EPFL

Applied Mechanical Design

Introduction

Prof. J. Schiffmann

École
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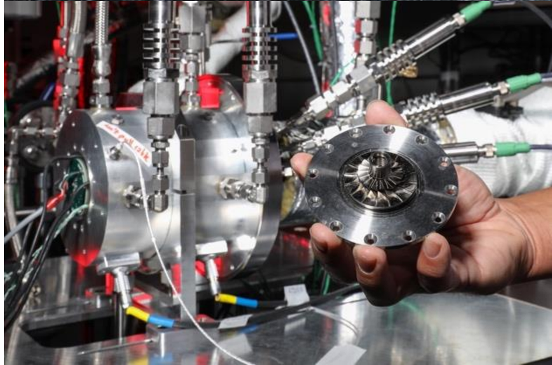
Presentation

- Laboratory for Applied Mechanical Design (MechE)
- Small scale turbomachinery
  - Heat pumps
  - Power cycles
  - Fuel cell blowers
- Gas lubricated bearings
- Automated design methodologies

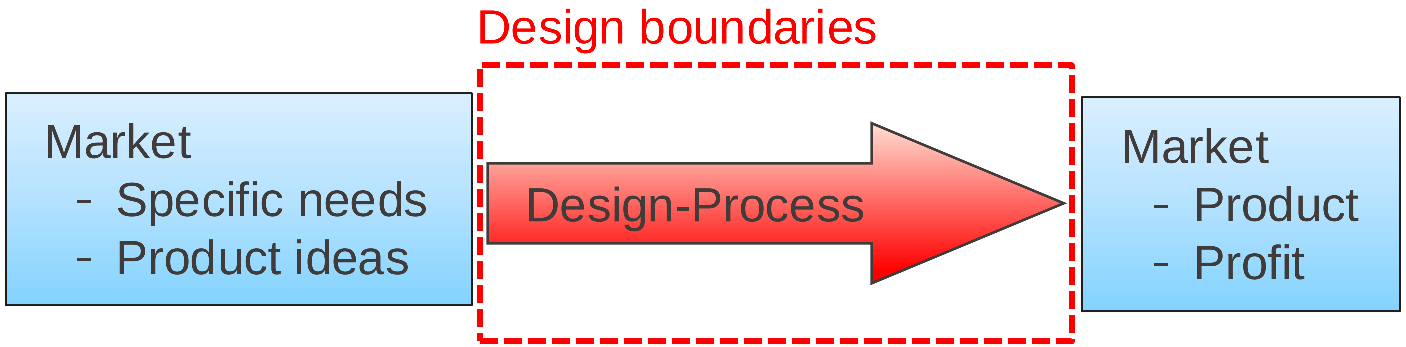


Introduction

- Context and objectives
- Project description
- Mechanical design process
- Organization

