4. Analyse and select an appropriate solution
5. Test and implement the chosen solution

The first step in the design process is the process definition. The definition usually contains a listing of the product or customer requirements / needs, and specifically information regarding product functions and features among other things. Secondly, pertinent information for the design of the product and its functional specifications is obtained. A survey concerning the availability of similar products in the market should be undertaken at this stage. Once the details of the design are clearly established, the design team with inputs from test, manufacturing, and marketing teams generates multiple alternatives (concept designs) to achieve the goals and requirements of the design. Considering cost, safety and other criteria for selection, the more promising concept designs are selected for further analysis. The detail design and analysis step enables a complete study of the solutions and results in the final design concept that best fits the product requirements. Following this step, a prototype of the design is fabricated and functional tests are carried out to verify and possibly modify the design.

When solving a design problem, it may be necessary at any point in the process to go back to a previous step. The solution chosen may prove unworkable for a variety of reasons and may require redefining of the problem, gathering more information, or developing different solutions. This continuous iterative process is represented in the following figure.



Although the brief descriptions of the activities within each step given above may give the impression that the steps are sequential and independent from each other, the iterative nature of the application of the process should be kept in mind.

1. Define the Problem

The solution to a design problem should begin with a clear, unambiguous definition of the problem. This definition may evolve through a series of steps or processes as a more complete understanding of the problem is developed.

Identify and Establish the Need

Engineering design activity usually occurs in response to a human need. Before a design problem definition statement can be developed, the design team must recognise the need for a new product, system, or machine. Although engineers are generally involved in defining the problem, they may not be the ones who initially recognise the need.

Ultimately, consumers establish a need, because they will purchase and use a product that they perceive as meeting a need for comfort, health, leisure, transportation, shelter, etc.

Develop a Problem Statement

The first step in the problem-solving process, therefore, is to formulate the problem in clear and unambiguous terms. Be aware that defining the problem is not the same as recognising a need. The problem definition statement results from first identifying a need however.

Once a need has been established, engineers define that need in terms of an engineering design problem statement. To reach a clear definition, they must collect data, perform experiments, and undertake computations that allow that need to be expressed as part of an engineering problem-solving process.

An important consideration is that the problem statement should specifically address the real need, yet be broad enough not to preclude certain possible solutions. A broad definition of the problem allows a wide range of alternative solutions, before the focus on a specific solution / concept, hence, the problem statement should be concise and flexible enough to allow for creative solutions.

Establish Criteria for Success

Criteria for success are the specifications that a design solution must achieve or the attributes it must possess to be considered successful. The design team should include criteria in the problem statement to provide guidance and direction towards the solution. At this stage in the design process, the criteria are preliminary. As the design solution develops, it is usually found that the initial criteria need to be redefined or modified. If the preliminary criteria are too specific, they may not allow flexibility through the design process.

The criteria that apply to a particular design problem are based on previous knowledge and the research that has been conducted. The list of criteria should be developed by the design team, which is made up of people from various engineering disciplines that have expertise

relevant to the problem, and also people from backgrounds other than engineering, such as managers, scientists, marketing, and manufacturing personnel. The design team must evaluate each criterion and decide if it is applicable to the design effort. Later in the design process, value judgements must be applied to the list of criteria, hence, it is not good practise to include those criteria that will be of relatively low priority in the evaluation of design solutions.

The following is a short list of preliminary criteria for a design problem, that will be included in the problem definition statement.

- The design must be low cost.
- The design should be safe, particularly with young children.
- The design should not be detrimental to the environment.
- The design should be aesthetically pleasing.
- The design should be simple to operate, with minimum human effort.
- The design must be disposable.

2. Gather relevant information

Before the team can proceed in the design process, it is necessary to collect all information that relates to the problem. Gathering relevant information can reveal facts about the problem that could necessitate in a redefinition of the problem. Information gathering for most design problems begins with asking the following questions. If the problem address a need that is new, then there are no existing solutions to the problem, so obviously some of the questions will not be asked.

- Is the problem real and its statement accurate?
- Is there really a need for a new solution or has the problem already been solved?
- What are the existing solutions to the problem?
- What is wrong with the way the problem is currently being solved?
- What is right with the way the problem is currently being solved?
- What companies manufacture the existing solution to the problem?
- What are the economic factors governing the solution?
- How much will customers pay for a solution to the problem?
- What other factors are important to the problem solution (such as safety, aesthetics & environmental issues)?

Search for Information Resources

Traditional publications are still an essential source of information to engineers and scientists. However, electronic information transfer and retrieval has now become a standard source for information searching. The design team will not limit themselves to a few sources of information, but will be prepared to seek whatever source of information that is relevant to a design problem.

Some common resources available are:

- Scientific encyclopaedias and technical handbooks
- Electronic catalogues, as found in reference libraries
- Indexes which categorise current works / publications in various disciplines
- The Internet

3. Generate multiple solutions

The next step in the design process begins with creativity in generating new ideas that may solve the problem. Start with existing solutions to the problem and deconstruct them – find out what’s wrong with those solutions and focus on how to improve their weaknesses / limitations. Consciously combine new ideas, tools, and methods to produce a completely unique and novel solution to the problem; this process is often called ‘synthesis’.

