Entrepreneurship in Electrical Engineering

PART 2

SYSTEMATIC DESIGN

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What is Design?

- the systematic and creative application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems
- the creative, iterative and often open-ended process of conceiving and developing components, systems and processes.
- requires the integration of engineering, basic and mathematical sciences. A designer works under constraints, taking into account economic, health and safety, social and environmental factors, codes of practice and applicable laws

Design as an Activity

- Affects all areas of life
- Uses laws and insights
- Builds on experience
- Is a prerequisite for the realization of ideas into reality
- Is a SOCIAL activity

To Design

- To imagine things that don't exist and bring them into the world
- These things are tangible
- Design is regarded as an art rather than science
  - Science: proceeds by laws (sometimes mathematical)
  - Art: proceeds by rules of thumb, intuition, feeling; but adheres to constraints and laws of nature

Engineering Design

- is a systematic intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy specified constraints (Dym and Little)
- is a bigger part of the product realization process
  - Includes sales, marketing, industrial design, manufacturing, etc
- must work together with other disciplines
- is the set of decision-making processes and activities used to determine the form of an object given the functions desired by the customer (Eggert)

Engineering Analysis

- Predict the behavior or function of an object using analytical equations or experimental methods
- Formulating
  - Understand and plan solution
  - Gathering information
  - Rough plan on how to solve
- Solving
  - Determine unknowns of the equations
  - Solve and label with units
- Checking
  - Does it make sense
- Essential, but not only component to design

Common problems with Understanding “Design”

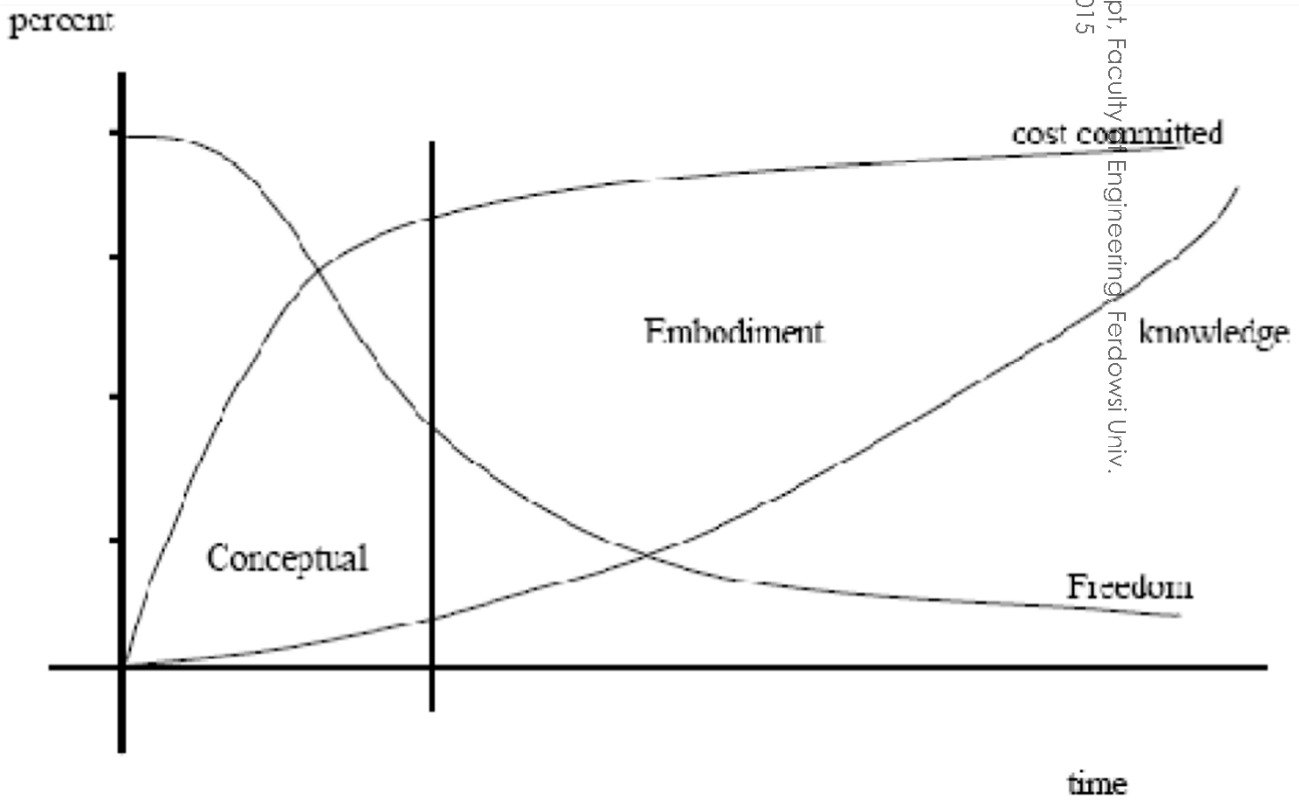
- Some common and dangerous thoughts
  - Design Cannot be taught
  - In order to design you must build stuff!
- Design is easy to demonstrate and not easy to articulate
- Mathematics provides a formal language to articulate behavior
  - Such mathematical models do not exist to describe design

Some features of “Design”

- Open ended problems
- Ill structured
- There are several acceptable solutions
- Design solutions cannot be simply found by using mathematical formulae and algorithms

