DESIGN & ENGINEERING

MODULE-2

Design process- Different stages in design and their significance; Defining the design space; Analogies and "thinking outside of the box"; Quality function deployment-meeting what the customer wants; Evaluation and choosing of a design.
Design Communication; Realization of the concept into a configuration, drawing and model. Concept of "Complex is Simple". Design for function and strength. Design detailing- Material selection, Design visualisation- Solid modelling; Detailed 2D drawings; Tolerancing; Use of standard items in design; Research needs in design; Energy needs of the design, both in its realization and in the applications.
An exercise in the detailed design of two products (Stapler/ door/clock)

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Introduction

Most engineering designs can be classified as inventions-devices or systems that are created by human effort and did not exist before or are improvements over existing devices or systems. Inventions, or designs, do not suddenly appear from nowhere. They are the result of bringing together technologies to meet human needs or to solve problems. Sometimes a design is the result of someone trying to do a task more quickly or efficiently. Design activity occurs over a period of time and requires a step-by-step methodology.

We described engineers primarily as problem solvers. What distinguishes design from other types of problem solving is the nature of both the problem and the solution. Design problems are open ended in nature, which means they have more than one correct solution. The result or solution to a design problem is a system that possesses specified properties.

Design problems are usually more vaguely defined than analysis problems. Suppose that you are asked to determine the maximum height of a snowball given an initial velocity and release height. This is an analysis problem because it has only one answer. If you change the problem statement to read, "Design a device to launch a 1-pound snowball to a height of at least 160 feet," this analysis problem becomes a design problem. The solution to the design problem is a system having specified properties (able to launch a snowball 160 feet), whereas the solution to the analysis problem consisted of the properties of a given system (the height of the snowball). The solution to a design problem is therefore open ended, since there are many possible devices that can launch a Snow ball to a given height. The original problem had a single solution: the maximum height of the snowball, determined from the specified initial conditions.

Solving design problems is often an iterative process:

As the solution to a design problem evolves, you find yourself continually refining the design. While implementing the solution to a design problem, you may discover that the solution you've developed is unsafe, too expensive, or will not work. You then "go back to the drawing board" and modify the solution until it meets your requirements. For example, the Wright brothers' airplane did not fly perfectly the first time. They began a program for building an airplane by first conducting tests with kites and then gliders. Before attempting powered flight, they solved the essential problems of controlling a plane's motion in rising, descending, and turning. They didn't construct a powered plane until after making more than 700 successful glider flights. Design activity is therefore cyclic or iterative in nature, whereas analysis problem solving is primarily sequential.

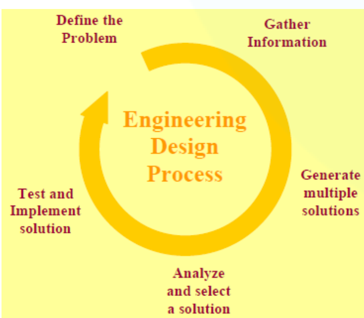
The solution to a design problem does not suddenly appear in a vacuum. A good solution requires a methodology or process. There are probably as many processes of design as there are engineers. Therefore, this lesson does not present a rigid "cookbook" approach to design but presents a general application of the five-step problem-solving methodology associated with the design process. The process described here is general, and you can adapt it to the particular problem you are trying to solve.

THE DESIGN PROCESS

The basic five-step process usually used in a problem-solving works for design problems as well. Since design problems are usually defined more vaguely and have a multitude of correct answers, the process may require backtracking and iteration. Solving a design problem is a contingent process and the solution is subject to unforeseen complications and changes as it develops. Until the Wright brothers actually built and tested their early gliders, they did not know the problems and difficulties they would face controlling a powered plane.
The five steps used for solving design problems are:
1. Define the problem
2. Generate concepts and gather pertinent information
3. Develop the solutions
4. Construct and test prototype
5. Evaluate and implement the solution
6. Present the solution

1. Define Problem

The first step in the design process is the problem definition. This definition usually contains a listing of the product or customer requirements and specially information about product functions and features among other things. In the next step, relevant information for the design of the product and its functional specifications is obtained. A survey regarding the availability of similar products in the market should be performed at this stage. Once the details of the design are clearly identified, the design team with inputs from test, manufacturing, and marketing teams generates multiple alternatives to achieve the goals and the requirements of the design. Considering cost, safety, and other criteria for selection, the more promising alternatives are selected for further analysis.
Detail design and analysis step enables a complete study of the solutions and result in identification of the final design that best fits the product requirements. Following this step, a prototype of the design is constructed and functional tests are performed to verify and possibly modify the design. When solving a design problem, you may find at any point in the process that you need to go back to a previous step. The solution you chose may prove unworkable for any number of reasons and may require redefining the problem, collecting more information, or generating different solutions. This continuous iterative process is represented in the Figure.



This document intends to clarify some of the details involved in implementing the design process. Therefore a description of the details involved in each step of the design process is listed below. Although the descriptions of the activities within each step 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 throughout the document.

You need to begin the solution to a design problem with a clear, unambiguous definition of the problem. Unlike an analysis problem, a design problem often begins as a vague, abstract idea in the mind of the designer. Creating a clear definition of a design problem is more difficult than, defining an analysis problem. The definition of a design problem may evolve through a series of steps or processes as you develop a more complete understanding of the problem. Identify and Establish the Need Engineering design activity always occurs in response to a human need. Before you can develop a problem definition statement for a design problem, you need to recognize the need for a new product, system, or machine. Thomas Newcomen saw the need for a machine to pump the water from the bottom of coal mines in England. Recognizing this human need provided him the stimulus for designing the first steam engine in 1712. Before engineers can clearly define a design problem, they must see and understand this need.

Although engineers are generally involved in defining the problem, they may not be the ones who initially recognize the need. In private industry, market forces generally establish the need for a new design. A company's survival depends on producing a product that people will buy and can be manufactured and sold at a profit. Ultimately, consumers establish a need, because they will purchase and use a product that they perceive as meeting a need for comfort, health, recreation, transportation, shelter, and so on. Likewise, the citizens of a government decide whether they need safe drinking water, roads and highways, libraries, schools, fire protection, and so on. The perceived need, however, may not be the real need. Before you delve into the details of producing a solution, you need to make sure you have enough information to generate a clear, unambiguous problem definition that addresses the real need. The following example illustrates the importance of understanding the need before attempting a solution.

