Usage of Design Methods in the Steps of Design Architecture

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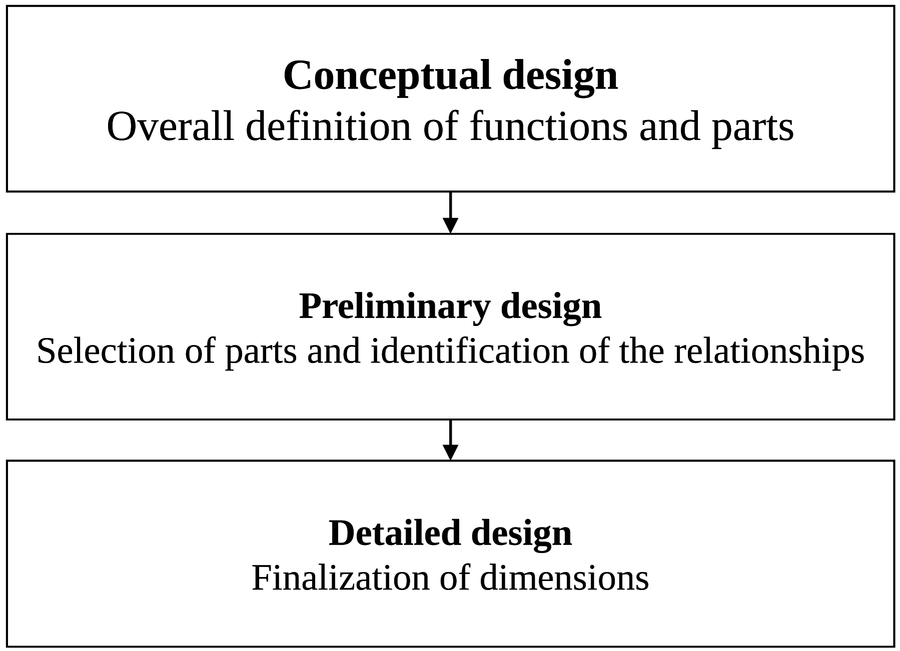
❑ What is Design Engineering?

Design { **Ad Hoc Process – Art: Subjective** / **Scientific Base – Science: Objective** }

- Decision making is typically carried out in the design process.
- Many engineers consider design as art.
- Researches are performed based on the scientific approaches.
- Are there any rigorous design methodologies with a definite form? Or are there any universal methods which can be used in any type of environment?
- Top down approach vs. Bottom up approach
- Synthesis vs. Analysis

❑ Classification of Design

- Classification of design based on the sequence: Design can be classified into conceptual design and detailed design from the viewpoint of the application of design methods.



<Sequence of design>

❑ Analytic Design Methods

- Analytic design is a design activity using scientific principles or a process with rigorous methods to achieve a good design. The utilized principle is a design methodology.
- Is design methodology a technique or a philosophy?
- Where did we apply analytic design methods?
- What did we find? Was it correct?

❑ Design Methods

- Conceptual design
    1. Axiomatic Design, TRIZ: Excellent for conceptual design
- Detailed design
    1. Optimization: Good for detailed design
    2. Structural optimization: Determination of structural configuration using optimization and FEM theories
    3. Design using Design of Experiments (DOE)
    4. Robust design: Insensitive design (The Taguchi method)
    5. Multidisciplinary Optimization (MDO)

