The Design Process

Three Major Phases
1. Conceptual Design
2. Embodiment Design
3. Detailed Design

Others
4. Planning for Manufacture
5. Planning for Distribution
6. Planning for Use
7. Planning for Retirement of Product
The Design Process

Define problem
Problem statement
Benchmarking
QFD
PDS
Project planning

Gather information
Internet
Patents
Trade
literature

Concept generation
Brainstorming
Functional decomposition
Morphological chart

Evaluation of concepts
Pugh concept selection
Decision matrices

Conceptual design

Product architecture
Arrangement of physical elements
to carry out function

Configuration design
Prelim. selection mats. & mfg.
Modeling/sizing of parts

Parametric design
Robust design
Tolerances
Final dimen., DFM

Detail design
Detailed drawings and specifications

Embodyment design
The Design Process

1. Conceptual Design

• Recognition of a need
• Definition of the problem
  • Includes defining the problem statement, design requirements, constraints, and risks.
• Gathering of information
• Developing alternative design concepts
• Evaluation of concepts and selection
The Design Process

2. Embodiment Design (Preliminary Design)

A. **Product Architecture** – arrangement of the physical functions

B. **Configuration Design** – preliminary selection of materials, modeling and size of parts

C. **Parametric Design** – creating a robust design, and selection of final dimensions/parameters and tolerances.

**Evaluation:** This process must also be accompanied by a series of evaluations to determine if the existing design concept remains feasible. Iteration is often required.
The Design Process

3. Detail Design (final design)

- Creation of final drawings and/or specifications.

- **Example** – final definition of flow rates, chemistries, process time, temperatures, etc. for a extractive metallurgy process.
2. Embodiment Design

A. **Product Architecture** – arrangement of the physical functions

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2. Embodiment Design

A. Product Architecture

Two types of product architecture

1. Integral Architecture
   - implementation of functions is accomplished by only one or a few modules
   - Components perform multiple functions
   - **Example**: crowbar (single component provides leverage and acts as handle)

2. Modular Architecture
   - Each module implements one or a few functions
   - Interactions between modules are well defined.
   - New products or functionality easily developed by adding, deleting, or swapping modules.
   - Benefits from economies of scale and rapid product development (develop new module, get new product)
   - **Example**: Modular hip assembly, Laser drilling/ablation equipment
Modular Architecture Example: Hip Joint
2. Embodiment Design
   A. Product Architecture

Four steps to developing product architecture
  1. Create a schematic diagram of the product (flow chart)
  2. Cluster the elements of the schematic
  3. Create a rough geometric layout
  4. Identify the interactions between modules and performance characteristics
2A. Architecture Schematic (Printer)
Clustering Elements into Modules/Groups
Physical Decomposition
Module and Subcomponent Definition

Product: Printer

- Paper Handling System
- Ink System
  - Ink Print Cartridge
  - Carriage Mechanism
- Chassis
  - Fan/Vents
  - Filter
  - Housing
- Base
- Electronics
  - Printer Controller & Display
  - Input Paper Tray
  - Hertzian Paper Index Mechanism
  - Output Paper Tray
  - Switch
  - Power Supply
Rough Geometric Layout

- Print Cartridge and Carriage
- Chassis
- Paper Handling System (Index and Advance Mechanism)
- Output Paper Tray
- Input Paper Tray
- Base
• Real Alloy uses NaCl:KCl: Cryolite flux
  • Remove impurities, oxidation protection, insulate melt
• Flux composition is important
  • ~48/48/4 provides the lowest melting point
  • KCl is more expensive than NaCl
• Real Alloy uses a 3rd party for composition analysis
  • 2-week turnaround
  • Flux consumed prior to receiving results
Problem Statement

The Real Alloy Design Team will design a method to quickly measure the composition of a NaCl-KCl flux.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Target</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>±0.50 wt%</td>
<td></td>
</tr>
<tr>
<td>Ease of use</td>
<td>Little to no training</td>
<td>Use by one technician</td>
</tr>
<tr>
<td>Compounds analyzed</td>
<td>KCl and NaCl</td>
<td>Future work, adding cryolite ($\text{Na}_3\text{AlF}_6$)</td>
</tr>
<tr>
<td>Turnaround time</td>
<td>&lt;1 hr</td>
<td></td>
</tr>
</tbody>
</table>
Differential Thermal Analysis

• Compared to AAS, ICP, Gravimetric, Titration
• Pros
  • Fast (less than an hour)
  • Relatively simple to perform
  • Inexpensive (<$2000 start up)
  • Works for all three of the materials
• Cons
  • Lower accuracy (~0.5% accuracy)
Technical Method

Thermal arrests and Differential Thermal Analysis (DTA)

2A. Design Architecture – Schematic

Relate Functions to Components

- Contain molten salt
  - Crucible
- Melt salt
  - Furnace
- Measure Temperature
  - Thermocouple/reader
- Measure Thermal Arrest
  - Thermocouple Reader, Comparative Thermocouple
- Analyze data/estimate composition
  - Need Thermodynamic Model
- Transfer material (to furnace, from furnace)
  - Need Gloves, Tongs, etc.
Equipment

2. Embodiment Design/A. Product Architecture

Define Interactions and Performance Characteristics (step 4)

Types of Interactions

1. **Spatial** – describes physical interfaces
2. **Energy** – how does energy flow between modules (electricity, heat, etc)?
3. **Information** - how does information (signals, feedback, etc) flow between modules?
4. **Material** – how does material flow between modules?