Common Design Process

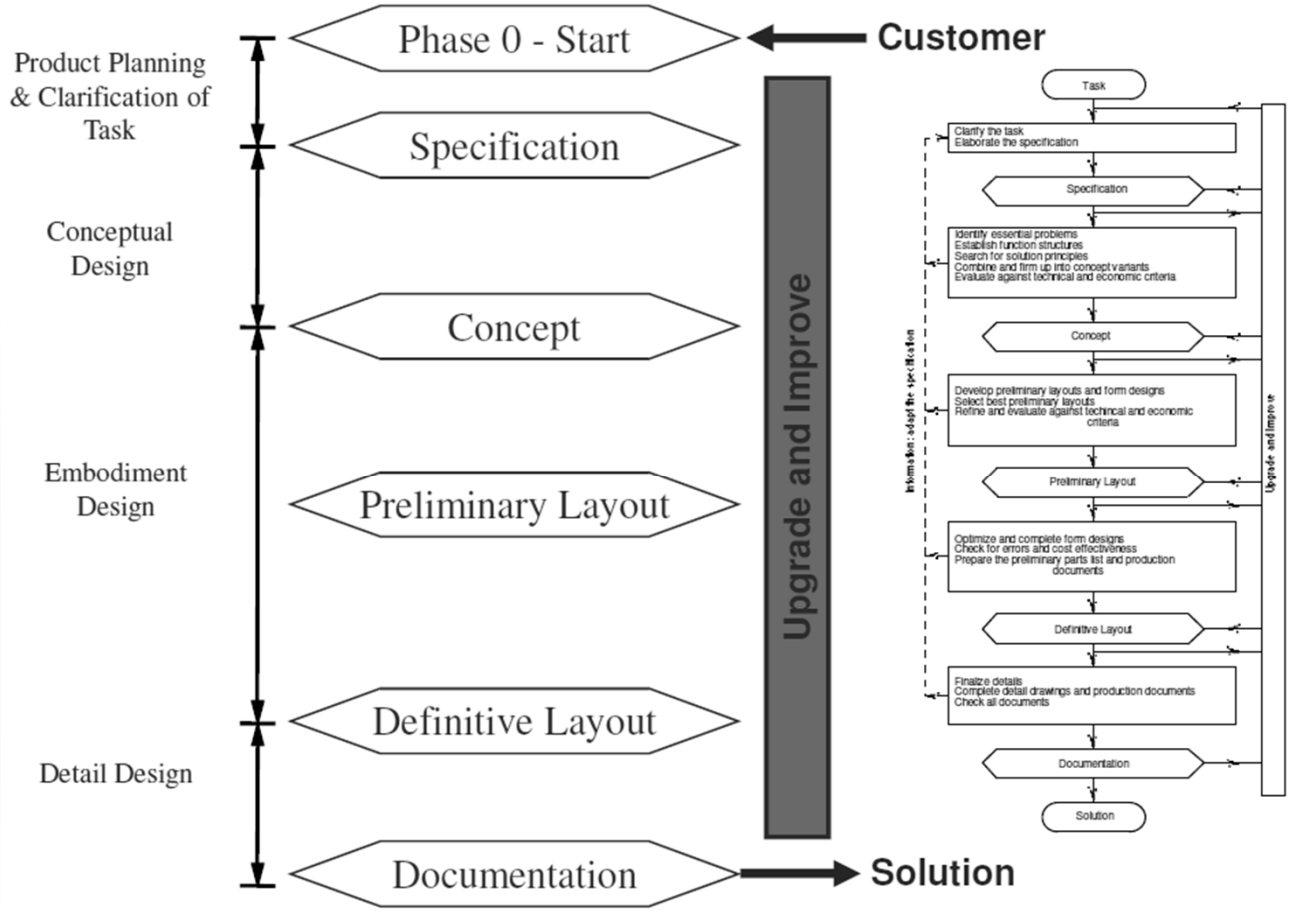
- Decisions made during a product's design phase generally establish the majority of manufacturing costs
- The National Research Council has determined that nearly 70% of a product's cost is determined in the first 5% of the design process



Some Requirements for Systematic Design

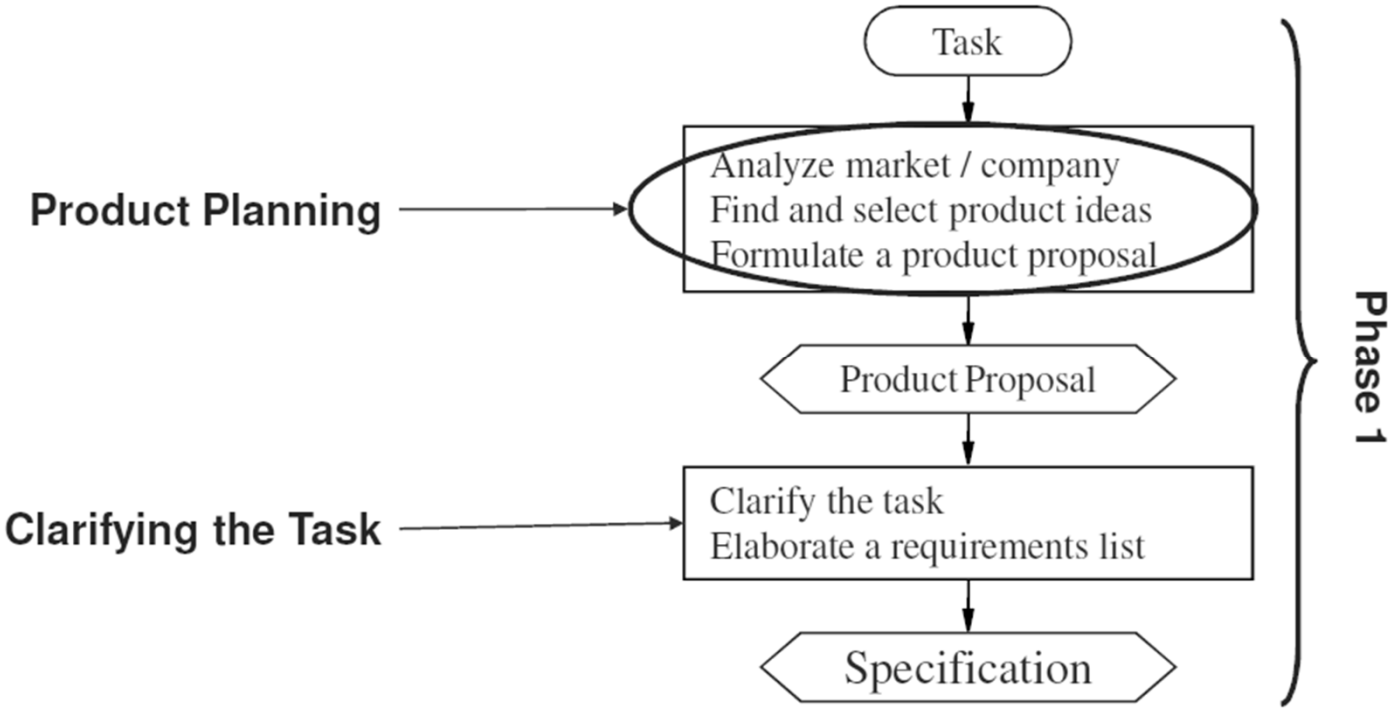
- be applicable to every type of design activity
- foster inventiveness and understanding
- be compatible with other disciplines
- not rely on chance
- facilitate the application of known solutions
- be compatible with electronic data processing
- be easily taught and learned
- reflect the findings of psychology and ergonomics
- emphasize the objective evaluation of results

Design : Systematic Approach



Design Phase 1 : Product Planning (PP)/Clarification of Task (CT)