The Context

- Boundaries seen by the design process

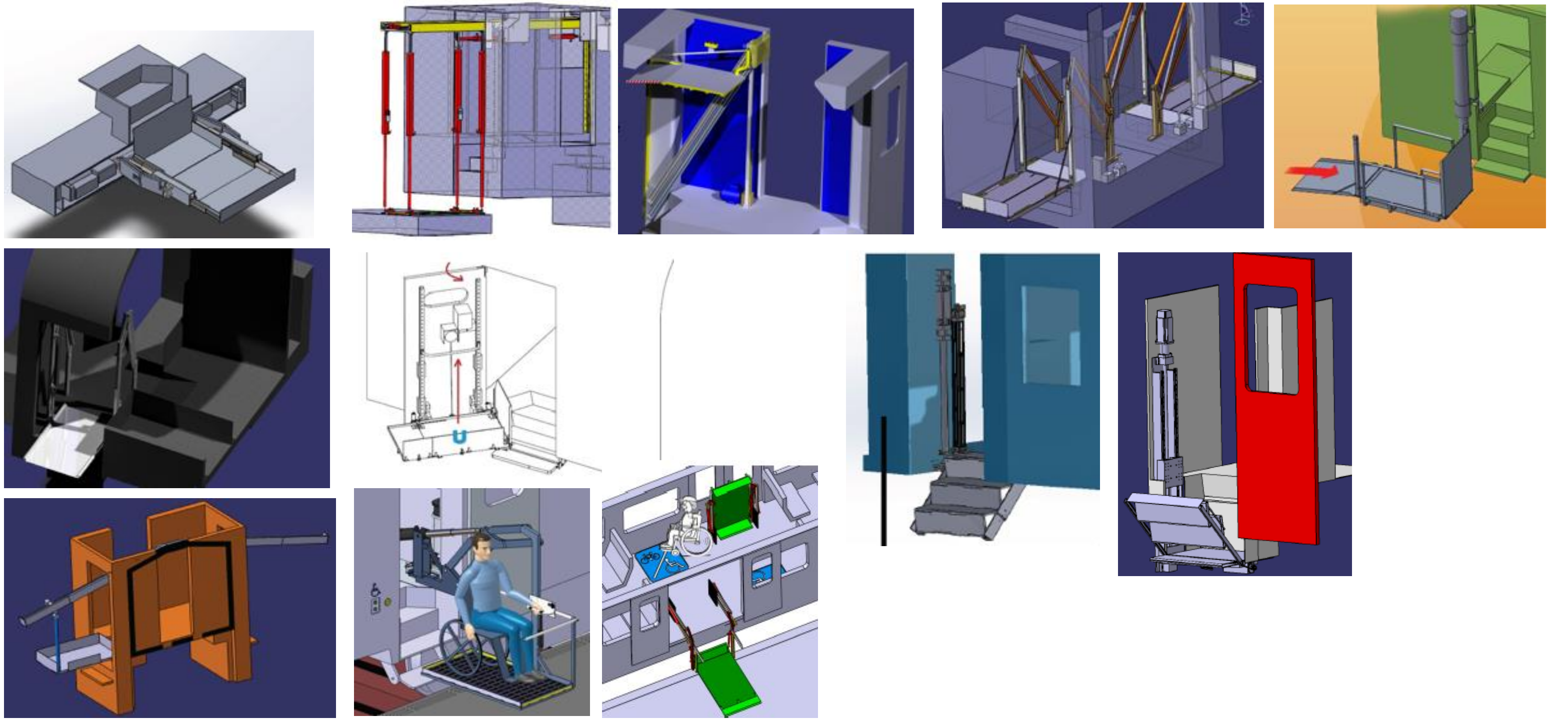


The Context

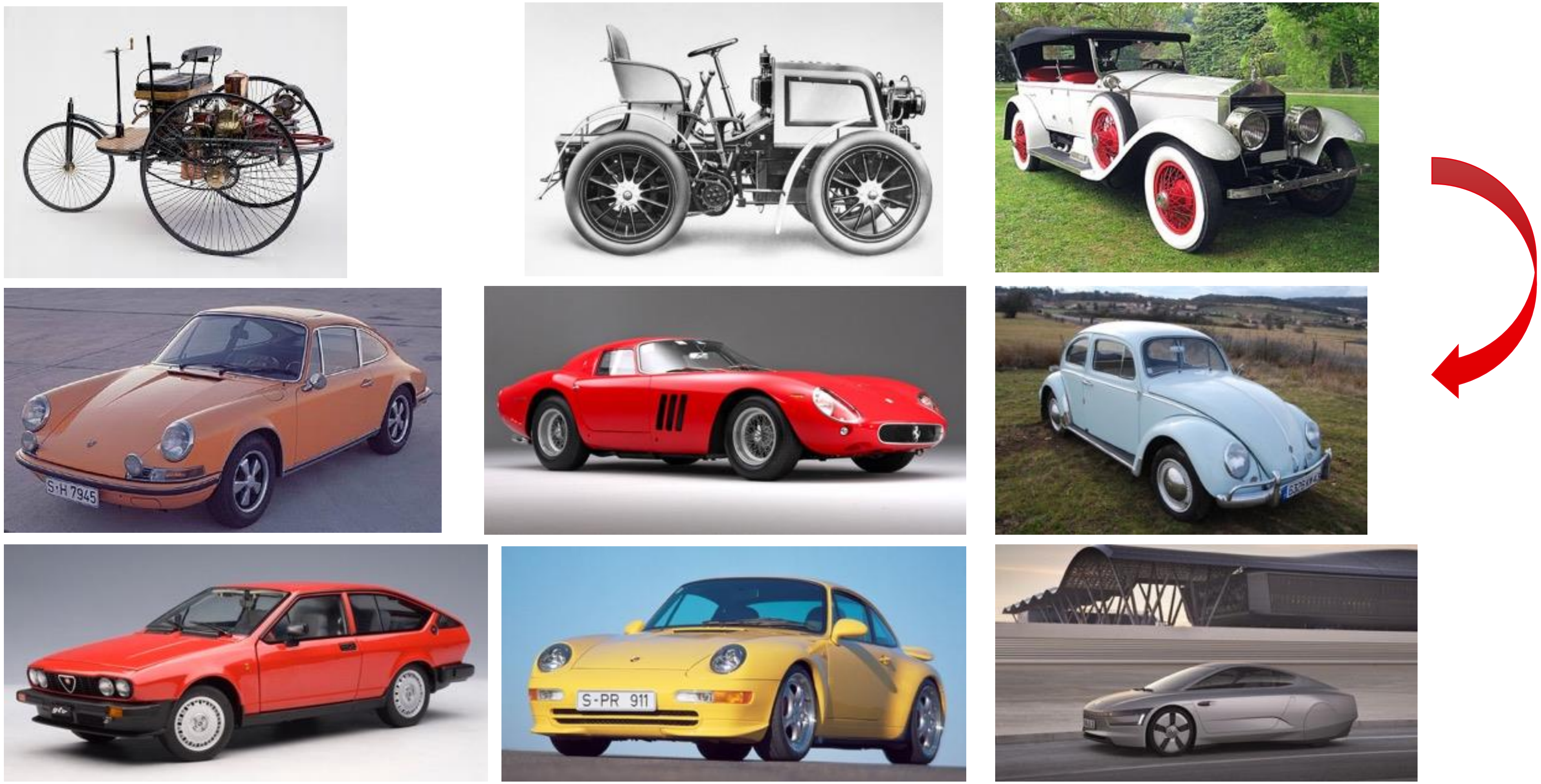
- Design is difficult. Why?
  - Problem is often ill-posed
  - Multiple objectives and criteria
  - Subjected to multiple constraints
  - Multiple users and user preferences
  - Multiple designers (culture, talent, experience, location, …)
  - Complex, dynamic marketplaces
  - Perfection is ill-defined
  - No two design problems are the same
  - No two solutions for the same problem are the same

Existence of Multiple Solutions

- Boarding assistance for trains



Solutions Evolve with Time



A Wealth of Possible Solutions…

- Different driving concepts

Internal combustion engine

Hybrid (internal combustion engine + electric

Fuel cell

Electric

Design as a Science

- Design is difficult because it is complex
- Is there a “Big Picture” solution?
  - Inspiration by characteristics of other complex fields

- Biology
- Economics
- Meteorology

Limited prediction in time and size scales
- “Small picture” phenomena can be described well
- “Big picture” phenomena cannot!

  → Leads to incomplete theories & limited acceptance

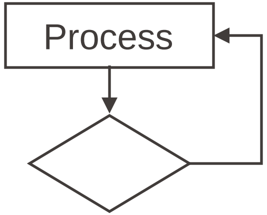
- Influencing the system is easy; controlling it is very hard
- Adaptive and iterative behavior is common
- System dynamics across disciplines are often similar
- Computer simulation tools have been a major help

Design Theory

- Current state of design theory
  - Several competing theories (none dominant)
  - Paucity of experimental evidence
  - Each theory covers different territory
  - Prediction power of success is very weak
  - Prescriptive power is mediocre due to the wide variety of design situations
  - Considerable achievement in “small picture” issues, i.e., CAD/CAE, CAM…
  - Lack of a dominant “big picture” theory
  - Agreement on process and on needed competences