Example: Automobile Airbag Inflation - How Not to Solve a Problem

A company that manufactures automobile airbags has a problem with an unacceptably high rate of failure in the inflation of the bag. During testing, 10 percent of the bags do not fully inflate. An engineer is assigned the job of solving the problem. At first the engineer defines the problem as a failure in the materials and construction of the inflation device. The engineer begins to solve this problem by producing a more robust inflation device. After considerable effort, the engineer discovers that improving the inflation device does not change the failure rate in the bags. Eventually, this engineer re-examines the initial definition of the problem. The company investigates the airbag inflation problem further and discovers that a high degree of variability in the tightness of folds is responsible for the failure of some bags to inflate. At the time the bags were folded and packed by people on an assembly line. With a more complete understanding of the need, the engineer redefined the problem as one of increasing the consistency in tightness of the folds in the bags. The final solution to this problem is a machine that automatically folds the bags. Often the apparent need is not the real need. A common tendency is to begin generating a solution to an apparent problem without understanding the problem. This approach is exactly the wrong way to begin solving a problem such as this. You would be generating solutions to a problem that has never been defined.

People have a natural tendency to attack the current solution to a problem rather than the problem itself. Attacking a current solution may eliminate inadequacies but will not produce a creative and innovative solution. For example, the engineer at the airbag company could have only looked at the current method for folding airbags-using humans on an assembly line. The engineer might have solved the problem with inconsistent tightness by modifying the assembly line procedure. However, the final solution to the problem proved to be more cost effective and reliable, in addition to producing a superior consistency in the tightness of the folds.

Develop a Problem Statement

The first step in the problem-solving process, therefore, is to formulate the problem in clear and unambiguous terms. Defining the problem is not the same as recognizing a need. The problem definition statement results from first identifying a need. The engineer at the airbag company responded to a need to reduce the number of airbag inflation failures. He made a mistake, however, in not formulating a clear definition of the problem before generating a solution. Once a need has been established, engineers define that need in terms of an engineering design problem statement. To reach a clear definition, they collect data, run experiments, and perform computations that allow that need to be expressed as part of an engineering problem-solving process.

Consider for example the statement "Design a better mousetrap." This statement is not an adequate problem definition for an engineering design problem. It expresses a vague dissatisfaction with existing mousetraps and therefore establishes a need. An engineer would take this statement of need and conduct further research to identify what was lacking in existing mousetrap designs. After further investigation the engineer may discover that existing mousetraps are inadequate because they don't provide protection from the deadly Hantavirus carried by mice. Therefore, a better mousetrap may be one that is sanitary and does not expose human beings to the Hantavirus. From this need, the problem definition is modified to read, "Design a mousetrap that allows for the sanitary disposal of the trapped mouse, minimizing human exposure to the Hantavirus."

The problem statement should specifically address the real need yet be broad enough not to preclude certain solutions. A broad definition of the problem allows you to look at a wide range of alternative solutions before you focus on a specific solution. The temptation at this point in the design process is to develop a preconceived mental "picture" of the problem solution. For example, you could define the better mousetrap problem as "Design a mousetrap that sprays the trapped mouse with disinfectant." This statement is clear and specific, but it is also too narrow. It excludes many potentially innovative solutions. If you focus on a specific picture or idea for solving the problem at this stage of the design process, you may never discover the truly innovative solutions to the problem. A problem statement should be concise and flexible enough to allow for creative solutions.

Here is one possible problem definition statement for our better mousetrap problem:

A Better Mousetrap: Certain rodents such as the common mouse are carriers and transmitters of an often fatal virus, the Hantavirus. Conventional mousetraps expose people to this virus as they handle the trap and dispose of the mouse. Design a mousetrap that allows a person to trap and dispose of a mouse without being exposed to any bacterial or viral agents being carried on the mouse.

2. Generate concepts

Before you can go further in the design process, you need to collect all the information available that relates to the problem. Novice designers will quickly skip over this step and proceed to the generation of alternative solutions. You will find, however, that effort spent searching for information about your problem will pay big dividends later in the design process. Gathering pertinent information can reveal facts about the problem that result in a redefinition of the problem. You may discover mistakes and false starts made by other designers. Information gathering for most design problems begins with asking the following questions. If the problem addresses a need that is new, then there are no existing solutions to the problems, so obviously some of the questions would not be asked.

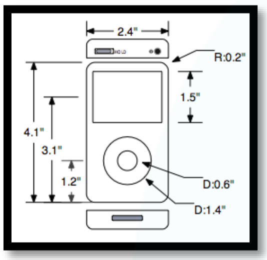
- Is the problem real and its statement accurate?
- Is there really a need for a new solution or has the problem already been solved?
- What are the existing solutions to the problem?
- What is wrong with the way the problem is currently being solved?
- What is right about the way the problem is currently being solved?
- What companies manufacture the existing solution to the problem?
- What are the economic factors governing the solution?

- How much will people pay for a solution to the problem?
- What other factors are important to the problem solution (such as safety, aesthetics and environmental issues)?

By answering above questions designer can develop new idea to solve any design problems. Designer may use scientific methodologies such as brain storming, decision matrix etc.
Solutions to engineering design problems do not magically appear. Ideas are generated when people are free to take risks and make mistakes. Brainstorming at this stage is often a team effort in which people from different disciplines are involved in generating multiple solutions to the problem.

3. Develop the solution

The next step in the design process begins with creativity in generating new ideas that may solve the problem. Creativity is much more than just a systematic application of rules and theory to solve a technical problem. You start with existing solutions to the problem and then tear them apart-find out what's wrong with those solutions and focus on how to improve their weaknesses. Consciously



Combine new ideas, tools, and methods to produce a totally unique solution to the problem. This process is called synthesis.
Detailed designs should be generated in this step by representing designs through technical drawings which consisting of relevant information's to manufacture the product.
If a solution is found to be invalid or cannot be justified, the designer must return to a previous step in the design process.