- Developing and formulating a promising product idea



Successful PP should consider : market, company and economy

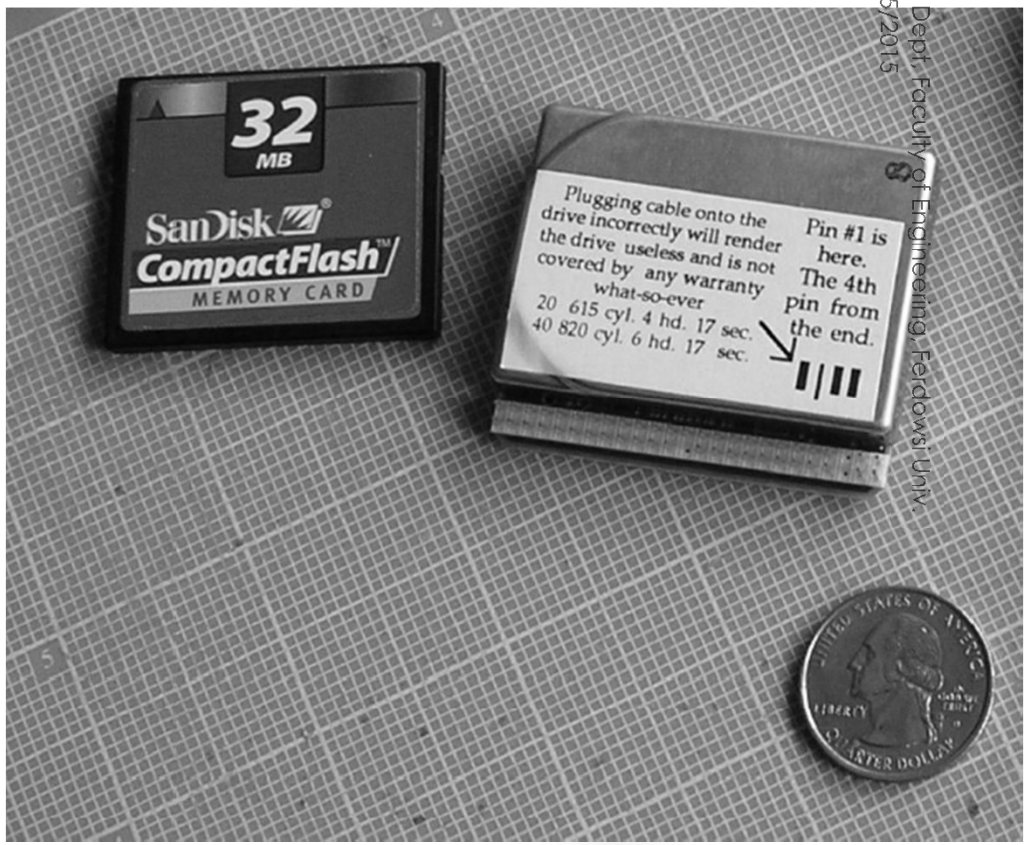
- Market
  - technical and economic position of product
  - changes in market requirements
  - suggestions and complaints of customers
  - technical and economic superiority of other products
- Other sources
  - economic and political changes ... oil prices ... regulations ... limitations ... culture
  - new technologies
  - environmental and recycling issues
- Within the company
  - company R&D
  - product evolution ... new functions to satisfy new market needs
  - process evolution ... new ways of doing / making things
  - rationalization of product line

Activities in Product Planning (PP)

- Analyze the situation
  - Analyze the situation of the company and products using knowledge of market and other sources
- Formulate search strategies
  - Take into account the goals, strengths and weaknesses of the company, market niches and needs
- Find product ideas
  - Search for new functions, working principles or geometries based on existing or extended energy, material signal flows
- Select product ideas
  - Using selection procedure that takes into account goals, strengths, and market
- Define products
  - Elaborate and evaluate product ideas. Results in a Product Proposal
- Technology push vs. customer pull:
  - Do you think that customers wanted to watch videos on their IPODS?

Product Planning : Case Study

- Kittyhawk drive
  - HP introduced in 1992
  - 1.3" Kittyhawk microdrive
  - 20 and 40 megabytes of storage
  - Tiny motion sensor that would park the heads if it detected the device being dropped
  - How not to bring a technology to market



Clarification Task

- Define the goals
- Clarify boundary conditions
- Dispel prejudice
- Make decisions

- Fixed solution ideas or concrete indications implicit in the task formulation often have an adverse effect on the final outcome

Clarification of Task

- What is the essence or crux of the problem?
- What implicit wishes and expectations are involved?
- Do the specified constraints actually exist?
- What paths are open for development?
- What are the objectives?
- What are essential properties?
- Avoid:
  - fixed solution ideas / solution-specific considerations
  - fictional constraints and concrete implications

Requirement List : Contains

- Problem Statement ...
  - Summary of the crux of the problem
- Project ID / Issue Date ...
  - the project identifier (e.g., project number and name) and the date the requirements list was generated
- Demands / Wishes ...
  - an indication of requirements that must be satisfied versus those that are less “critical”
- Group or Individual Responsible ...
  - the name of the group(s) / individual(s) responsible for specific requirements
- Modifications / Date ...
  - the date and type of modification made to requirements
- Requirements ...
  - Particular characteristics of the intended solution, quantified (if possible) and clearly arranged

Requirements : Categories

- Geometry
  - size, height, breadth, length, diameter, space requirement, number, arrangement, connection
- Kinematics
  - type of motion, direction of motion, velocity, acceleration
- Forces
  - direction and magnitude of force, frequency, weight, load, deformation, stiffness, elasticity, stability, resonance
- Energy
  - output, efficiency, loss, friction, ventilation, state, pressure, temperature, heating, cooling, supply, storage, capacity, conversion

Requirements : Categories

- Material
  - physical and chemical properties of the initial and final product, auxiliary materials, prescribed materials (food regulations, etc.)
- Signals ...
  - inputs and outputs, form, display, control equipment
- Safety ...
  - direct safety principles, protective systems, operator and environmental safety
- Ergonomics ...
  - man-machine relationship, type of operation, clearness of layout, lighting, aesthetics

Requirements : Categories

- Production ...
  - factory limitations, maximum possible dimensions, preferred production methods, means of production, achievable quality and tolerances
- Quality Control ...
  - possibilities of testing and measuring, application of special regulations and standards
- Assembly ...
  - special regulations, installation, siting, foundations
- Transport ...
  - lifting, clearance, transportation