Solutions to engineering design problems do not magically appear. Ideas are generated when design teams are free to take risks and make some mistakes in the process.

Brainstorming at this stage is often a team effort in which people from different disciplines are involved in generating multiple solutions to the problem.

4. Analyse and select an appropriate solution

Once the design team have conceived alternative solutions to the design problem, they must analyse those solutions and decide upon which solution is best suited for implementation. Analysis is the evaluation stage of the proposed designs. At this stage in the design process, it concerns the results of the design analysis, and is highly subjective, hence should be made by a team of experienced people.

Analysis of design solutions

Before deciding which design solution concept to implement, there is a need to analyse each alternative solution against the selection criteria defined in step 1, and several types of analysis should be performed on each design. The following is a list of analysis that may be considered; bear in mind that the significance of each varies depending on the nature of the problem and the solution.

- Functional analysis
- Industrial design / ergonomics
- Mechanical / strength analysis
- Electrical / electromagnetic
- Manufacturability / testability
- Product safety & reliability
- Economic and market analysis
- Regulations & standards

Functional analysis

Determines whether the given solution will function in the way it should, and is fundamental to the evaluation and success of all designs. A design solution that does not function properly is a failure even if it meets all other criteria.

Ergonomics

This is the human factor in engineering. It is the study of how people interact with machines. People occupy a space in or around the design, and they may provide a source of power or control or act as a sensor for the design. A design solution can be considered successful if the design fits the people using it; e.g. the handle of a power tool must fit the hand of everyone using it. The tool must not be too heavy or cumbersome to be manipulated by all sizes of people using the tool. The geometric properties of people – their weight, height, reach, circumference, etc., are called anthropometric data. Anthropometric data are used by design engineers to ensure that their design fits the user, and a good design will be adjustable enough to fit 95% of the people who will use it.

Product safety and Liability

To assure that the use of the design does not cause injury to humans, but can also extend beyond, to include property damage and environmental damage from the use of the design. Engineers must also consider the issue of safety in design because of liability arising from the use of an unsafe product. The only way to ensure that a design will not cause injury or losses to design safety into the product. Inherent safety is impossible to design into some products, such as rotating machinery and vehicles, so designs should include adequate protection for users of the product.

To protect themselves in a product liability case, engineers must use current design procedures during the design process. They must keep records of all calculations and methods employed in the design process. The designer must also appreciate other ways that people could use / misuse the product.

Economic and Market Analysis

The purpose of most engineering designs is to produce a product that generates a profit for the company. Each alternative design must be evaluated against criteria such as; sales features, potential market, cost of manufacturing, advertising, etc. Many good ideas never get into production because the manufacturing costs exceed what people will pay for the product.

Mechanical / Strength Analysis

Engineering analysis of preliminary designs often include the analysis of its mechanical features. It should also determine the effect of shocks and repetitive or dynamic loading over the life of the product, and many systems generate heat, so the design should account for this when used in normal operation.

The Decision Process

After analysing the alternative solutions, a decision must be made as to which solution is deemed the best. In order to evaluate each solution objectively against the stated design criteria or requirements, a quantitative basis for judging and evaluating each design alternative is needed. One commonly used method to formalise the decision-making process is a decision matrix; a mathematical tool used to derive a number that specifies and justifies the best decision. It is essentially a means of ranking desirable attributes or criteria for the design solution. A rating factor may also be used to represent how well a solution satisfies a given criterion, in comparison to the alternatives. Computer models and prototypes can also yield valuable information to assist in the decision phase.

5. Test and Implement the solution

This is the final phase of the design process, and refers to testing, construction, and manufacturing of the chosen solution to the design problem. The design team should consider several methods of implementation, such as prototyping and concurrent engineering, together with distinct activities that occur during implementation; e.g. documenting the design solution and applying for patents.

Prototyping

First stage of testing and implementation, and involves building a prototype of the product – the first fully operational production of the complete design solution. A prototype is not fully tested and may not fully work or operate as intended, but its purpose is to test the design solution under real conditions.

Concurrent Engineering

Most traditional design methods are primarily serial or sequential; each step in the process is completed in a particular order or sequence only after the previous steps have been completed. Concurrent engineering has the ability to implement parallel design and analysis in which safety, manufacturability, serviceability, marketability, and regulatory compliance are all considered early on and during the process. Concurrent engineering is possible through the application of modern Computer Aided Engineering (CAE) tools and manufacturing software. Rapid prototyping proves highly beneficial for concurrent engineering, meaning also that the entire design cycle therefore becomes almost paperless. Since design is an iterative process, concurrent engineering significantly shortens the time between iterations, and therefore, a product can reach market much quicker, at a lower cost, and with a higher quality.

Documentation

This is a very important aspect of design, and necessitates clear communications of the solutions so that a third party can understand what has been created; usually consisting of a design or technical report. Some people reading the documentation may not have the technical abilities of the design team, hence the communication of the design must be obvious, clear and unambiguous.

Applying for Patents

For the development of an original and novel solution, part of the implementation phase may include applying for a patent covering the design solution / invention. It will not necessarily protect against someone else copying the design, but it should give specific rights to manufacture and sell the design for a prescribed period. Patent applications are overseen by a Government organisation, and generally involve employing specialist patent lawyers to ensure a robust and successful application.