Analyse and select suitable solution:

Once you've conceived alternative solutions to your design problem, you need to analyze those solutions and then decide which solution is best suited for implementation. Analysis is the evaluation of the proposed designs. You apply your technical knowledge to the proposed solutions and use the results to decide which solution to carry out. You will cover design analysis in more depth when you get into upper-level engineering courses.
At this step in the design process, you must consider the results of your design analysis. This is a highly subjective step and should be made by a group of experienced people. This section introduces a systematic methodology you can use to evaluate alternative designs and assist in making a decision.

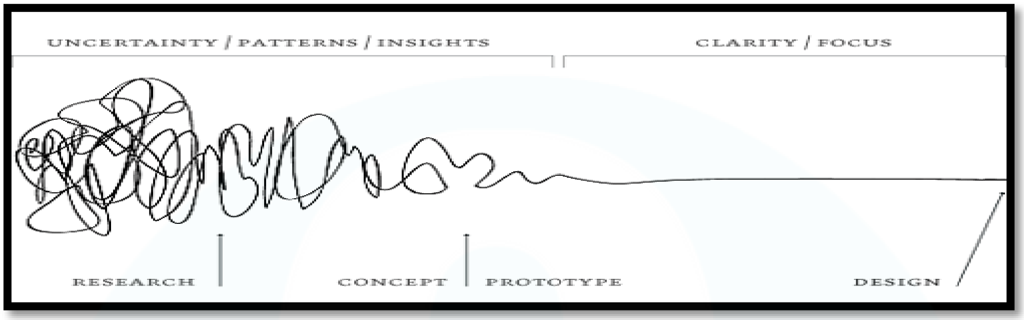
Analysis of Design Solutions:
Before deciding which design solution to implement, you need to analyze each alternative solution against the selection criteria defined in step l. You should perform several types of analysis on each design. Every design problem is unique and requires different types of analysis. The following is a list of analysis that may need to be considered; bear in mind that the importance 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 and liability

- Economic and market analysis
- Regulatory and Compliance

4. Construct and test prototype

The final phase of the design process is implementation, which refers to the testing, construction, and manufacturing of the solution to the design problem. You must consider several methods of implementation, such as prototyping and concurrent engineering, as well as distinct activities that occur during implementation, such as documenting the design solution and applying for patents.



Prototyping:

The first stage of testing and implementation of a new product, called prototyping, consists of 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 work or operate as intended. The purpose of the prototype is to test the design solution under real conditions. For example, a new aircraft design would first be tested as a scale model in a wind tunnel. Wind tunnel tests would generate information to be used in constructing a full-size prototype of the aircraft. Test pilots then fly the prototype extensively under real conditions. Only after testing under all expected and unusual operating conditions are the prototypes brought into full production.

5. Evaluate and implement solution

Testing and verification are important parts of the design process. At all steps in the process, you may find that your potential solution is flawed and have to back up to a previous step to get a workable solution. Without proper testing at all stages in the process, you may find yourself making costly mistakes later.