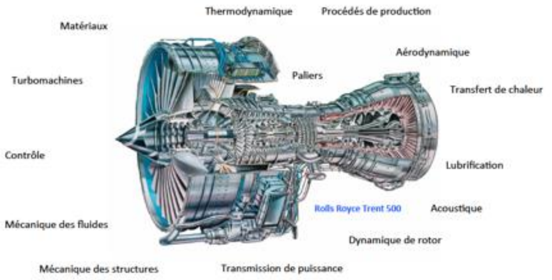
The Competences

Process competence



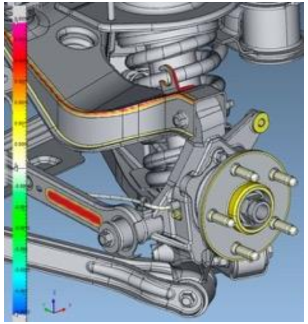
Design methods,
planning, business tools, ...

Disciplinary competence



Materials, engineering science,
manufacturing techniques,
laws, norms, ...

Tool competence



CAD, CAM, simulation,
networks, databases.....

Social competence

Teamwork, moderation,
presentation techniques, ...

Globalization

Languages, culture, mindsets, flexibility, ...

Pedagogical Objectives

- Toolbox to approach ill-posed, open-solution problems
- Establish detailed set of specifications & functional analysis
- Learn to use appropriate tools for concept sizing
- Project planning & teamwork
- Report writing & presentations

How to Achieve Objectives

- Exposure to concrete ill-posed design problem
- Group work throughout the term
- Lectures offering tools and methodologies
- Glimpse at what your future work as engineer in industry could look like

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The Competences

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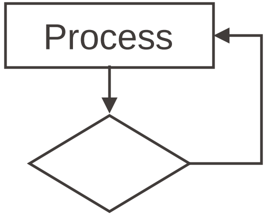

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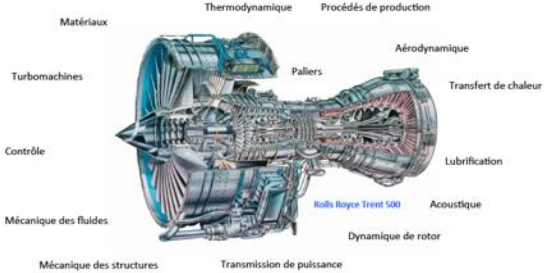

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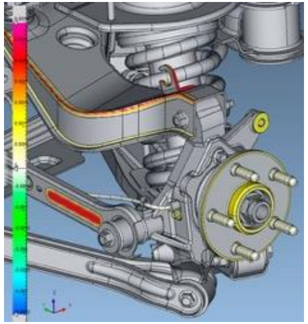

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Project Description

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Mechanical Design

The Process

An Introduction

Prof. J. Schiffmann

École polytechnique fédérale de Lausanne

The Process I

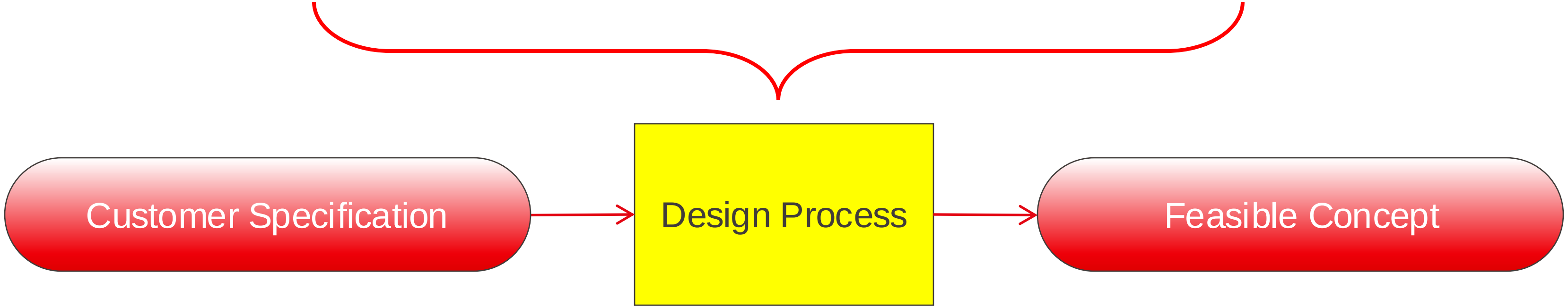
- Client needs to solve problem or has specific need
- Problem statement is often brief and incomplete

