Rethinking the System Development Process in Light of Design Theory

Ronald E. Giachetti, Ph.D.

Systems Engineering
Naval Postgraduate School
Monterey, CA 93940
regiache@nps.edu

Clifford A. Whitcomb, Ph.D.

Systems Engineering
Naval Postgraduate School
Monterey, CA 93940
cawhitco@nps.edu

May 2, 2016

Worldviews on Design

Worldview

Worldview, *Weltanschuuang*, and mental models describe deeply held beliefs about how the world works and that influence our thoughts and actions.

Two worldviews:

- **Positivism** – There is a single objective truth, which individuals can know via the scientific method. The *Technical Rational Design* approach.

- **Interpretivism** – People view the world via experiences and their interaction with the world. The *Design Thinking* approach.

The dominant approach to engineering design based on the worldview that we can know, define, and measure stakeholder value, system requirements, and then systematically search for the set of Pareto optimal designs.

- Simon was an early proponent with his publication of *Design of the Artificial*(1969) formulating design as a search problem suitable for artificial intelligence.

- Pahl and Beitz wrote an influential German text, *Konstruktionslehre: Grundlagen erfolgreicher Produktentwicklung. Methoden und Anwendung* (1984), systemizing the design process into four phases.

The Technical Rational Design perspective underlies the systems engineering process models of waterfall and vee.

Design Optimization Model

Find the design(s) to maximize value subject to system requirements.

$$\begin{array}{ll}
\arg\max_{\mathbf{D^k}} & \mathbf{V^k} = (V_1^k, ..., V_l^k) \\
\text{subject to} & r_j(\mathbf{D^k}) \leq 0 \qquad\qquad\qquad\qquad j = 1 \ldots m \\
& \Delta_i^{ll} \leq d_i \leq \Delta_i^{ul} \qquad\qquad\qquad\qquad i = 1 \ldots n
\end{array}$$