Performance Characteristics

For each module define the following:
1. Functional requirements (what will it do?)
2. Drawings or sketches of the module and component parts
3. Preliminary component selection for the module
4. Detailed description of placement within product
5. Detailed description of interface with neighboring modules
6. Accurate modules for expect interaction between modules
The Design Process

2. *Embodiment Design (Preliminary Design)*

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2. Embodiment Design

B. Configuration Design

Goal: specify the configuration of the design and associated modules to meet their intended function. Involves

- Preliminary selection of materials
- Selecting component manufacturing methods (casting, forging, machining, etc)
- Sizing of parts
- Modeling of system (stress, thermo, heat, fluid, mixing, etc.)
2B. Configuration Design Process

Starting with the design architecture, the configuration design process involves three basic steps:

(1) **Generate alternative design configurations**
(2) **Analyze Design Configurations**
   - How does each configuration meet the functional requirements and overall design requirements/specifications?
(3) **Evaluate Configuration Designs**
   - This is a preliminary design evaluation to select between various design configurations. Full design analysis is reserved for parametric design.
   - Use decision matrix and module based evaluations/models/tests

**FIGURE 8.6**
Four possible configurations of features for a right-angle bracket. (a) Bent from a flat plate. (b) Machined from a solid block. (c) Bracket welded from three pieces. (d) Cast bracket.
2B. Configuration Design (Cont’d)

General configuration design rules

1. Clarity of Function
   • The relationship between inputs/outputs (energy, material, signal) and function should be unambiguous and, when possible, functions should be independent
   • Braking system should not interact with steering system (e.g. require same signal or energy input)

2. Simplicity
   • Design to the minimum complexity level while still achieving function. (KISS)
   • Design should be easily understood and produced.

3. Safety
   • As much as possible, safety should be guaranteed by direct design, not by secondary methods (labels, guards, etc.).
More about safety

Safety

- As much as possible, safety should be guaranteed by direct design, not by secondary methods (labels, guards, etc.).

Direct Safety

- Involves design approaches that prevent accidents from happening
- Fail safe, redundancy, visible checks
- Evaluate risk, reliability, availability, cost
- Safety preserved for operator, society, and environment (and equipment)

Indirect Safety and Chain of Failure

- What if ____{breaks, loosens, slips, rusts, fails, etc.}?
- What is the next safety barrier item (in the chain of failure)?
- Warnings are not legally sufficient defense against claims of negligent product design

Scope: Safety design evolves safety of function, working principle, layout, operation (e.g. ergonomics), manufacturability, assembly/transport, operation, maintenance, recycling
2B. Configuration Design

General Design Principles

(1) **Force Transmission** – involves designing with an understanding of how forces will be transmitted within and between components to minimize/eliminate sections of potential weakness (e.g. maintain low nominal stresses, reduce stress concentration, maintain uniform stress distribution) [mechanical design focus]

(2) **Division of Tasks** – similar to clarity of function. Critical functions require components designed for that single function. Resist assigning multiple functions to a single component to avoid compromising performance of individual functions. *Must balance performance vs. cost.*

(3) **Self-Help** – where possible make designs that are “fail safe”, self-reinforcing, or self-protecting. For example, O-ring seal that provides better sealing with increased pressure. **Austenitic manganese parts** – improved wear performance in response to heavy deformation.

(4) **Stability** – design should be developed to recover appropriately from a disturbance. For example, ship that rights itself in high seas or plating bath chemistry that stabilizes after chemical excursion.
2B. Configuration - Design Checklist

1. Identify how each component/part may fail in service (wear, corrosion, overload, fatigue).
2. Identify ways that component/module functionality might be compromised.
3. Identify possible materials and manufacturing issues.
4. Identify areas of limited design knowledge base. Are there “unknown” areas of the design?

This process typically requires a Failure Modes and Effects Analysis (FMEA).
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2. Embodiment Design

C. Parametric Design

• Once a final design configuration is selected the design variables (parameters) must be set through evaluation.

• Design attributes for each component are identified in configuration design and become design variables (component attributes that may be varied by designer)

• This process involves detailed modeling and analysis to determine the final design parameters.

• System level evaluation and parametric analysis.

• Output:
  • Robust design
  • Final sizing of parts, tolerances, flow rates, chemistry, etc.
2. Embodiment Design

C. Parametric Design (Cont’d)

Parametric Design Steps

1. Generate alternative designs (combinations of design variables). E.g. part size, materials, flow rates, tolerance, etc.

2. Analyze/evaluate the alternative designs

3. Select best alternative design

4. Refine/optimize
Example: Anodizing
What are the design variables? How would you analyze/evaluate?

The Design Process

<table>
<thead>
<tr>
<th>Solution No.</th>
<th>Type</th>
<th>Cycle time, min</th>
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<tbody>
<tr>
<td>1</td>
<td>Alkali</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>Alkaline etching</td>
<td>50-71</td>
</tr>
<tr>
<td>3</td>
<td>Desmutting</td>
<td>Room</td>
</tr>
<tr>
<td>4</td>
<td>Anodizing</td>
<td>70-75</td>
</tr>
<tr>
<td>5</td>
<td>Sealing</td>
<td>100</td>
</tr>
</tbody>
</table>

Fig. 5 Operations sequence in sulfuric acid anodizing of architectural parts
The Design Process

3. Detail Design (final design)

• Detailed design is the phase where “all of the details are brought together, all decisions are finalized and decision is made to release to production”

• Creation of final drawings and/or specifications.

• **Example** – final definition of flow rates, chemistries, process time, temperatures, etc. for an extractive metallurgy process.

• The line between embodiment design and final design is often blurred.
3. Detailed Design (Final Design)

Steps

• Make/Buy Decisions
• Finalize selection and sizing of components
• Complete engineering drawings
• Complete Bill of Materials (BOM)
• Verification and Prototype Testing Completed
• Final Cost Estimate
• Prepare Design Project Report
• Final Design Review
• Release to Manufacturing (order material, fabricate, etc.)