- Documentation addressed to client
- Gives detail on design process, calculations, assembly drawings, manufacturing and materials

Customer Specification → Design Process → Feasible Concept

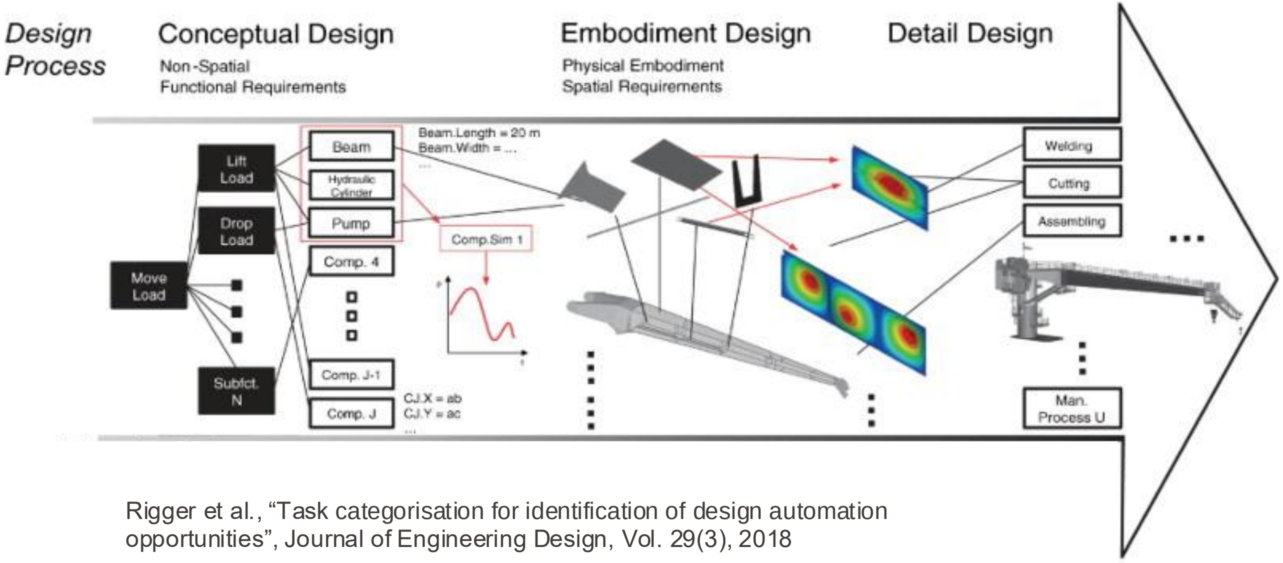
The Process II

- Iterative & systematic process during which engineers generate (synthesis), evaluate (analysis) and specify (documentation) concepts such that they fulfil the customer specifications