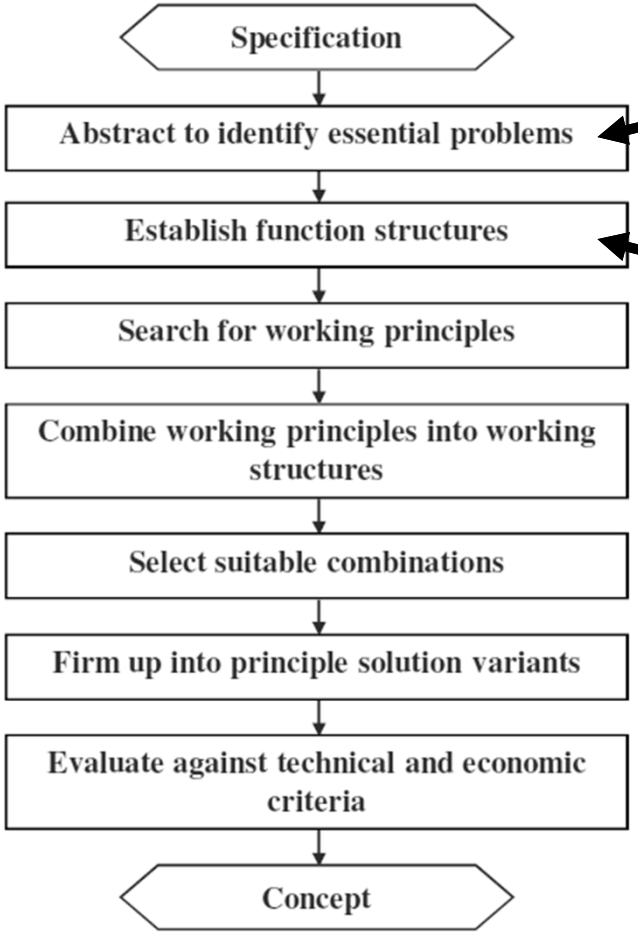
Requirements : Categories

- Operation ...
  - quietness, wear, destination/environment, special uses, market
- Maintenance ...
  - service, inspection, repair, painting, cleaning
- Recycling ...
  - reuse, reprocessing, waste disposal, storage
- Costs ...
  - maximum permissible manufacturing costs, investment, depreciation
- Schedules ...
  - end date of development, project planning and control, delivery date

Output of Phase 1

- Deliverables:
  - Detailed Product Proposal
  - Requirements List
- Make a decision to proceed to Phase 2
- Answer the following questions:
  - Has the task been clarified sufficiently to allow for development of a solution in the form of a design?
  - Must further information be acquired?

Phase 2 : Conceptual Design



- Remove false functions
  - Eliminate functions that do not have
  - bearing on the product
- Start in the function domain
  - What must the product do?
  - What must the product look like

- Define the goals
- Clarify boundary conditions
- Dispel prejudice
- Search for variants
- Evaluate
- Make decisions

Conceptual Design

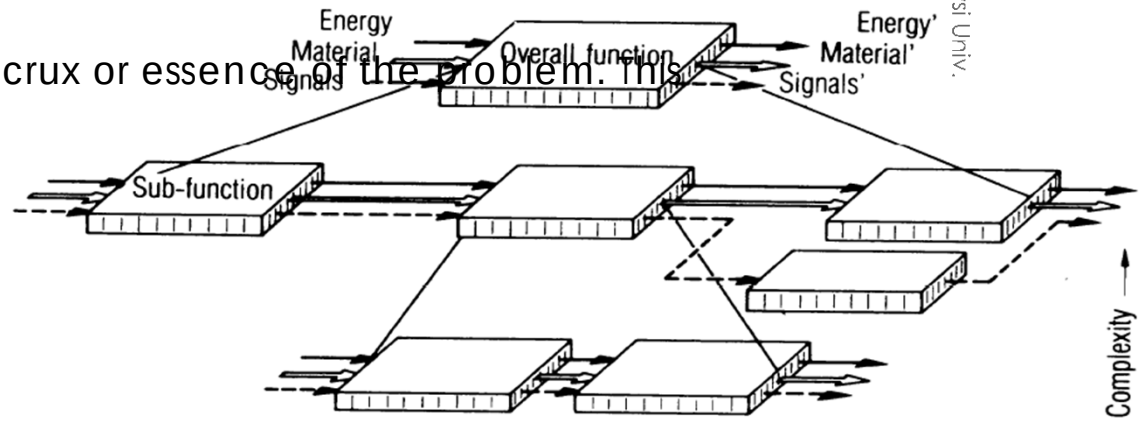
- The main goals in conceptual design:
  - by the identification of the essential problems through abstraction,
  - by the establishment of function structures, and
  - by the search for appropriate working principles and their combination,
- The basic solution path is laid down through the elaboration of a solution principle
- Concepts are developed from the solution principle
- The difference between
  - What and how
  - Principle and principal

Abstracting to Identify Essential Problems

- What is Abstraction?
  - Ignoring what is particular or incidental and emphasizing what is general
  - Identifying fictitious constraints and eliminating all but genuine restrictions
- Why is Abstraction Necessary?
  - To establish the crux or essence of the design task
  - Essential constraints become clear without prejudicing the choice of a particular solution.
  - To overcome prejudices, or conventions which, coupled with risk aversion, may lead to solution fixation

Establishing Function Structures

- What is a function?
  - A function specifies the relationship between inputs and outputs.
- Why function structures?
  - Express relationships between inputs and outputs independently of the solution. Facilitate the subsequent search for solutions.
- Where do I start?
  - Use abstraction to identify the crux or essence of the problem. This becomes the overall function.