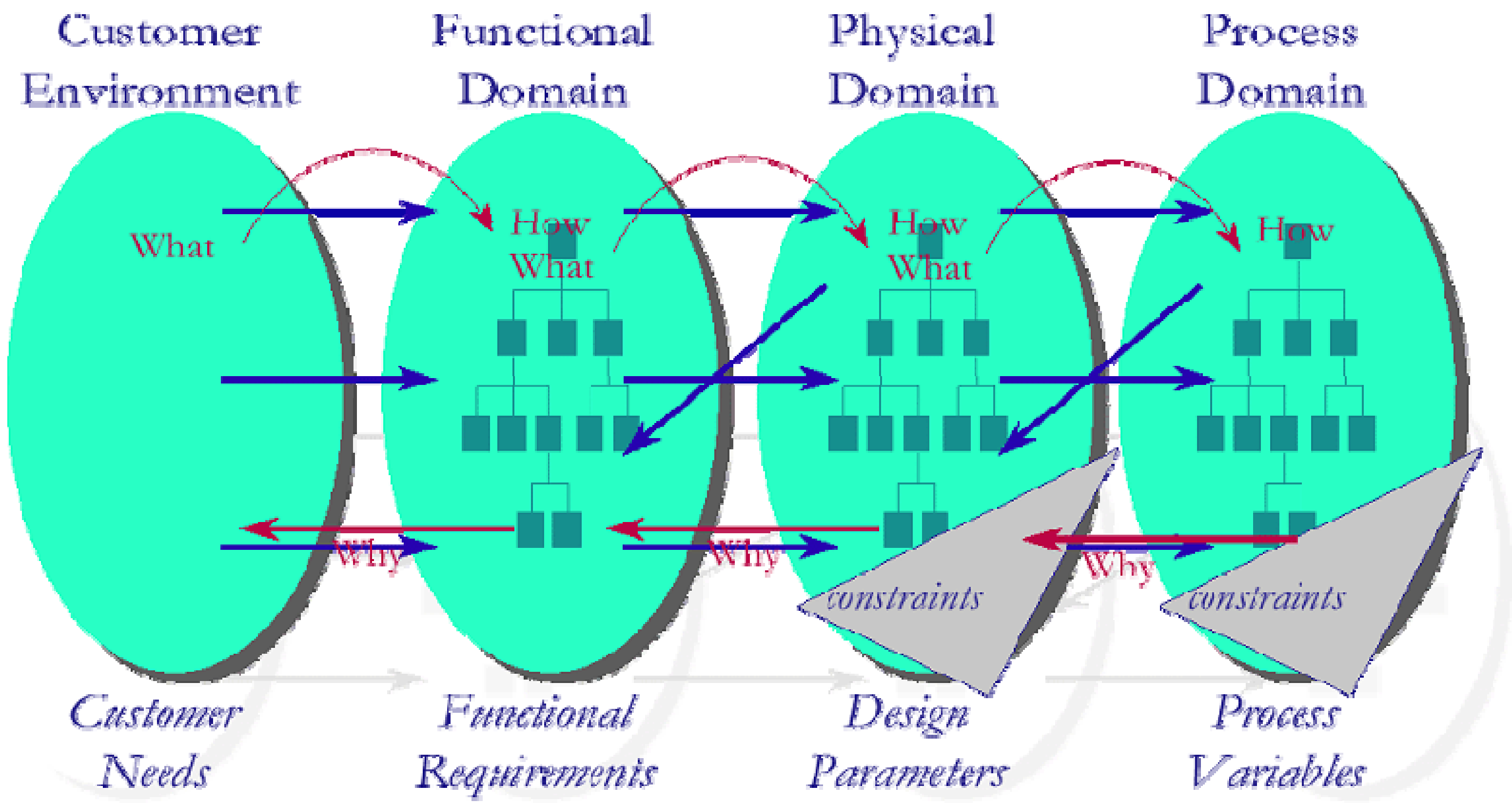
Which one has more impact? Where do we spend the resources?

❑ Axiomatic Design

- The design process is a continual interplay between *what* designers want to achieve and *how* they achieve it.

- The *objective of axiomatic design* is to "establish a science base for design and to improve design activities by providing the designer with a theoretical foundation based on logical and rational thought processes and tools." [Suh (2000)].

❑ Axiomatic Design: Domain and Mapping



❑ Axiomatic Design: Axioms

Axiom 1 : The Independence Axiom

Maintain the independence of functional requirements (FRs).

Alternate Statement 1 **: An optimal design always maintains the independence of FRs**

Alternate Statement 2**: In an acceptable design, the DPs and the FRs are related in such a way that a specific DP can be adjusted to satisfy its corresponding FR without affecting other functional requirements.**

Axiom 2 : The Information Axiom

Minimize the information content of the design.

