The Product Design Phase

Goal:
- Refine the concepts already generated into quality products.
  - Giving flesh to what was the skeleton of an idea (hardware design, shape design, or embodiment design)

Steps:
- Generate Product (chapter 10)
- Evaluate the product (chaps 11, 12)
- Decision Making

*Drawings, Bills of Materials, and other preliminary records of the product design effort
Drawings Produced during Product Design

- Layout Drawings:
- Detail Drawings:
- Assembly Drawings:
- Graphical Models produced in CAD Systems:
Layout Drawings

- A layout drawing is a working document that supports the development of the major components and their relationship.

- Characteristics:
  - Frequently changed during the design process. Care should be taken not to lose the records of changes.
  - A layout drawing is made to scale.
  - Only the important dimensions are shown.
  - Tolerances are usually not shown, unless they are critical.
  - Notes on the layout drawing are used to explain in a design feature or the function of the product.
  - A layout drawing often becomes obsolete as detail drawings and assembly drawings are developed.
Detail Drawings

- The detail of individual components, developed as the product evolves on the layout drawing, are documented on detail drawings.

- Characteristics:
  - All dimensions must be tolerated. No tolerance indicates the use of standard tolerances used in a company.
  - Materials and manufacturing detail must be in clear and specific language.
  - Drawing standards (ANSI Y 14.5M-1994, Dimensions and Tolerancing, and DOD-STD-100, Engineering Drawing Practices, or company standards) should be followed.
  - Detail drawings are a final presentation of the design effort and will be used to communicate the product to manufacturing. Thus, a signature block for management approval is a standard part of a detail drawing.
Assembly Drawings

- Assembly drawings are made to show how the component fit together.
- Characteristics:
  - Each component is identified with a number or letter keyed to the bill of materials (BOM).
  - References can be made to other drawings and specific assembly instructions for additional needed information.
  - Necessary detailed views are included to convey information not clear in the major views.
  - Assembly drawings require a signature block.
Graphical Models produced in CAD Systems

Positive Aspects:
- Rapid representation of concepts and the ability to see how they assemble and operate without the need for hardware.
- Improves the design process because features, dimensions, and tolerances are developed and recorded only once (less potential error).
- Easy to ensure that mating components fit together.
- Detail and assembly drawings are produced semi-automatically, reducing the need to have expert knowledge of drafting methods and drawing standards.
- Files created are useful for making prototypes and developing figures for any other purposes.

Negative Aspects:
- There is a tendency to abandon sketching although sketches are a rapid way to develop a high number of ideas. (Longer time for solid modeling)
- Too much time is often spent on details too soon because solid model systems require details in order to even make a rough drawing.
- Often valuable design time is spent just using the tool.
- Many solid modeling systems require the components and assemblies to be planned out ahead of time. These systems are more like an automated drafting system than a design aid.
Bills of Materials (Part Lists)

- **An index to the product**
  - It is a good practice to generate the BOM as the product evolves on a spreadsheet, which is easy to update.
  - To keep lists to a reasonable length, a separate list is made for each assembly.

- **Minimum Pieces of Information on BOM**
  - The item number or letter
  - The part number
  - The quantity needed in the assembly
  - Name or Description of the Component
  - Material from which the component is made
  - Source of the component (if the component is purchased from other companies)

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<th>Item</th>
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<th>Quantity</th>
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<td>1</td>
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Product Data Management

- A major undertaking in a company is to manage design information, a company’s most valuable asset.

- **Product Data Management Systems (PDMs)**
  - Database programs used to support the management of documents and files, product structure and processes for better management of both product and process information
  - Records stored in PDMS
    - CAD files (all kinds of drawings and solid models)
    - Text documents (meeting notes, contracts, etc.)
    - Spread sheets (QFD, decision matrices, and other analysis)
    - Database reports
    - Parts libraries, vendor data, engineering change orders
  - PDMs allow easy search and organization of the data.
  - PDMs allow management of the way people create and modify data.
  - PDMs help support the task schedule by the tools to support the development and maintenance of Gantt charts, worker allocation, and task definitions.
The goal of product generation is to transform the design concepts into products that perform the desired functions.