$$\mathbf{D^k} = \left(d_1^k, ..., d_n^k \right)$$
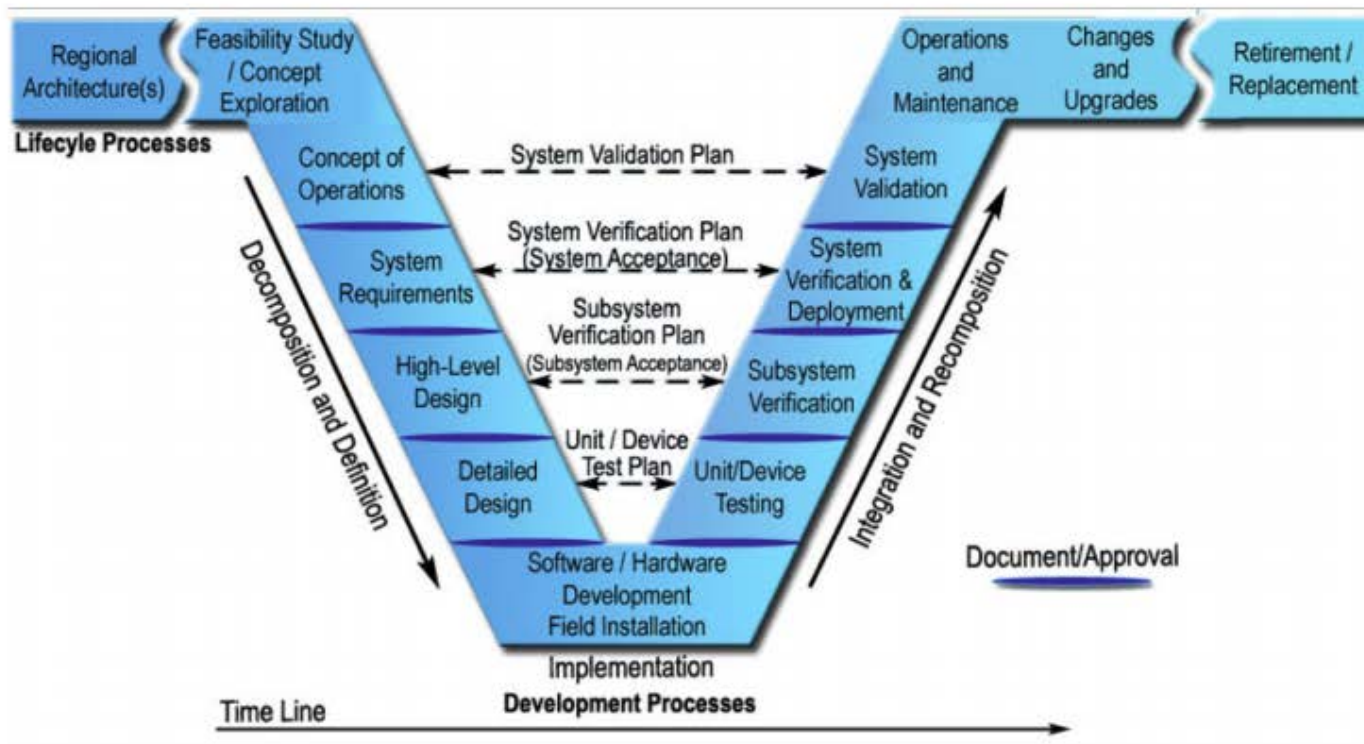
$$V_l^k = f\left(d_1^k, ..., d_n^k, n_1, ..., n_p \right)$$
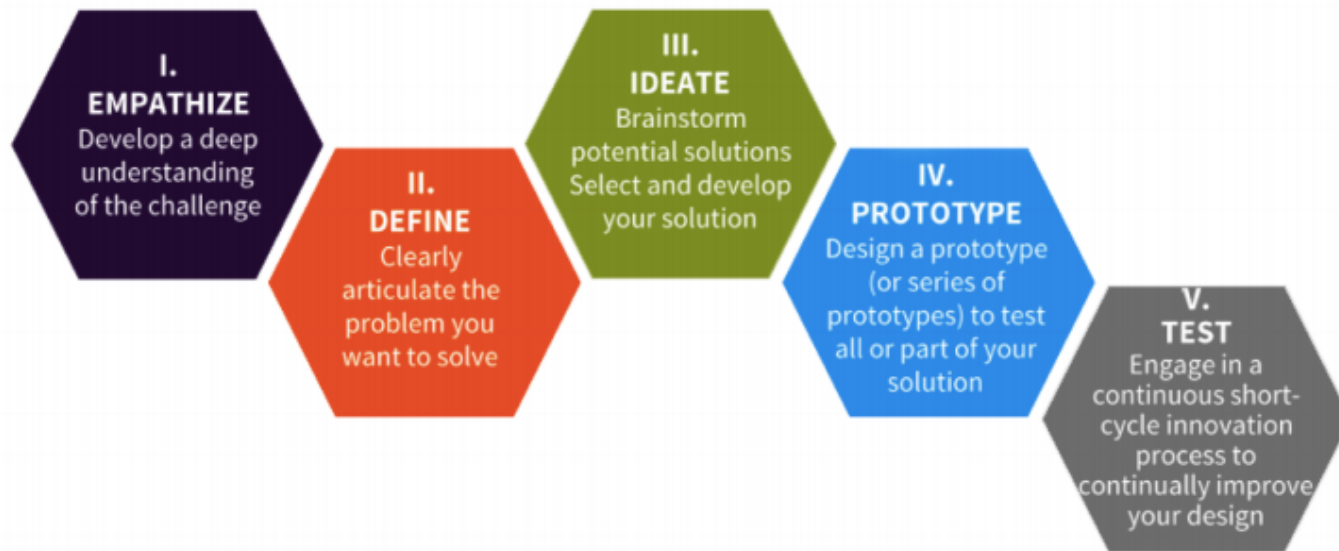
$$d_i \in \Delta_i$$

The Vee Process Model is the *de facto* standard for describing the systems engineering process.

- Adhere's to Technical Rational Design perspective
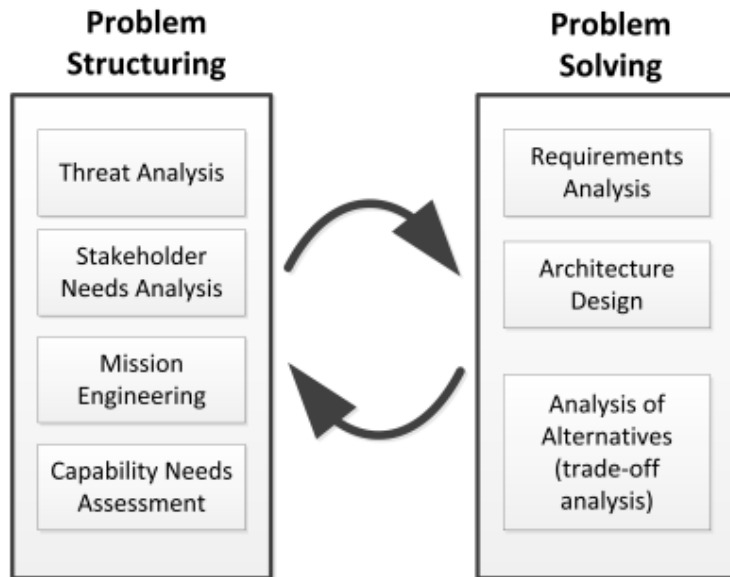
- Top-down approach

Observe how designers think and extract knowledge about the design process from these observations.