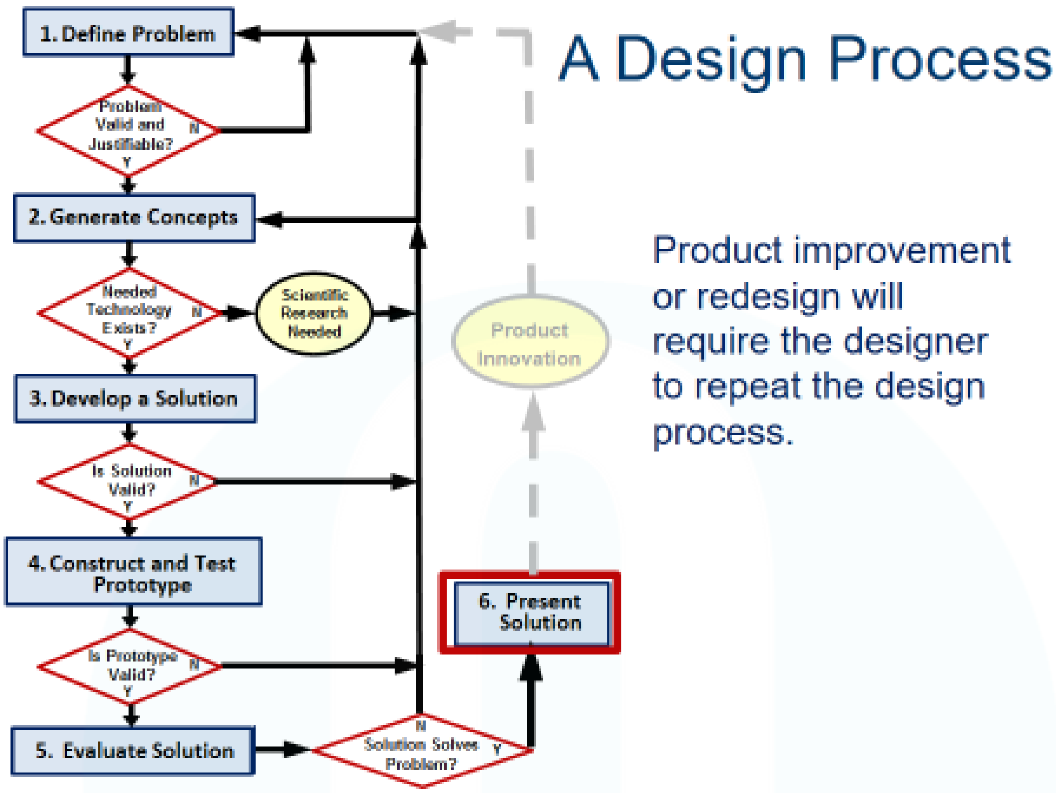
6. Present solutions

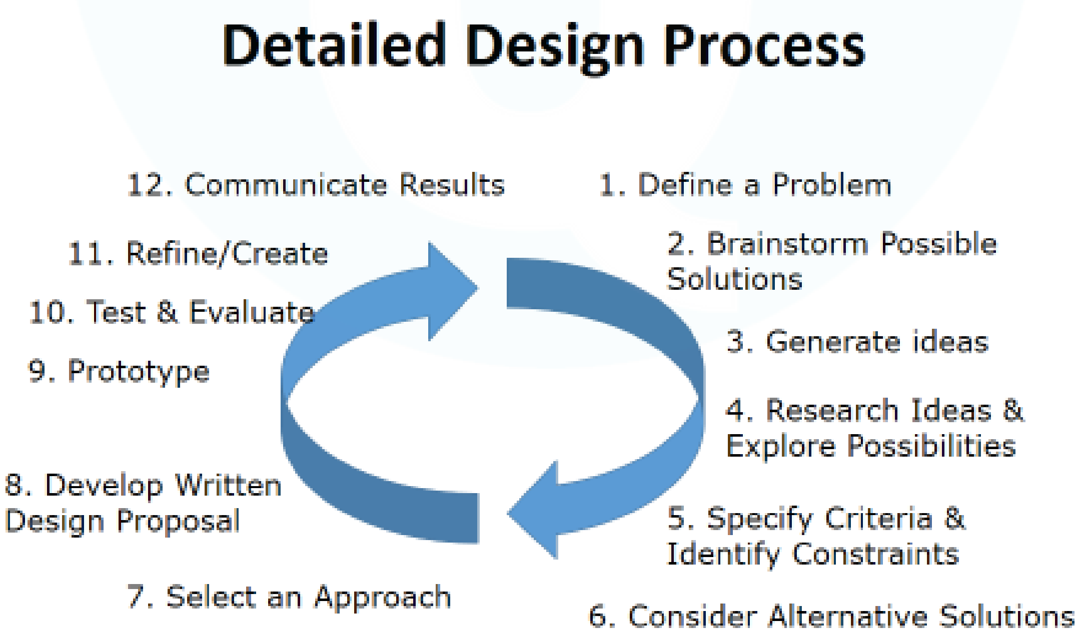
Communicating the solution to a design problem through language, both written and oral, is a vital part of the implementation phase. Many people you will be communicating with do not have technical training and competence. They may be the general public, government officials, or business leaders. Successful engineers must possess more than just technical skills. The ability to communicate and sell a design solution to others is also a critical skill.

You can use graphs, charts, and other visual materials to summarize the solution process and present your work to others. Multimedia techniques, including Power Point presentations, slides, sounds, videos, and computer-generated animations, are often used to clearly communicate the solution to a design problem.

Documentation: One of the most important activities in design is documenting your work, clearly communicating the solution to your design problem so someone else can understand what you have created. Usually this consists of a design or technical report.

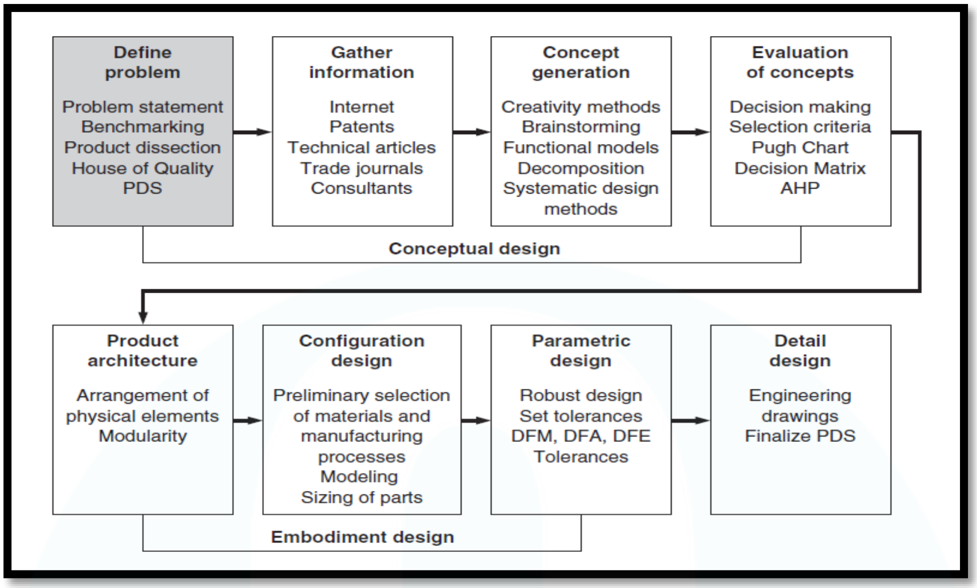
Schematic representations of design process





Conceptual Design & Embodiment Design

The total design process can be divided in to three as shown in the figure:



1. Conceptual Design

Conceptual design is the process by which the design is initiated, carried to the point of creating a number of possible solutions, and narrowed down to a single best concept. It is sometimes called the feasibility study. Conceptual design is the phase that requires the greatest creativity, involves the most uncertainty, and requires coordination among many functions in the business organization.

The following are the discrete activities that we consider under conceptual design Identification of customer needs: The goal of this activity is to completely understand the customers' needs and to communicate them to the design team.

● Problem definition: The goal of this activity is to create a statement that describes what has to be accomplished to satisfy the needs of the customer. This involves analysis of competitive products, the establishment of target specifications, and the listing of constraints and trade-offs.

● Gathering information: Engineering design presents special requirements over engineering research in the need to acquire a broad spectrum of information.

● Conceptualization: Concept generation involves creating a broad set of concepts that potentially satisfy the problem statement. Team-based creativity methods, combined with effi cient information gathering, are the key activities.

● Concept selection: Evaluation of the design concepts, modifying and evolving into a single preferred concept, are the activities in this step. The process usually requires several iterations.

● Refinement of the PDS: The product design specification is revisited after the concept has been selected. The design team must commit to achieving certain critical values of design parameters, usually called critical-to-quality (CTQ) parameters, and to living with trade-offs between cost and performance.

● Design review: Before committing funds to move to the next design phase, a design review will be held. The design review will assure that the design is physically realizable and that it is economically worthwhile. It will also look at a detailed product development schedule. This is needed to devise a strategy to minimize product cycle time and to identify the resources in people, equipment, and money needed to complete the project.