Hair Dryer Function Structure

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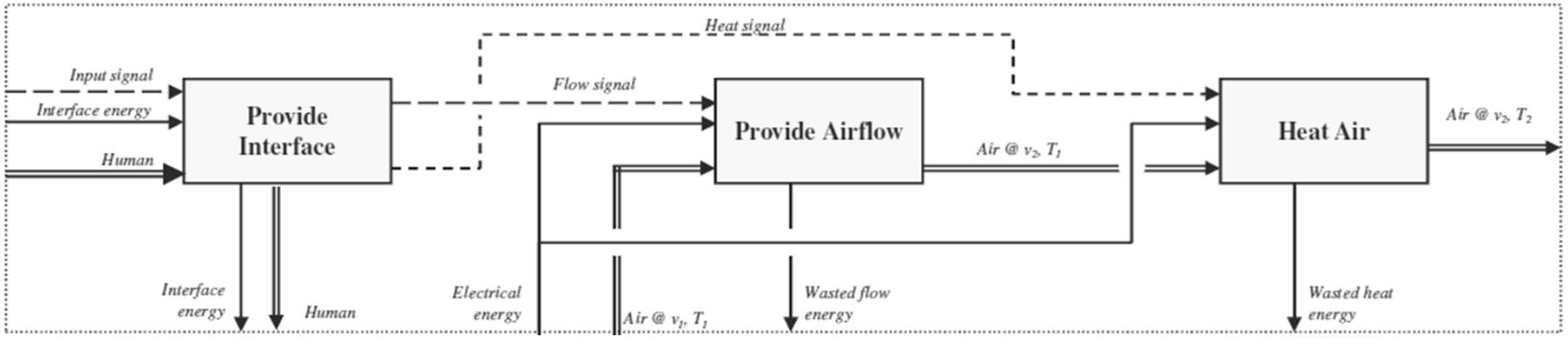
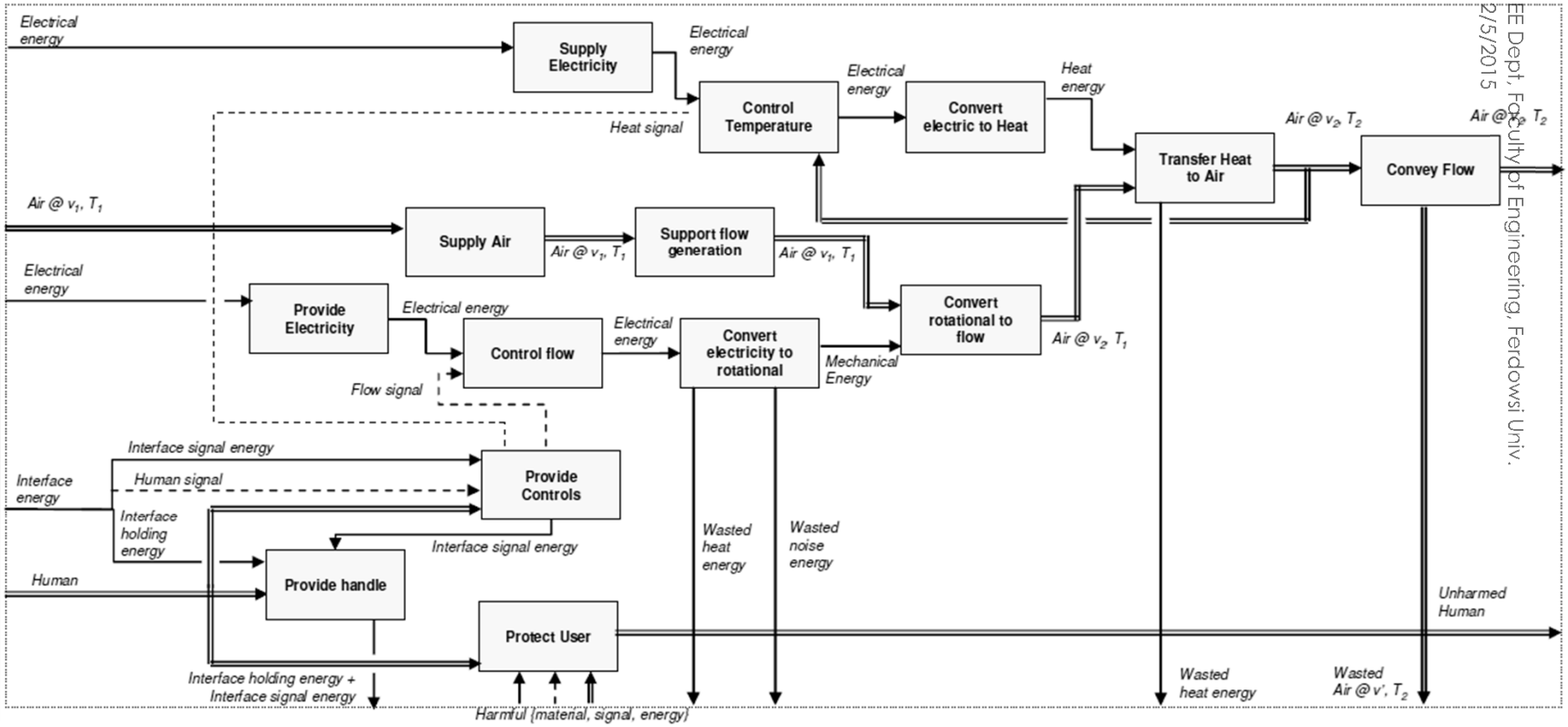


Hair Dryer Function Structure



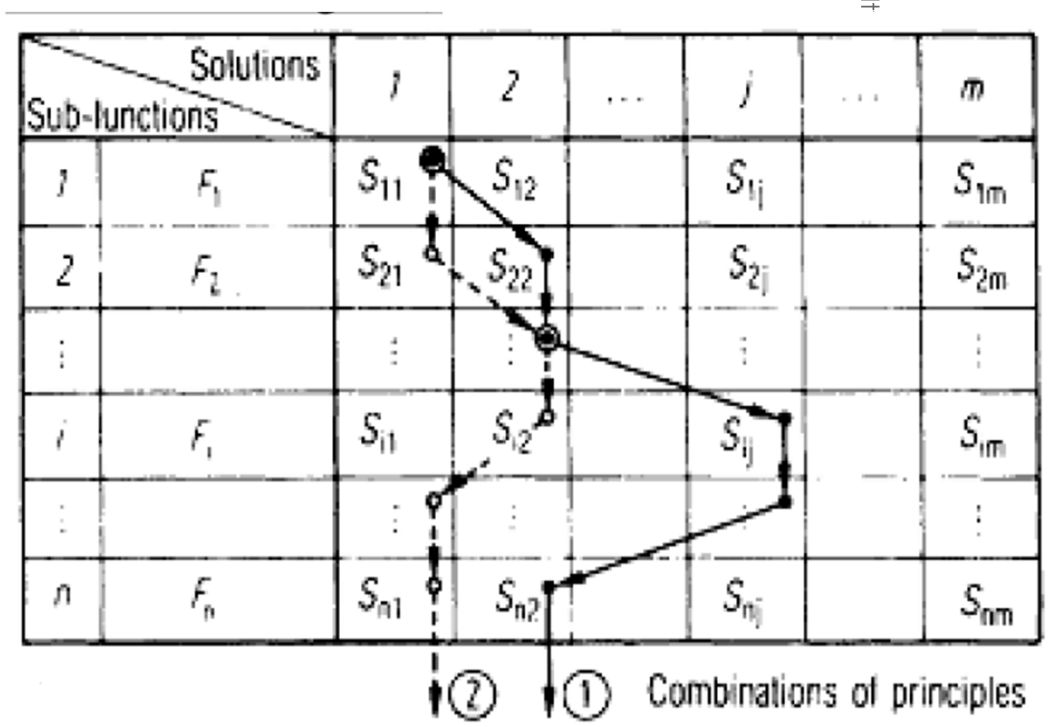
Search for Solutions

- Search for solution (working) principles to fulfill all leaf-functions.
  - Working principles represent a physical effect and preliminary embodiment (e.g., “cartoon” sketch).
  - Use ideation techniques, searches, and analysis of known or existing systems to
- determine as many working (solution) principles as possible
  - Catalog the solution principles for all of the sub-functions

Sub-Functions \ Solutions		1	2	...	j	...	m
1	F_1	S_{11}	S_{12}		S_{1j}		S_{1m}
2	F_2	S_{21}	S_{22}		S_{2j}		S_{2m}
⋮		⋮	⋮		⋮		⋮
i	F_i	S_{i1}	S_{i2}		S_{ij}		S_{im}
⋮		⋮	⋮		⋮		⋮
n	F_n	S_{n1}	S_{n2}		S_{nj}		S_{nm}

Working Structures

- Combine solution (working) principles into working structures.
- Use a morphological chart to help identify combinations (i.e., working structures)
- Each combination of working principles should fulfill the overall function (i.e., assure both physical and geometric compatibility and a smooth flow of Energies, Materials, and Signals)