The Process III

- The design process undergoes various steps



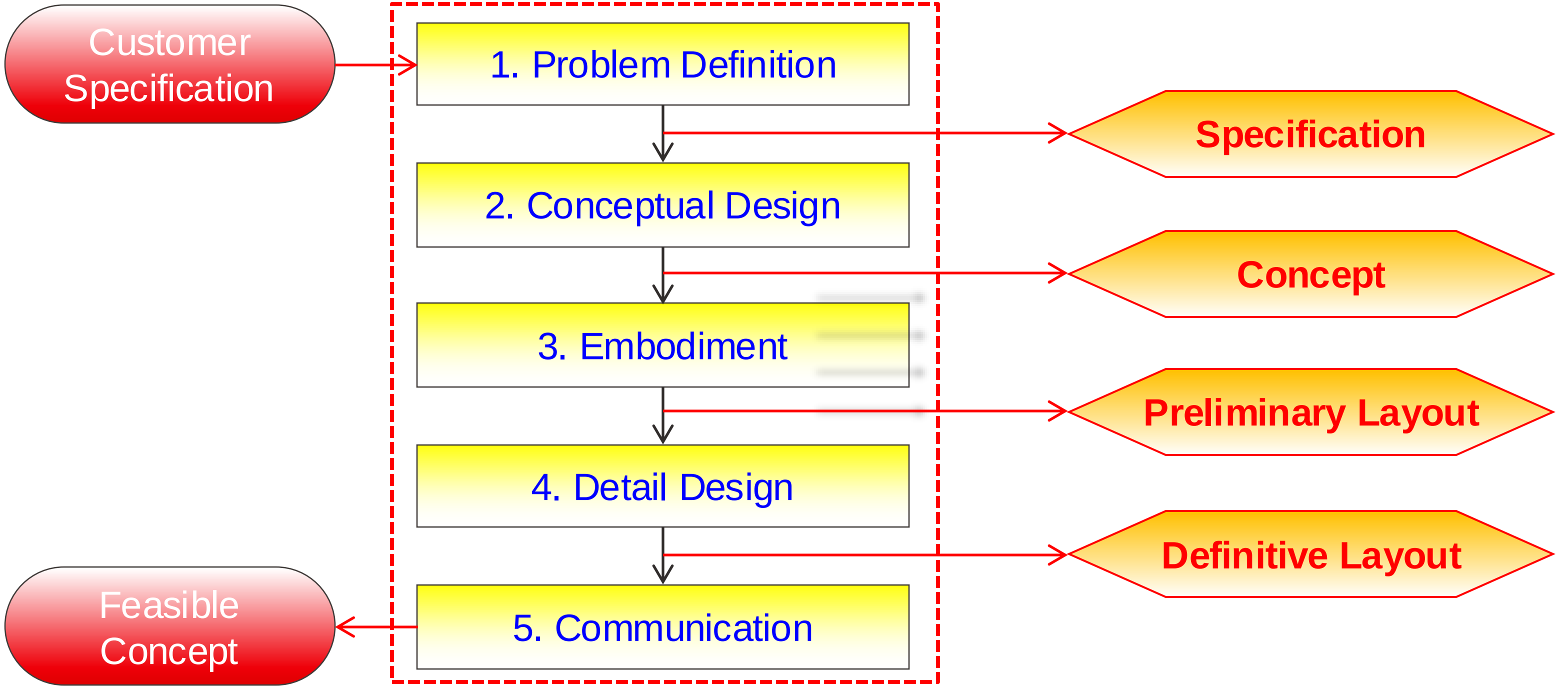
Rigger et al., “Task categorisation for identification of design automation opportunities”, Journal of Engineering Design, Vol. 29(3), 2018

The Process IV

- Classification of design activities
  - *Conceptualizing* → searching for solution principles
  - *Embodying* → engineering a solution through arrangement and shape
  - *Detailing* → finalizing product and operating details
  - *Analyzing* → apply engineering tools to size concept and predict its performance in view of specifications
  - *Information management* → gathering required information to support product lifecycle during all phases of the design process

The Process V

- Phases of design process (Pahl & Beitz)