Source: Stanford Institute of Design, dschool.stanford.edu

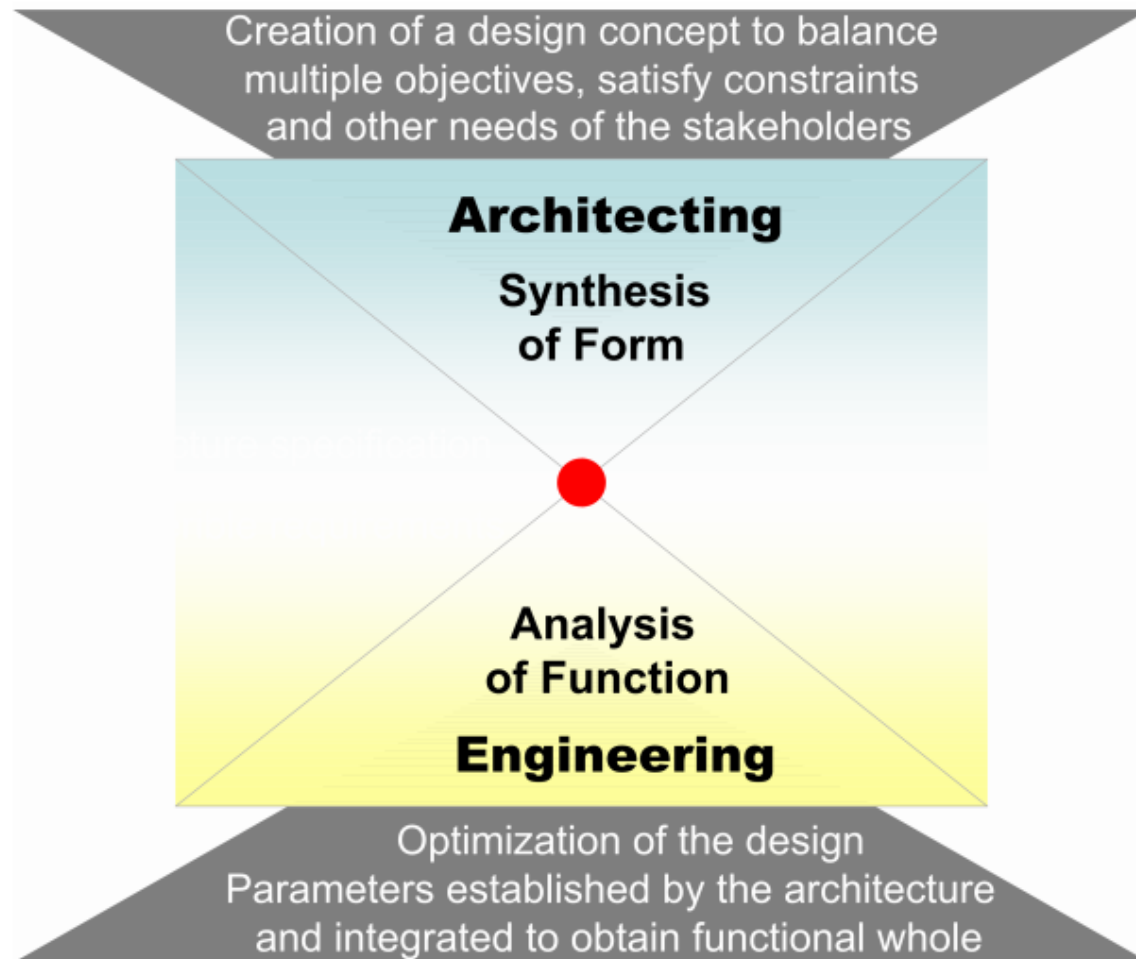# Iterating between problem and design spaces

The designer iterates between structuring the problem and solving the problem.

Designers use prototypes and do extensive test and evaluation.