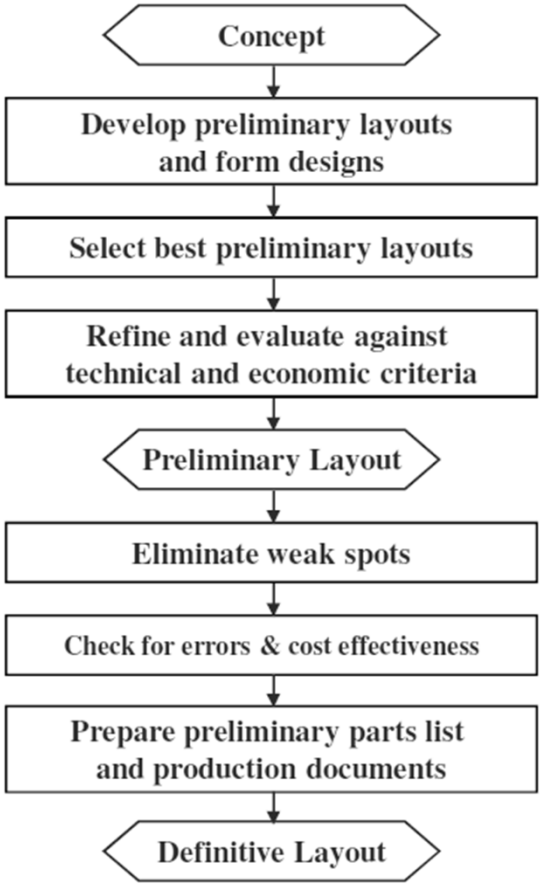
Working Principles to Concept Variants

- Selecting suitable combinations of working principles
  - Are the combinations of working principles likely to meet budgetary and other requirements?
- Firm up into concept variants
  - Qualitative to Quantitative Transition
    - Simplified calculations
    - Geometrical sketches and studies
    - Experiments on essential properties, model building
    - Simulations
    - Market, literature or patent search
- Evaluate concept variants against technical and economic criteria

Outcome of Phase 2

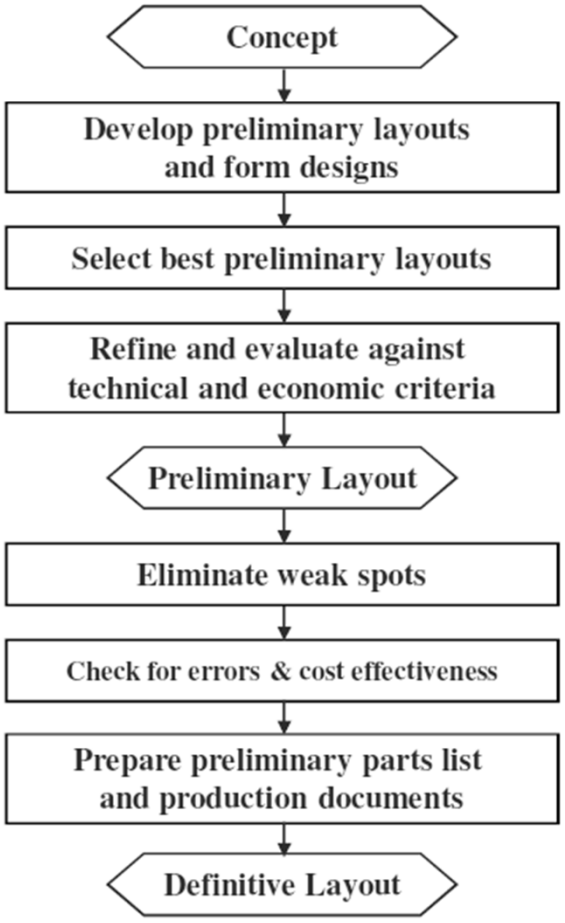
- Deliverables:
  - Abstract Requirements List
  - Function Structure
  - Morphological Matrix
  - Solution Selection and Evaluation
- Make a decision to proceed to Phase 3
- Answer the following questions:
  - Have sets of working principles (i.e. viable concepts) been identified to satisfy the requirements of the design
  - Have I properly abstracted and searched broadly for working principles
  - Am I design fixated and have I put added constraints to the design space?

Phase 3 :Embodiment Design (ED)



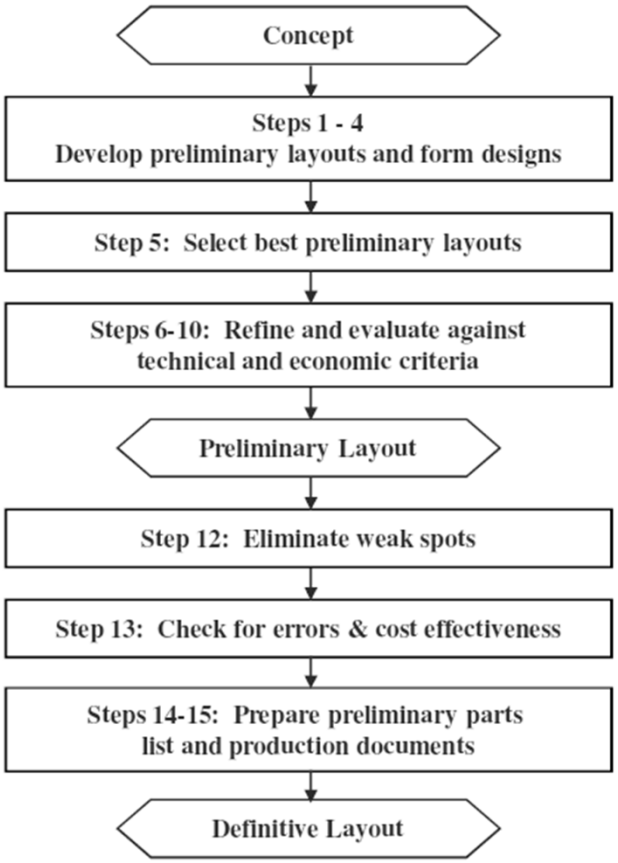
- Begins with a concept and ends with a definitive layout:
  - Working structure (Concept)
  - Technical details are added
- Fleshing out a selected concept
  - Start with embodiment-determining requirements and their function carriers or working principles
  - Proceed with requirements having less impact on embodiment