Such refinement requires work on all the elements in the figure.
Form Generation

- Form development is the evolution of **components**, how they are **configured** relative to each other and how they are **connected** to each other within the **constraints**.
  - Understand the spatial constraints:
  - Configure components:
  - Develop Connections: Create and refine interfaces for functions:
  - Develop Components:

- **Understand the Spatial Constraints:**
  - Spatial constraints are the walls or envelope for the product.
  - Some spatial constraints are for functionally needed space.

- **Configure Components:**
  - Configuration is the architecture, structure, or arrangement of the components and assemblies of components in the product.
  - Developing the configuration involves decisions that divide the product into individual components and develop the location and orientation of them.
Form Generation

- **Configure Components:**
  - Configuration is the architecture, structure, or arrangement of the components and assemblies of components in the product.
  - Developing the configuration involves decisions that divide the product into individual components and develop the location and orientation of them.
  - 6 Reasons to decompose a product or assembly into separate components: components must be separate if:
    - They need to move relative to each other;
    - They need to be of different materials for functional purposes;
    - They need to be moved for accessibility;
    - They need to accommodate material or production limitations;
    - There are available standard components that can be considered for the product;
    - Separate components would minimize costs.

- **Location and Orientation of the Components with each other:**
  - Location: Measure of relative position in a space (x, y, z)
  - Orientation: angular relationship of the components
Form Generation

- **Develop Connections (Create and refine interfaces for functions):**
  - A key step when embodying a concept because the connections or interfaces between components support their function and determine their relative positions and locations.
  - Guidelines to help develop and refine the interfaces between components:
    - Interfaces must always reflect force equilibrium and consistent flow of energy, material, and information
      - They are means through which the product will be designed to meet the functional requirements.
    - After developing interfaces with external objects, consider the interfaces that carry the most critical functions.
      - In general, most critical functions are those that seem hardest to achieve or those described as most important in the customers’ requirements.
    - Try to maintain functional independence in the design of an assembly or component.
      - This means that the variation in each critical dimension in the assembly or component should affect only one function.
    - Exercise care when separating the product into separate components.
      - Complexity arises since one function often occurs across many components or assemblies and since one component may play a role in many functions.
    - Creating and refining interfaces may force decompositions that result in new functions or may encourage the refinement of the functional breakdown.
Form Generation

- **Develop Connections (Create and refine interfaces for functions):**
  - **Types of Connections:**
    - Fixed, nonadjustable connection
    - Adjustable connection
      - Should allow at least 1-DOF that can be locked.
    - Separable connection
    - Locator connection
      - The interface determines the location or orientation of one of the components relative to another.
      - Care must be taken in these connections to account for errors that can accumulate in joints.
    - Hinged or pivoting connection
      - Many connections have one or more degrees of freedom.
      - The ability to transmit energy and information is usually key to the function of the device
  - **Degrees of Freedom (DOF):**
    - Number of directions required for complete description of location and orientation of a component moving relative to another.
    - Fundamentally, every connection between 2 components has 6 DOF – 3 translations and 3 rotations.
    - It is the design of connections that determine how many DOF the final product will have.
Examples of Connections with Varying DOF

3 DOF Situation

A single pin or short wall was inserted into B for positioning A. The effect will be to only limit the position of A relative to B in the +x direction.

Most joints need to position parts relative to each other and transmitted forces. Thus, it is worthwhile to think in terms of positioning and then force transmission.

Efforts to fully constrain along the x-axis. Putting a second support on the x-axis to limit motion in –x direction can have unintended consequences.
Examples of Connections with Varying DOF

Block A restriction in x-direction and z-rotation

Block A fully constrained under the force F.