2. **Embodiment Design**

Structured development of the design concept occurs in this engineering design phase. It is the place where flesh is placed on the skeleton of the design concept. An embodiment of all the main functions that must be performed by the product must be undertaken. It is in this design phase that decisions are made on strength, material selection, size, shape, and spatial compatibility. Beyond this design phase, major changes become very expensive. This design phase is sometimes called preliminary design. Embodiment design is concerned with three major tasks—product architecture, configuration design, and parametric design.

● Product architecture:

Product architecture is concerned with dividing the overall design system into subsystems or modules. In this step we decide how the physical components of the design are to be arranged and combined to carry out the functional duties of the design.

● Configuration design of parts and components:

Parts are made up of features like holes, ribs, splines, and curves. Configuring a part means to determine what features will be present and how those features are to be arranged in space relative to each other. While modeling and simulation may be performed in this stage to check out function and spatial constraints, only approximate sizes are determined to assure that the part satisfies the PDS. Also, more specificity about materials and manufacturing is given here. The generation of a physical model of the part with rapid prototyping processes may be appropriate.

● Parametric design of parts:

Parametric design starts with information on the configuration of the part and aims to establish its exact dimensions and tolerances. Final decisions on the material and manufacturing processes are also established if this has not been done previously. An important aspect of parametric design is to examine the part, assembly, and system for design robustness. Robustness refers to how consistently a component performs under variable conditions in its service environment.

3. **Detailed Design**

In this phase the design is brought to the stage of a complete engineering description of a tested and producible product. Missing information is added on the arrangement, form, dimensions, and tolerances, surface properties, materials, and manufacturing processes of each part. This results in a specification for each special-purpose part and for each standard part to be purchased from suppliers. In the detail design phase the following activities are completed and documents are prepared:

● Detailed engineering drawings suitable for manufacturing. Routinely these are computer-generated drawings, and they often include three-dimensional CAD models.

● Verification testing of prototypes is successfully completed and verification data is submitted. All critical-to-quality parameters are confirmed to be under control. Usually the building and testing of several preproduction versions of the product will be accomplished.

● Assembly drawings and assembly instructions also will be completed. The bill of materials for all assemblies will be completed.

● A detailed product specification, updated with all the changes made since the conceptual design phase, will be prepared.

● Decisions on whether to make each part internally or to buy from an external supplier will be made.
● With the preceding information, a detailed cost estimate for the product will be carried out.
● Finally, detail design concludes with a design review before the decision is made to pass the design information on to manufacturing.

Phases I, II, and III take the design from the realm of possibility to the real world of practicality. However, the design process is not finished with the delivery of a set of detailed engineering drawings and specifications to the manufacturing organization. Many other technical and business decisions must be made that are really part of the design process. A great deal of thought and planning must go into how the design will be manufactured, how it will be marketed, how it will be maintained during use, and finally, how it will be retired from service and replaced by a new, improved design.

Generally these phases of design are carried out elsewhere in the organization than in the engineering department or product development department. As the project proceeds into the new phases, the expenditure of money and personnel time increases greatly.

Follow this link to download presentation on design process
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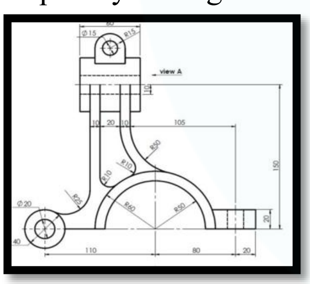
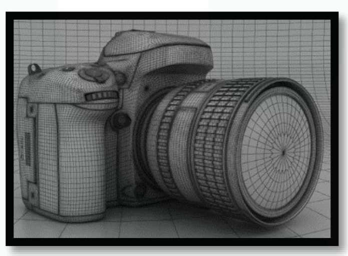
Design Communication

It must always be kept in mind that the purpose of the design is to satisfy the needs of a customer or client. Therefore, the finalized design must be properly communicated, or it may lose much of its impact or significance. The communication is usually by oral presentation to the sponsor as well as by a written design report. Surveys typically show that design engineers spend 60 percent of their time in discussing designs and preparing written documentation of designs, while only 40 percent of the time is spent in analyzing and testing designs and doing the designing. Detailed engineering drawings, computer programs, 3-D computer models, and working models are frequently among the "deliverables" to the customer.



2D Drawings



3D Drawings

3D Printed Models2D

It hardly needs to be emphasized that communication is not a one-time occurrence to be carried out at the end of the project. In a well-run design project there is continual oral and written dialog between the project manager and the customer.

Note that the problem-solving methodology does not necessarily proceed in the order just listed. While it is important to define the problem early on, the understanding of the problem improves as the team moves into solution generation and evaluation. In fact, design is characterized by its iterative nature, moving back and forth between partial solutions and problem definition. This is in marked contrast with engineering analysis, which usually moves in a steady progression from problem setup to solution.

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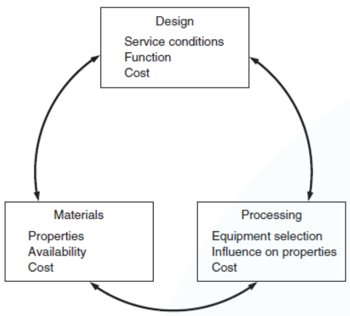
Material Selection

Materials and the manufacturing processes that convert them into useful parts underlie all of engineering design. There are over 100,000 engineering materials to choose from. The typical design engineer should have ready access to information on 30 to 60 materials, depending on the range of applications he or she deals with. The recognition of the importance of materials selection in design has increased in recent years. Concurrent engineering practices have brought materials specialists into the design process at an earlier stage. The importance given to quality and cost aspects of manufacturing in present-day product design has emphasized the fact that materials and manufacturing are closely linked in determining final product performance.