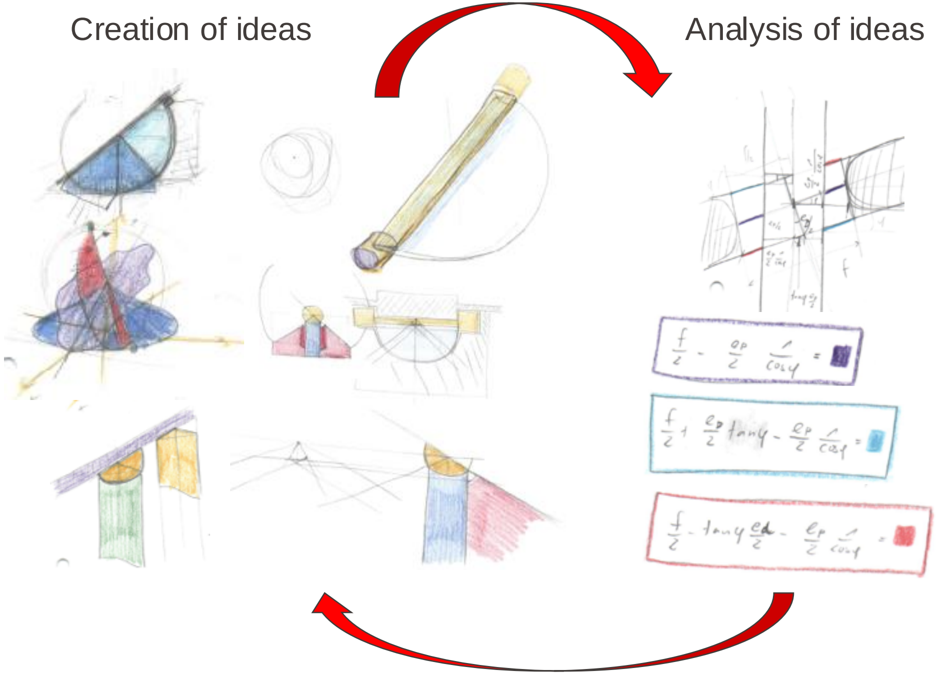
The Process VI

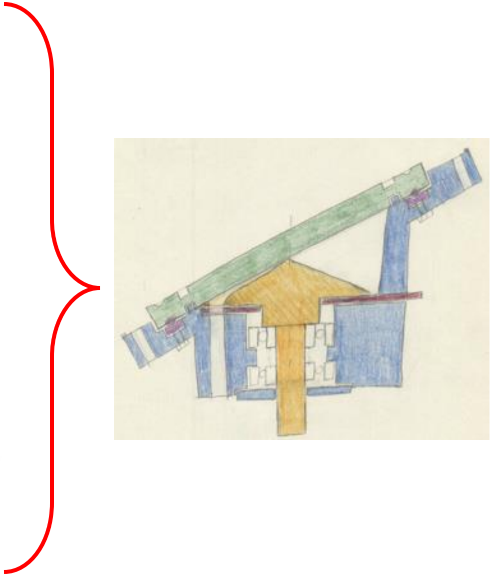
- Creative, analytical and iterative process!