Other fully constrained blocks.
Form Generation

- Develop Components:
  - Determine adequate shape and size of each component.
    - Critical dimensions on most components are found in functional interfaces.
    - In designing the bodies of components, be aware that stiffness determines the adequate size more frequently than stress.
  - Use force flow visualization to estimate the required stiffness and strength of each component.
  - Use standard shapes when possible.

Major functions are to transfer forces and clear (not interfere with) other components.
Form Generation

- Material between interfaces generally serves 3 main purposes.
  - To carry forces or other forms of energy between interfaces with sufficient strength and rigidity
  - To act as an enclosure or guide for other components
  - To provide appearance surfaces

- When the body of a component provides the function (e.g. needed mass, stiffness, or strength), shape of the component can be as important as the interface.
  - It is best to connect interfaces with strong structural shape.
  - Size and shape (area an polar moment of inertia) of the component should be considered.
    - Rod to resist tension or compression
    - Hollow cylinder to resist torque
    - I-beam to carry bending loads in the most efficient way possible
Form Generation

- **Force Flow Visualization**
  - A good method to visualize how forces are transmitted through components and assemblies
  - **Method**
    - Treat forces like a fluid that flows in and out of the interfaces and through the component.
    - The fluid takes the path of least resistance through the component.
    - Sketch multiple flow lines. The direction of each flow line will represent the maximum principal stress at the location.
    - Label the flow lines for the major types of stress occurring at the location: tension (T), Compression (C), shear (S), or bending (B).
      - B can be decomposed into T and C.
      - S must occur between T and C on a flow line.
    - Remember that force is transmitted at interfaces primarily by compression. Shear only occurs in adhesive, welded and friction surfaces.
  - **Advantages:**
    - Force flow helps us visualize the stresses in a component or assembly.
    - It is best if the force paths are short and direct.
      - The more indirect the path, the more potential failure points and stress concentrations.
Examples of Force Flow Visualization
Form Generation

- **Refine and Patch**
  - Refine is to make an object less abstract (or more concrete).
  - Patching is to change a design without changing its level of abstraction.
    * The goal is to make things work and to make them simpler.

- **Types of Patching**
  - Combining is making one component serve multiple functions or replace multiple components.
    * strongly encouraged when the product is evaluated for its ease of assembly.
  - Decomposing is breaking a component into multiple components or assemblies.
    * It is worthwhile to consider returning to the beginning of the design process.
  - Magnifying means making a component or some feature of it bigger relative to adjacent items.
    * Exaggerating the size or number of a feature often increases one’s understanding.
  - Minifying means making a component or some feature of it smaller.
    * Eliminating, streamlining, or condensing a feature may improve the design.
  - Rearranging means reconfiguring the components or their features.
    * This often leads to new ideas because the reconfigured shapes force to rethinking of how the component fulfills the functions.
  - Reversing means transposing or changing the view of the component or feature.
  - Substituting means identifying other concepts, components, or features that will work in place of the current idea.
    * Care must be taken because new ideas sometimes carry with them new functions.
Materials and Process Selection

- Material and production processes selected must evolve as the shape of the product evolves in concurrent engineering.

- Information influencing the embodiment of the product:
  - Quantity of the product to be manufactured
  - Prior-use knowledge
    - When studying existing devices, get into the habit of determining what kind of materials were used for what types of functions.
  - Knowledge and experience
  - Availability of a material
Vendor Development

- Mechanical designers seldom design basic mechanical components (such as bolts, nuts, gears, or bearings) for each new product since such components are readily available.
  - This is not true in designing an orthopaedic implant.

- Advantages of using a components available through vendors.
  - Vendors have history of designing and manufacturing the product, so they already have the expertise and machinery to produce a quality product.
  - They already know what can go wrong during design and production.
  - They specialize in the design and manufacture of the component, so they can make it in volumes high enough to keep the cost below what can be achieved through an in-house effort.

- After using concurrent engineering which involves a small number of vendors in the design process from the beginning and includes them in the decisions that affect what they will be supplying, many companies have been able to reduce the number of vendors.
  - These tight relationships lead to improved product quality.