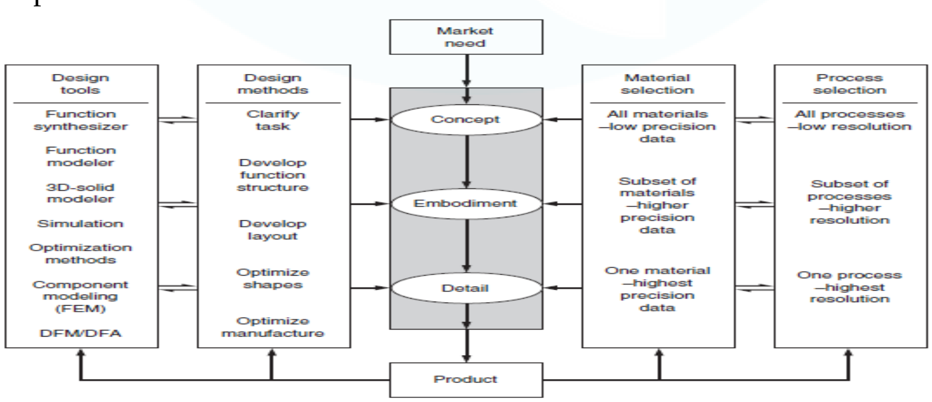


Moreover, the pressures of worldwide competition have increased the level of automation in manufacturing to the point where material costs comprise 60 percent or more of the cost for most products. Finally, the extensive activity in materials science worldwide has created a variety of new materials and focused our attention on the competition between six broad classes of materials: metals, polymers, elastomers, ceramics, glasses, and composites. Thus, the range of materials available to the engineer is much broader than ever before. This presents the opportunity for innovation in design by utilizing these materials to provide greater performance at lower cost. Achieving these benefits requires a rational process for materials selection.

Material Selection & Design

An incorrectly chosen material can lead not only to failure of the part but also to excessive life-cycle cost. Selecting the best material for a part involves more than choosing both a material that has the properties to provide the necessary performance in service and the processing methods used to create the finished part.

A poorly chosen material can add to manufacturing cost. Properties of the material can be enhanced or diminished by processing, and that may affect the service performance of the part. Faced with the large number of combinations of materials and processes from which to choose, the materials selection task can only be done effectively by applying simplification and systemization. As design proceeds from concept design, to configuration and parametric design (embodiment design), and to detail design, the material and process selection becomes more detailed. Figure below compares the design methods and tools used at each design stage with materials and processes selection.



At the concept level of design, essentially all materials and processes are considered in broad detail. The task is to determine whether each design concept will be made from metal, plastics, ceramic, composite, or wood, and to narrow it to a group of materials within that material family. The required precision of property data is rather low. Note that if an innovative choice of material is to be made it must be done at the conceptual design phase because later in the design process too many decisions have been made to allow for a radical change. The emphasis at the embodiment phase of design is on determining the shape and size of a part using engineering analysis. The designer will have decided on a class of materials and processes, such as a range of aluminum alloys, wrought and cast. The material properties must be known to a greater level of precision. At the parametric design step the alternatives will have narrowed to a single material and only a few manufacturing processes. Here the emphasis will be on deciding on critical tolerances, optimizing for robust design, and selecting the best manufacturing process using quality engineering and cost modeling methodologies. Depending on the importance of the part, materials properties may need to be known to a high level of precision. This may require the development of a detailed database based on an extensive materials testing program. Thus, material and process selection is a progressive process of narrowing from a large universe of possibilities to a specific material and process.

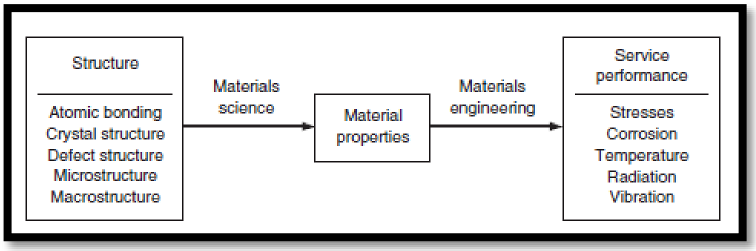
Criteria for Material Selection

Materials are selected on the basis of four general criteria:

- Performance characteristics (properties)
- Processing (manufacturing) characteristics
- Environmental profile
- Business considerations

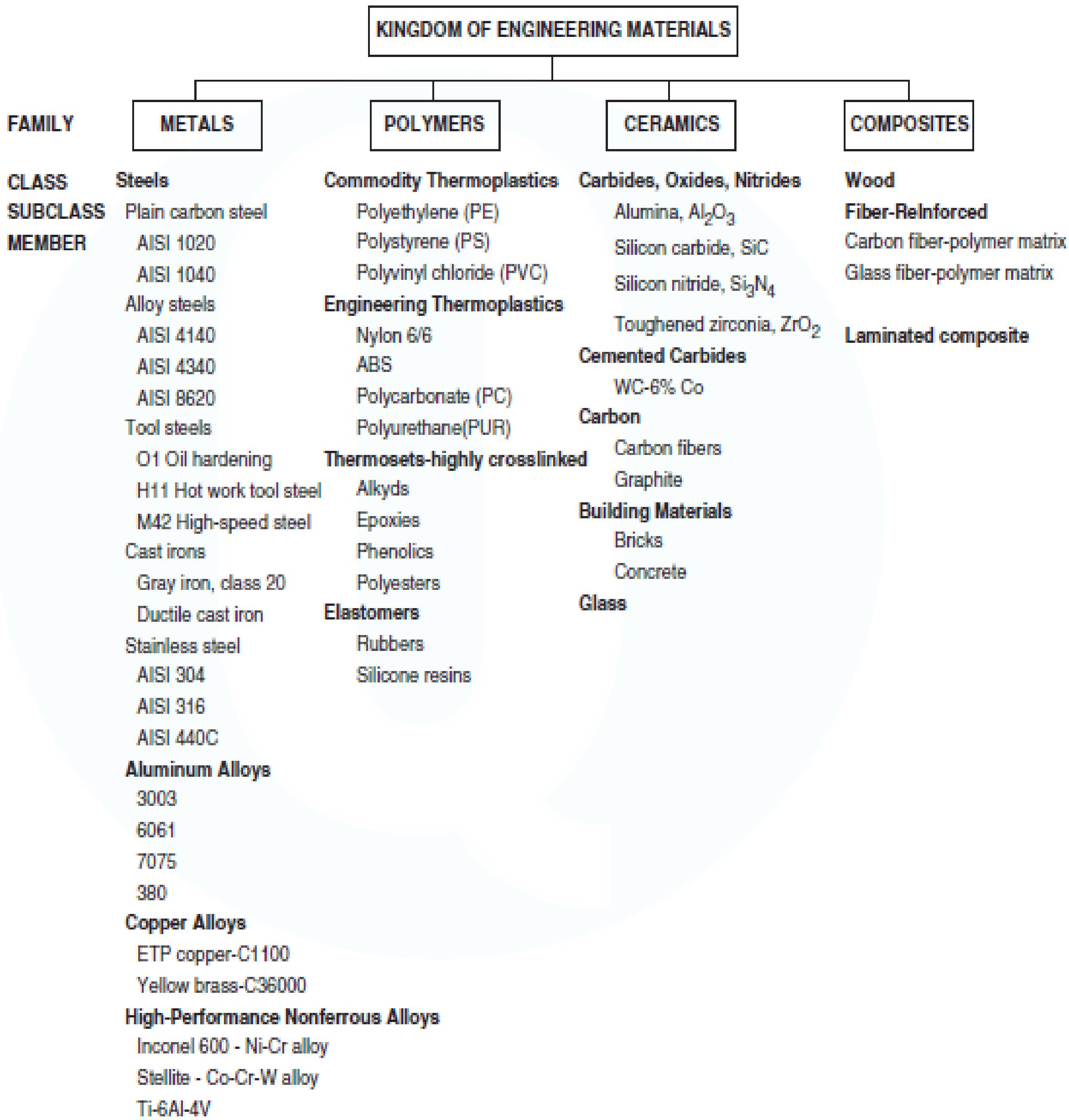
Materials selection, like other aspects of engineering design, is a decision-making process. The steps in the process are as follows:

1. Analysis of the materials requirements. Determine the conditions of service and environment that the product must withstand. Translate them into material properties.
2. Screening for candidate materials. Compare the needed properties with a large materials property database to select a few materials that look promising for the application.
   Usually, steps 1 and 2 are performed in the conceptual phase of design.
3. Analysis of candidate materials in terms of trade-offs of product performance, cost, manufacturability, and availability to select the best material for the application.
   This is done in the embodiment phase of design.
4. Development of design data for critical systems or components. Determine experimentally the key material properties for the selected material to obtain statistically reliable measures of the material performance under the specific conditions expected to be encountered in service. It is not always necessary to carry out this step, but when it is, it is usually part of the detail design phase.



Classification of Materials

We can divide materials into metals, ceramics, and polymers. Further division leads to the categories of elastomers, glasses, and composites. Finally, there are the technologically important classes of optical, magnetic, and semiconductor materials. An engineering material is a material that is used to fulfill some technical functional requirement, as opposed to being just used for decoration. Those materials that are typically used to resist forces or deformations in engineering structures are called structural materials.



Properties of Materials

The performance or functional requirements of a material are usually given by a definable and measurable set of material properties. The first task in materials selection is to determine which material properties are relevant to the application. We look for material properties that are easy and inexpensive to measure, are reproducible, and are associated with a material behavior that is well defined and related to the way the material performs in service. For reasons of technological convenience we often measure something other than the most fundamental material property. For example, the elastic limit measures the first significant deviation from elastic behavior, but it is tedious to measure, so we substitute the easier and more reproducible 0.2 % offset yield strength. That, however, requires a carefully machined test specimen, so the yield stress may be approximated by the exceedingly inexpensive and rapid hardness test.

A Short List of Material Properties

Structure-Insensitive Properties	Structure-Sensitive Properties
Melting point, T_m	Strength, σ_f, where f denotes a failure mode
Glass transition temperature, for polymers, T_g	Ductility
Density, ρ	Fracture toughness, K_{Ic}
Porosity	Fatigue properties
Modulus of elasticity, E	Damping capacity, η
Coefficient of linear thermal expansion, α	Creep
Thermal conductivity, k	Impact or shock loading resistance
Specific heat, c_p	Hardness
Corrosion rate	Wear rate or corrosion rate

first step in classifying material properties is to divide them into structure insensitive properties and structure-sensitive properties, in above Table Both types of properties depend on the atomic binding energy and arrangement and packing of the atoms in the solid, but the structure-sensitive properties also depend strongly on the number, size, and distribution of the imperfections (dislocations, solute atoms, grain boundaries, inclusions, etc.) in the solid. Except for modulus of elasticity and corrosion in this table, all of the structure-insensitive properties are classified as physical properties.

The Material Selection Process

In design we considered the important issue in materials selection of identifying the appropriate material properties that allow the prediction of failure-free functioning of the component. The equally important task of identifying a process to manufacture the part with the material is discussed in Chap. 13. While these are important considerations, they are not the only issues in materials selection. The following business issues must also be considered. Failure to get a positive response in any of these areas can disqualify a material from selection.

1. Availability
   Are there multiple sources of supply?
   What is the likelihood of availability in the future?
   Is the material available in the forms needed (tubes, wide sheet, etc.)?
2. Size limitations and tolerances on available material shapes and forms, e.g., sheet thickness or tube wall concentricity
3. Excessive variability in properties
4. Environmental impact, including ability to recycle the material
5. Cost. Materials selection comes down to buying properties at the best available price.

A Material Selection Example

Consider the question of materials selection for an automotive exhaust system. The product design specification states that it must provide the following functions:

- Conduct engine exhaust gases away from the engine
- Prevent noxious fumes from entering the car
- Cool the exhaust gases
- Reduce the engine noise
- Reduce the exposure of automobile body parts to exhaust gases
- Affect the engine performance as little as possible
- Help control unwanted exhaust emissions
- Have an acceptably long service life

Have a reasonable cost, both as original equipment and as a replacement part. The basic system configuration is a series of tubes that collect the gases at the engine and convey them to the rear of the automobile. The size of the tubes is determined by the volume of gases to be carried away and the extent to which the exhaust system can be permitted to impede the flow of gases from the engine (back pressure). In addition, a muffler is required for noise reduction and a catalytic converter to change polluting gases to less harmful emissions.