Architecting is primarily about decision making

Creation of a design concept to balance
multiple objectives, satisfy constraints
and other needs of the stakeholders

Architecting

**Synthesis
of Form**

**Analysis
of Function**

Engineering

Optimization of the design
Parameters established by the architecture
and integrated to obtain functional whole

Engineering is primarily about optimizing

Architecture decisions determine design space

Architecture Alternatives

Sloop   Ketch   Trimaran
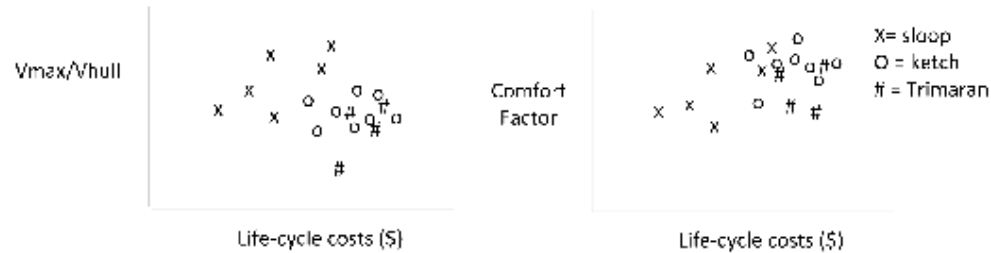
X = sloop
O = ketch
# = Trimaran

Vmax/Vhull

Comfort Factor

Life-cycle costs ($)   Life-cycle costs ($)

Design Parameter	sloop	ketch	trimaran
Length overall (d_1)	x	x	x
Beam(d_2)	x	x	x
Draft(d_3)	x	x	x
Headsail area(d_4)	x	x	x
Mainsail area(d_5)	x	x	x
Mizzensail area(d_6)		x	
Bridgedeck Width(d_7)			x
Distance between Ama's(d_8)			x

Requirements either:

1. Value Statements – max or min increases stakeholder value
2. Restrictions – limits on admissible values of design variables

Requirement Define
Feasible Regions

Design Space
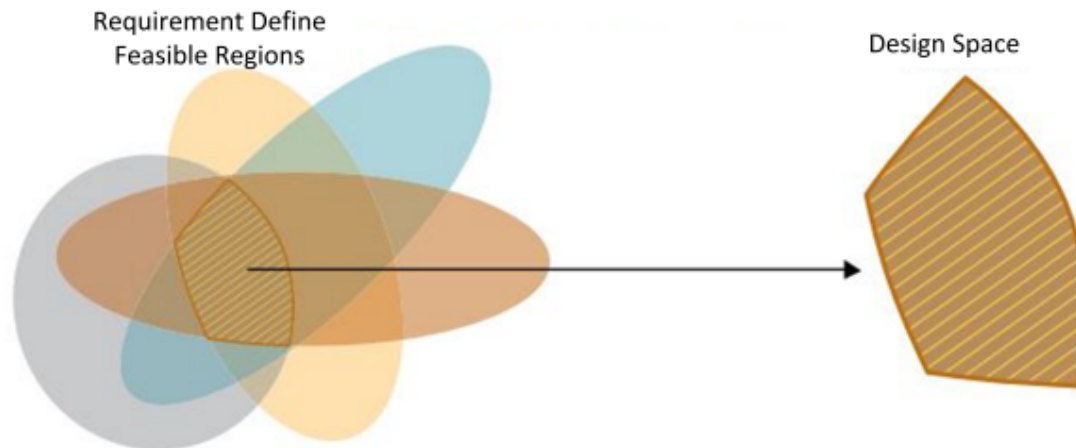
Figure 1: LT Ryan Beall used a laser cutter to rapid prototype a glider to test performance of a guidance control system he designed and built.

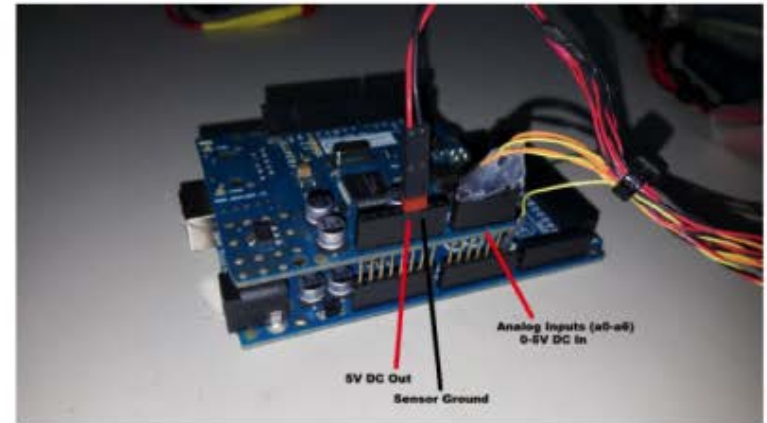Figure 2: LT Robert Fauci rapidly created and built a controller with Arduino to test the performance of solar energy powered unmanned system.