Alternate Statement **: The best design is a functionally uncoupled design that has minimum information content.**

❑ Axiomatic Design: Design Equation

- Design Equation

$$\{FRs\} = [A]\{DPs\}$$

where [A] is a matrix defined as the Design Matrix that characterizes the product design.

$$[A] = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

❑ Axiomatic Design: Design Equation

- Uncoupled design

$$[A]=\begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ 0 & 0 & A_{33} \end{bmatrix}$$

- Decoupled design

$$[A]=\begin{bmatrix} A_{11} & 0 & 0 \\ A_{21} & A_{22} & 0 \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

- Coupled design: Not recommended

$$[A]=\begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

❑ Axiomatic Design: Design Equation

- In a *coupled design*, the desired changes to an FR cannot be achieved without affecting other FRs.
- In a *decoupled design*, each FR can be satisfied without iteration by changing the DPs in a particular sequence.
- In an *uncoupled design*, each DP affects a unique FR.

❑ Axiomatic Design: Information Axiom

- If multiple designs which satisfy the Independence Axiom are found, the one with the least information content is the best one.
- Information content is defined by the probability to satisfy the corresponding functional requirement (probability of success).
- The probability of success is one of the defined quantities for information content.
- At this moment, it is the only information measure that is accepted.
- Information content is related to robust design.
- More research is needed.

❑ Optimization

- Design optimization: engineering design that adopts the optimization theory.

- Formulation for design optimization

Find $\mathbf{b} \in R^n$

to minimize $f(\mathbf{b})$

subject to $h_i(\mathbf{b}) = 0 \quad i = 1, \ldots, l$

$g_j(\mathbf{b}) \leq 0 \quad j = 1, \ldots, m$

$\mathbf{b}_\mathrm{L} \leq \mathbf{b} \leq \mathbf{b}_\mathrm{U}$

$\mathbf{b} \in R^n$: design variable vector with n components

$f(\mathbf{b})$: objective function

$h_i(\mathbf{b})$: the *i*th equality constraint

$g_j(\mathbf{b})$: the *j*th inequality constraint

$\mathbf{b}_\mathrm{L}, \mathbf{b}_\mathrm{U}$: lower and upper bound vectors for **b**

l, m : numbers of equality and inequality constraints, respectively

- Appropriate formulation leads to a good solution.
- It is efficient to employ design optimization in the detailed design stage.
- The optimization theory is used to solve the above problem.
- The solution of the above problem satisfies the Karush-Kuhn-Tucker necessary conditions.
- However, it is not easy to handle the K-K-T conditions directly.
- A numerical method can be an alternative.

❑ Formulation of Structural Optimization

- A structural design problem is formulated as follows:

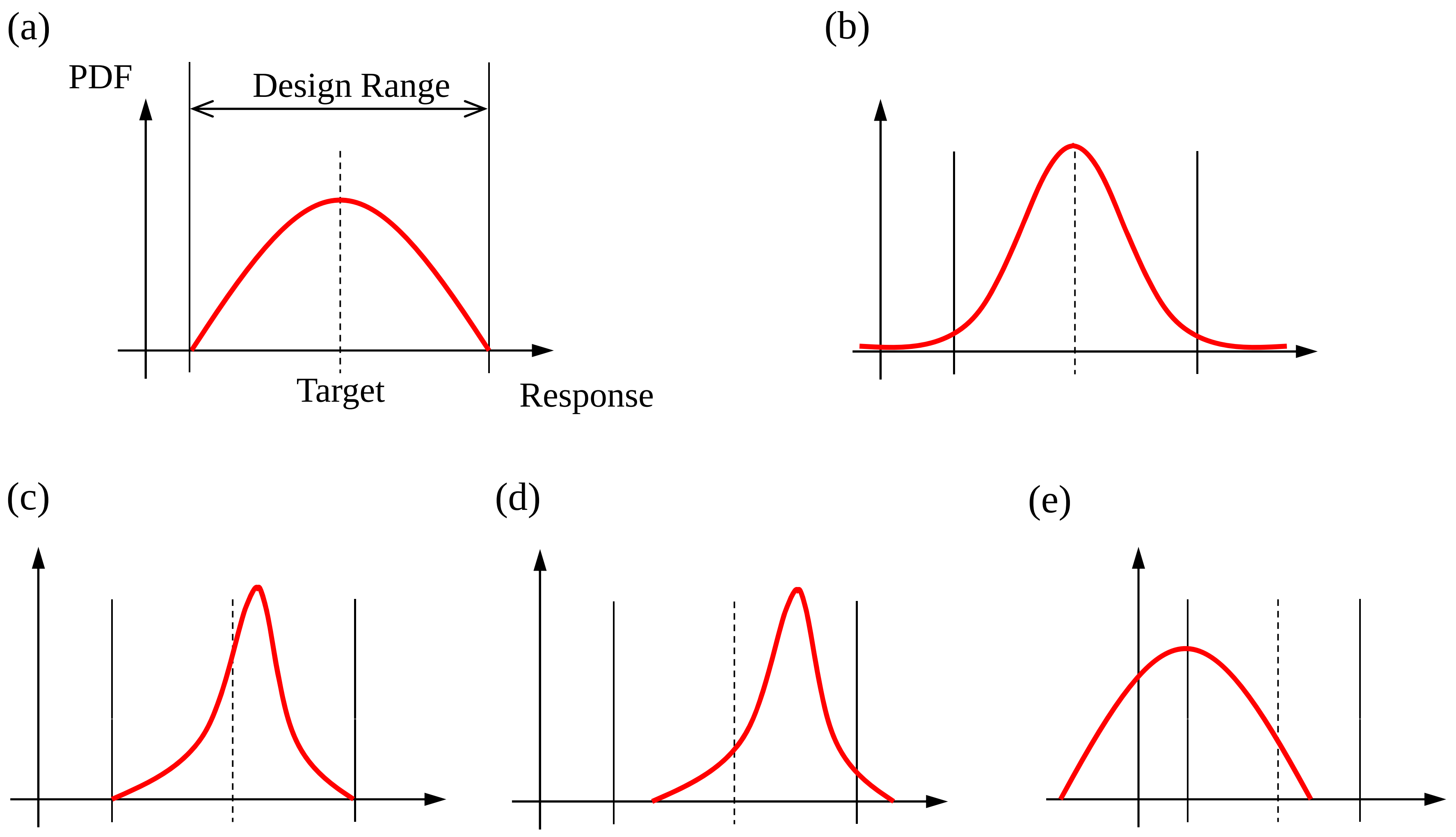
$$
\begin{aligned}
&\text{Find} && \mathbf{b} \in R^n,\ \mathbf{z} \in R^l,\ \xi \in R^1 \\
&\text{to minimize} && f(\mathbf{b}, \mathbf{z}, \xi) \\
&\text{subject to} && \mathbf{K}(\mathbf{b})\mathbf{z} = \mathbf{f} \\
& && \mathbf{K}(\mathbf{b})\mathbf{y} - \xi \mathbf{M}(\mathbf{b})\mathbf{y} = \mathbf{0} \\
& && g_j(\mathbf{b}, \mathbf{z}, \xi) \le 0, \quad j = 1, \ldots, m \\
& && \mathbf{b}_{\mathrm{L}} \le \mathbf{b} \le \mathbf{b}_{\mathrm{U}}
\end{aligned}
$$

- Objective function and constraints: weight, displacement, stress, natural frequency, etc.

- Design variables:

  1. Sectional dimensions (size optimization)
  2. Coordinates of nodes (shape optimization)
  3. Material distribution (topology optimization)

❑ Robust Design (Which One is a Good Design?)



Summary

- Currently various design methods are being utilized in their own ways.
- Students learn the design methods very easily. Especially, if math is involved, they think it is worthy.
- Engineers still tend to believe in their intuition in the design process.
- Managers tend to use the design methods as slogans or mottos.
- In academic society, they try to define design methods for publication.
- Wise and practical collaboration is expected.