Overview of Embodiment Design



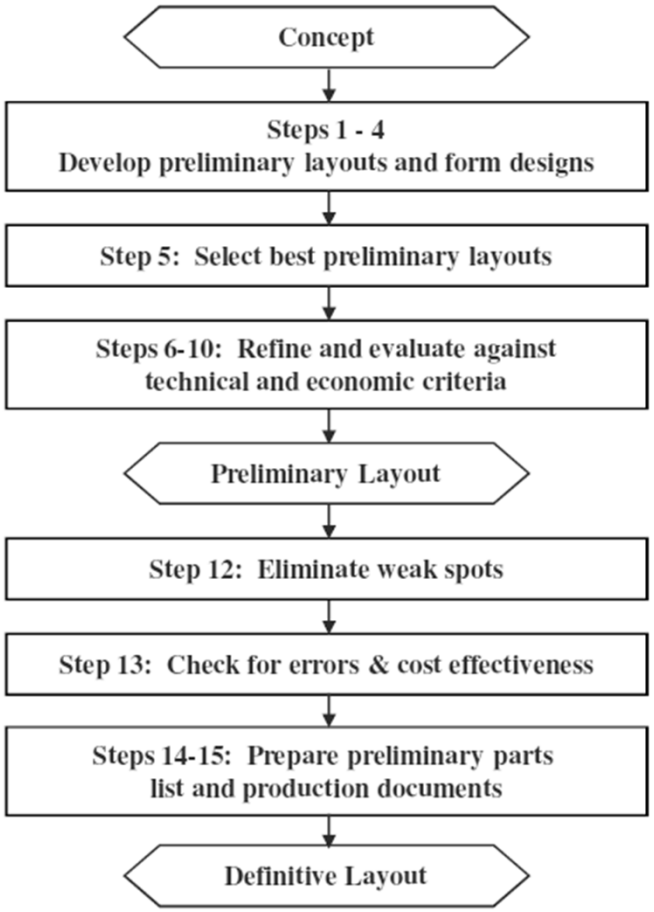
- General steps of embodiment design:
  - Preliminary layout and form design
  - Definitive layout and form design
  - Completion of checks & optimization (Only after checks, can you move on to detail design!)
- Characteristics of embodiment design:
  - Complexity!! Many simultaneous, interdependent activities!
  - Analysis and synthesis alternate and complement each other! Optimization and error ID + solution search and evaluation. Some steps must be repeated at a higher info level.
  - Proceed from qualitative to quantitative, from abstract to concrete, from rough to detailed, with provisions for checks and corrections (I.e., iterations!).

Steps of Embodiment Design



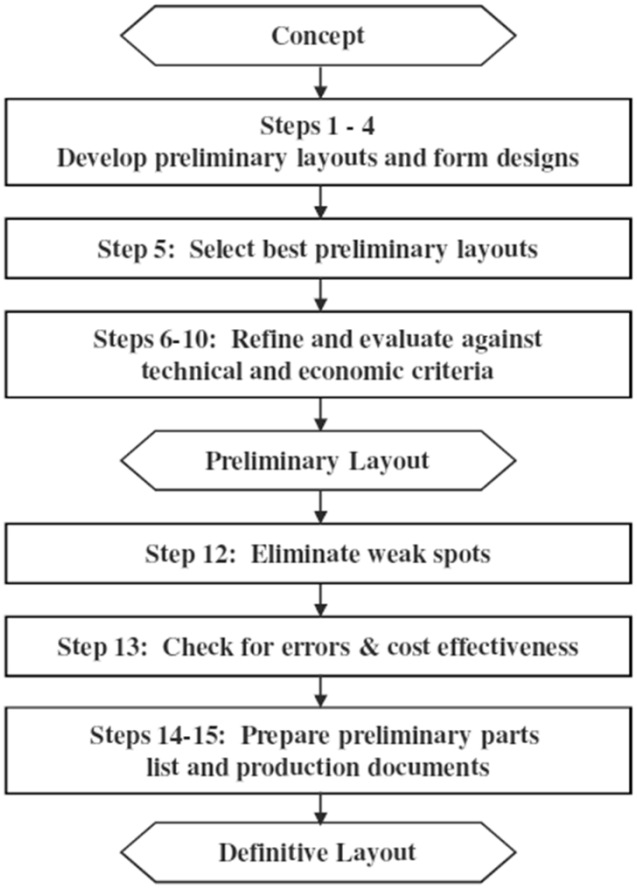
- 1. Identify requirements that have a crucial bearing on the embodiment of the design
  - size determining requirements such as output, through-put, size of connectors, etc.
  - arrangement determining requirements such as direction of flow, motion, position, etc.
  - material determining requirements such as resistance to corrosion, service life, specified materials, etc.
- 2. Produce scale drawings of the spatial constraints determining or restricting the embodiment design (e.g., clearances, installation requirements, etc.)
  - Top-down assembly modeling versus bottom-up modeling
- 3. Establish rough layout (based on concepts) which emphasizes the embodiment-determining main function carriers, that is, the assemblies and components fulfilling the main functions.
  - Which main functions and function carriers determine the size, arrangement and component shapes of the overall layout?
  - What main functions must be fulfilled by which function carriers jointly or separately?
- 4. Determine preliminary layouts and form designs for the embodiment-determining main function carriers.

Steps of Embodiment Design



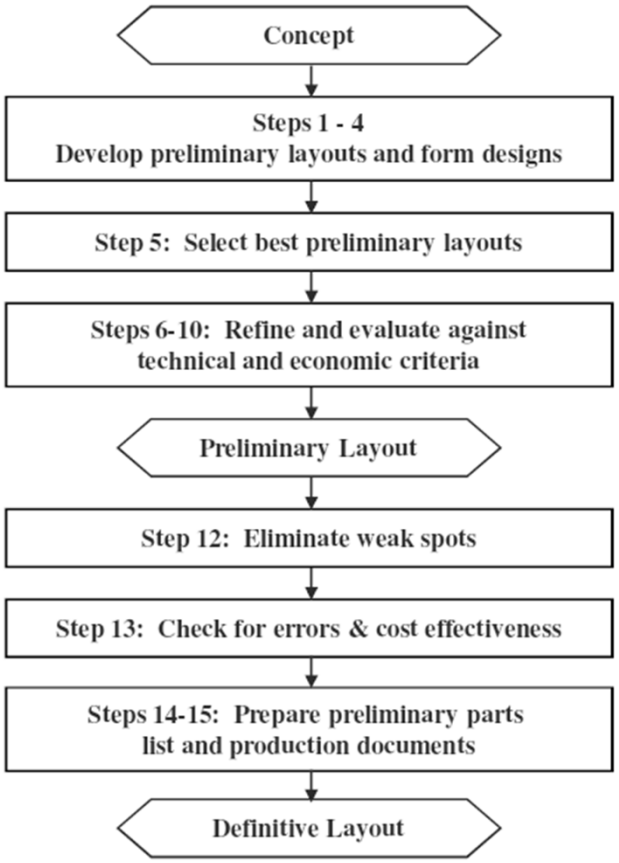
- 5. Select one or more suitable preliminary layouts
- 6. Develop preliminary layouts and form designs for remaining function carriers.
- 7. Determine which essential auxiliary functions are needed.
  - Exploit known solutions if available (e.g., atalogues)
  - Search for special solutions
- 8. Develop detailed layouts and form designs for main function carriers in accordance with embodiment design rules and guidelines.
  - Consider compatibility with auxiliary functions
  - Divide into assemblies or areas to be elaborated individually if necessary