Google's Project Loon iteratively and incrementally progressed through 14 prototypes of the high altitude balloon. From right to left, the evolution of Loon's high-tech payload, starting with a styrofoam picnic cooler.

Deferred and delayed committment until uncertainty resolved

Knowledge about the design problem

Design freedom
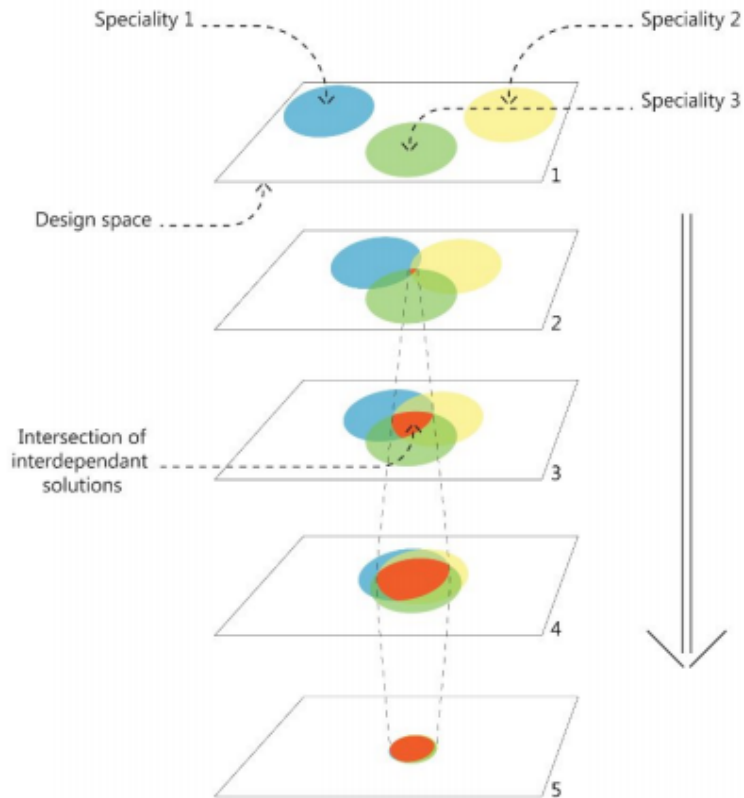
Time into design process

Percentage
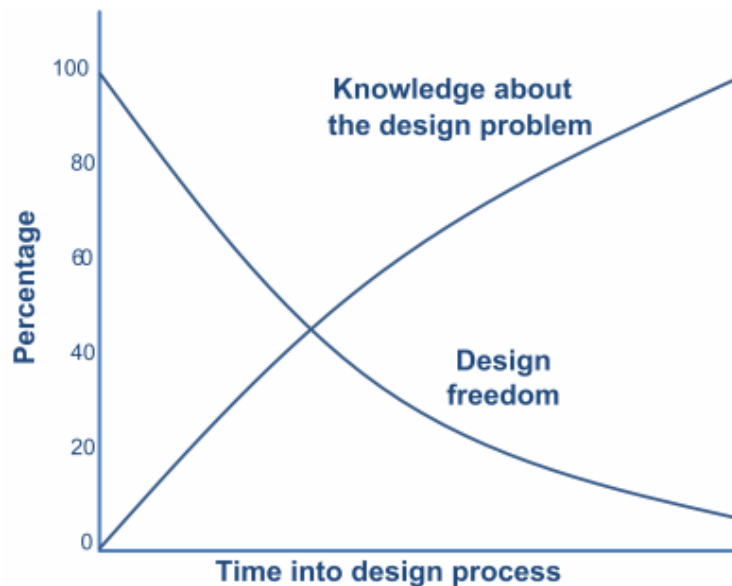
Source: *Engineering Design* , Fourth Edition by Dieter, Schmidt

Characteristics of design favor delaying decisions:

- Uncertainty high in early phases, low in later phases
- Early decisions have large cost and performance impact

Set-based design

Work with sets of design points

Learn about design as team progresses

Delay specific design decision until more is known

Figure 4: Design Commons Laboratory with students working on a design problem

Figure 5: Modular and reconfigurable furniture, whiteboards, and other items to facilitate collaboration and creativity

Summary

- Worldview of knowledge acquisition and design

- Technical Rational Design vice Design Thinking

- Appropriateness of each approach to systems engineering process phase

  - architecture vice design
  - requirements as value statements vice restrictions
  - prototyping
  - iterative and incremental development
  - deferring decisions until uncertainty resolved

- Importance of teaching design thinking in engineering curriculum