Material Requirements for an Automotive Exhaust System

- Mechanical property requirements not overly severe.
- Suitable rigidity to prevent excessive vibration
- Moderate fatigue resistance
- Good creep resistance in hot parts

Limiting property: corrosion resistance, especially in the cold end where gases condense to form corrosive liquids.

Properties of unique interest: The requirements are so special that only a few materials meet them regardless of cost.

- Pt-base catalysts in catalytic converter
- Special ceramic carrier that supports the catalyst

Previous materials used: Low-carbon steel with corrosion-resistant coatings.

Material is relatively inexpensive, readily formed and welded. Life of tailpipe and muffler is limited.

Newer materials used: With greater emphasis on automotive quality, many producers have moved to specially developed stainless steels with improved corrosion and creep properties. Ferritic 11% Cr alloys are used in the cold end components and 17 to 20% Cr ferritic alloys and austenitic Cr-Ni alloys in the hot end of the system.

Tolerance

A tolerance is the permissible variation from the specified dimension. The designer must decide how much variation is allowable from the basic dimension of the component to accomplish the desired function. The design objective is to make the tolerance no tighter than necessary, since smaller tolerances increase manufacturing cost and make assembly more difficult.

1. Bilateral tolerance
   The variation occurs in both directions from the basic dimension. That is, the upper limit exceeds the basic value and the lower limit falls below it.
   2.500 ± 0.005 (This is the most common way of specifying tolerances)

2. Unilateral tolerance:
   The basic dimension is taken as one of the limits, and variation is in only one direction
   $2.500^{+0.000}_{-0.010}$

Each manufacturing process has an inherent ability to maintain a certain range of tolerances, and to produce a certain surface roughness (finish).To achieve tolerances outside of the normal range requires special processing that typically results in an exponential increase in the manufacturing cost. Thus, the establishment of the needed tolerances in embodiment design has an important influence on the choice of manufacturing processes and the cost. Fortunately, not all dimensions of a part require tight tolerances. Typically those related to critical-to quality functions require tight tolerances. The tolerances for the noncritical dimensions should be set at values typical for the process used to make the part.

Design Standards and Codes

While we have often talked about design being a creative process, the fact is that much of design is not very different from what has been done in the past. There are obvious benefits in cost and time saved if the best practices are captured and made available for all to use. Designing with codes and standards has two chief aspects:

- It makes the best practice available to everyone, thereby ensuring efficiency and safety, and
- It promotes interchangeability and compatibility. With respect to the second point, anyone who has traveled widely in other countries will understand the compatibility problems with connecting plugs and electrical voltage and frequency when trying to use small appliances.

A code is a collection of laws and rules that assists a government agency in meeting its obligation to protect the general welfare by preventing damage to property or injury or loss of life to persons. A standard is a generally agreed-upon set of procedures, criteria, dimensions, materials, or parts. Engineering standards may describe the dimensions and sizes of small parts like screws and bearings, the minimum properties of materials, or an agreed-upon procedure to measure a property like fracture toughness. The terms standards and specifications are sometimes used interchangeably. The distinction is that standards refer to generalized situations, while specifications refer to specialized situations. Codes tell the engineer what to do and when and under what circumstances to do it. Codes usually are legal requirements, as in the building code or the fi re code. Standards tell the engineer how to do it and are usually regarded as recommendations that do not have the force of law. Codes often incorporate national standards into them by reference, and in this way standards become legally enforceable.

Standards are often prepared by individual companies for their own proprietary use. They address such things as dimensions, tolerances, forms, manufacturing processes, and finishes. In-house standards are often used by the company purchasing department when outsourcing. The next level of standard preparation involves groups of companies in the same industry arriving at industry consensus standards. Often these are sponsored through an industry trade association, such as the American Institute of Steel Construction (AISC) or the Door and Hardware Institute. Industry standards of this type are usually submitted to the American National Standards Institute (ANSI) for a formal review process, approval, and publication. A similar function is played by the International Organization for Standardization (ISO) in Geneva, Switzerland.

Applications and benefits of design standards

- Standards are a "COMMUNICATION" tool that allows all users to speak the same language when reacting to products or processes
- They provide a "Legal," or at least enforceable, means to evaluate acceptability and sale-ability of products and/or services
- They can be taught and applied globally!
- They, ultimately, are designed to protect the public from questionable designs, products and practices
- They teach us, as engineers, how we can best meet environmental, health, safety and societal responsibilities

Download presentation on Material Selection, Design Standards and Tolerance
http://www.slideshare.net/naseelazeeniya/material-selection-and-design-standards

Quality Function Deployment

Quality function deployment (QFD) is a planning and team problem-solving tool that has been adopted by a wide variety of companies as the tool of choice for focusing a design team's attention on satisfying customer needs throughout the product development process. The term deployment in QFD refers to the fact that this method determines the important set of requirements for each phase of PDP planning and uses them to identify the set of technical characteristics of each phase that most contribute to satisfying the requirements. QFD is a largely graphical method that aids a design team in systematically identifying all of the elements that go into the product development process and creating relationship matrices between key parameters at each step of the process. Gathering the information required for the QFD process forces the design team to answer questions that might be glossed over in a less rigorous methodology and to learn what it does not know about the problem. Because it is a group decision-making activity, it creates a high level of buy-in and group understanding of the problem. QFD, like brainstorming, is a tool for multiple stages of the design process.

In fact, it is a complete process that provides input to guide the design team. Quality function deployment (QFD) is a method to help transform customer needs (the voice of the customer [VOC]) into engineering characteristics (and appropriate test methods) for a product or service. It helps create operational definitions of the requirements, which may be vague when first expressed.

Benefits of adopting QFD

- ✓ Reduced time to market
- ✓ Reduction in design changes
- ✓ Decreased design and manufacturing costs
- ✓ Improved quality
- ✓ Increased customer satisfaction

Process of QFD

- ✓ Identify customer wants
- ✓ Identify how the good/service will satisfy customer wants
- ✓ Relate customer wants to product how's
- ✓ Identify relationships between the firm's how's
- ✓ Develop importance ratings
- ✓ Evaluate competing products