Steps of Embodiment Design



- 9. Develop detailed layouts and form designs for auxiliary function carriers
  - Use standard parts, if possible.
  - Combine all function carriers into overall layouts
- 10. Evaluate layouts against technical and economic criteria
  - – Make sure all designs are at the same level of embodiment, BUT
  - – don't go beyond the level of detail required by evaluation. You may need only a preliminary layout, or you may need more details to choose among alternative layouts.
- 11. Fix preliminary overall layout
- 12. Optimize and complete form designs for the selected layout.
  - Eliminate weak points
  - Adopt suitable solutions from less favored variants

Steps of Embodiment Design



- 13. Check layout design for errors
  - in function, spatial compatibility, etc.
  - achievement of objectives with respect to cost and quality
- 14. Prepare preliminary documentation.
  - parts lists
  - production documents
  - assembly documents
- 15. Fix definitive layout design and pass on to detail design phase

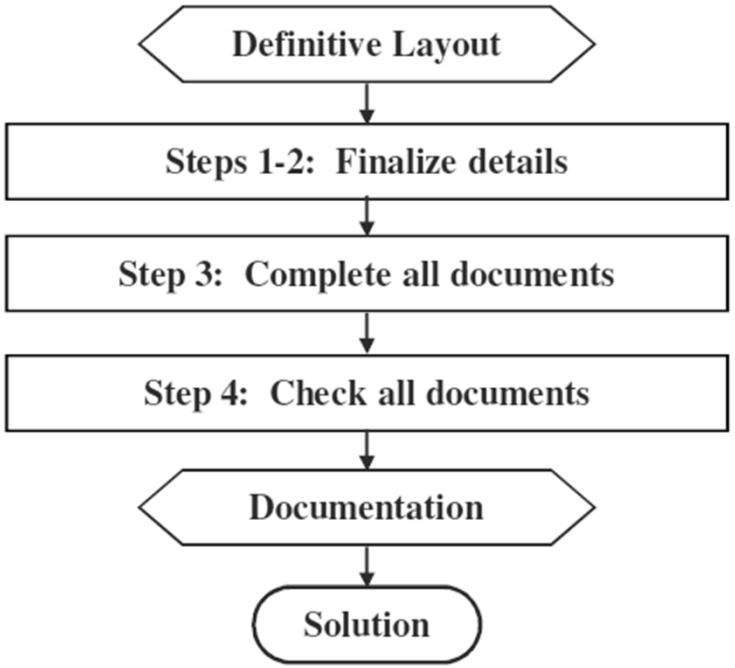
Considerations in Embodiment Design

- Basic rules of clarity, simplicity, and safety are derived from general objectives,
  - fulfillment of the technical function and economic feasibility
- General considerations for evaluating alternatives
  - Durability, deformation, stability, expansion, ergonomics, aesthetics, ease of assembly
- Designer determines the value of solutions wrt specific objective(s).
  - Value of a concept is not absolute
  - Establish objectives from:
    - requirements list
    - technical properties (e.g., Fig 7.3)
- All embodiment designs must have same degree of correctness and information content
- Production costs must be determined to the extent possible
- Evaluation should include a search for weak spots. Look for opportunities to combine strong aspects of different alternatives.

Outcome of Phase 3

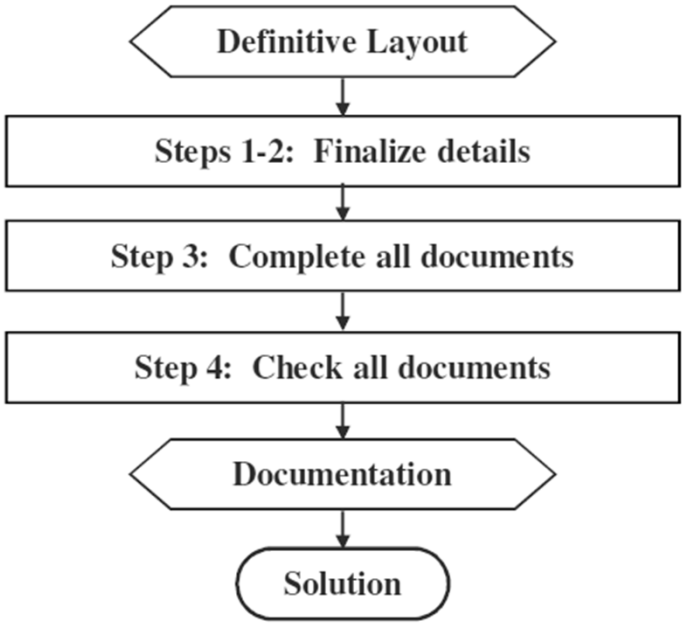
- Deliverables:
  - General Layout Requirements
    - The requirements related to the layout of the design
  - Preliminary Layouts
    - The general layout of the product solution neutral format
  - Solution Evaluation
    - A systematic method to evaluate the more detailed design
  - Preliminary Diagram
- The general layout of the final design with minimal knowledge about the details of the final product
- A definitive layout for which production documents can be prepared with minimal detail design.
- Before proceeding to Phase 4, ask yourself:
  - Am I satisfied that this definitive layout satisfies all relevant and appropriate requirements (function, layout, assembly, costs, maintenance, etc.)?
  - Am I ready to prepare final production documents for this design (tolerances, assembly processes, materials, tooling, etc.) without delay?

Phase 4 : Detail Design (DD)



- Begins with a definitive layout and ends with product documentation
  - The use of Computer-aided design tools
  - Final design specifications
    - Form
    - Dimensions
    - Surface quality
    - Properties
- Final chance to identify and correct mistakes

Steps in Detail Design



- 1. Finalize the definitive layout
  - Detailed drawings of components
  - Detailed optimization of shapes,
  - Materials, surfaces, tolerances and fits
- 2. Integrate individual components into assemblies and assemblies into overall product
  - include assembly drawings
  - Parts lists (BOM)
- 3. Complete production documents
  - manufacturing
  - assembly
  - transport
  - operating instructions
- 4. Check all documents, especially detail drawings and parts lists for:
  - observation of general and in-house standards
  - accuracy of dimensions and tolerances
  - other essential production data
  - ease of acquisition, e.g., availability of standard parts

Key Deliverables

Phase	Deliverable	Value
Planning and Clarification of Task	Requirements list	Identifies customers want for the product
Conceptual Design	Abstract requirements list	Identifies the function specific requirements to form solution-neutral problem statements
	Function structure	Identifies the functions and organized the flow of energy, matter and signal
	Morphological matrix	Catalogs the working principles and organizes them to meet the functions
	Solution evaluation	Systematic method to evaluate concepts in order to proceed with the design
Embodiment Design	General layout requirements	The requirements that only deal with the layout of the design are identified
	Preliminary layouts	Form the general layout of the produce in still a solution neutral format
	Solution evaluation	Again, systematic method to evaluate, in more detail, design as they proceed
	Preliminary Diagram	Help to envision the layout of the design in with minimal knowledge about the details of the product
Detail Design	Final Layout, forms, dimensions	Enables the part to be made, operated, assembled, etc.