Creation of ideas

Analysis of ideas

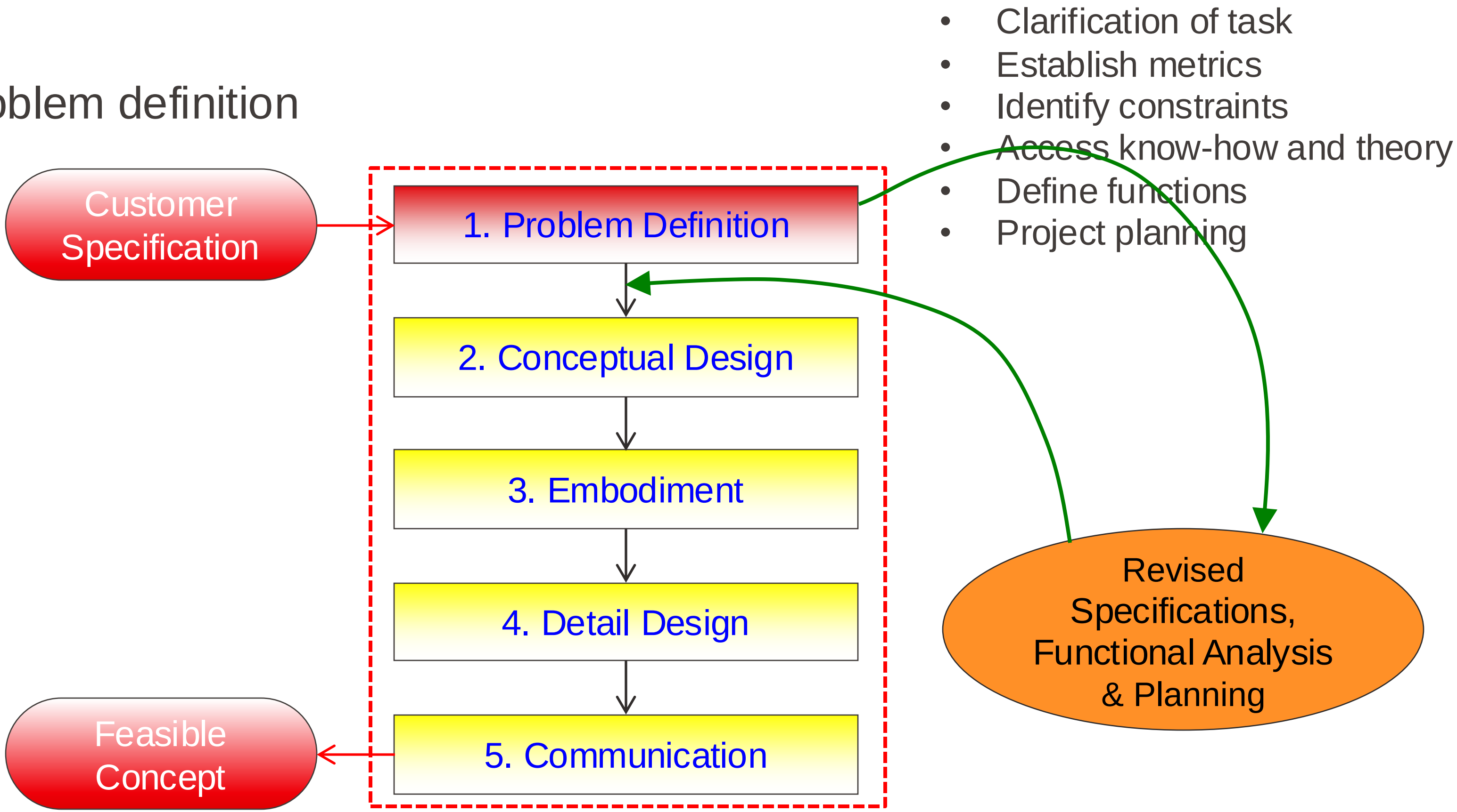
Concept





Process Initialization

- Problem definition



Problem Definition I

- Key task is understanding customer problem
- Customer demands often vague, qualitative & incomplete

Problem Definition II

- Clarification of task
  - What is essence or crux of the problem?
  - What implicit wishes and expectations are involved?
  - What is context of customer needs?
  - Do the specified constraints exist?
  - What paths are open for development?
  - What are measurable objectives?
  - What are essential properties?

- Avoid at all cost
  - Fixed ideas & solution-specific considerations
  - Fictional constraints

Problem Definition III

- Ways to tackle problem definition
  - Critical questioning of your customer
  - Questioning of potential customer clients
  - Functional decomposition
  - Open discussions within design team

- Results are:
  - Set of revised specifications
  - Functional layout
  - Project plan

Legal document engaging design team contractually.
Often a large document!

Problem Definition IV

- Set of specifications contains
  - Problem Statement
    - Summary of crux of problem
  - Demands and wishes (constraints / criteria)
    - Indication of requirements that must be satisfied vs. those that are less "critical"
  - Group or individual responsible
    - Name of individual responsible for specific requirements
  - Modifications and dates
    - Date and type of modifications made to specifications
  - Requirements
    - Characteristics, quantified and clearly arranged

Problem Definition V

- Typical categories of specifications

1. Geometry

Size, height, breadth, length, diameter, space requirement, number, arrangement, connection

2. Kinematics

Type, direction, velocity, acceleration of motion

3. Forces

Direction, magnitude, frequency, weight, load, deformation, stiffness, elasticity, stability, resonance

4. Energy

Output, efficiency, friction, ventilation, pressure, temperature, heating, cooling, supply, storage, capacity, conversion

5. Material

Physical and chemical properties, auxiliary materials, prescribed materials

6. Signals

Input & output, form, display

7. Safety

Protective systems, operator and environmental safety

8. Ergonomics

Man-machine relationship, type of operation, clearness of layout, lighting, aesthetics

9. Production

Limitations, maximum possible dimensions, preferred methods, means of production, achievable quality and tolerances

10. Quality Control

Possibilities of testing and measuring, application of special regulations and standards

11. Assembly

Special regulations, installation, siting, foundations

12. Operation

Quietness, wear, destination / environment, special uses, market

13. Maintenance

Service, inspection, repair, painting, cleaning

14. Recycling

Reuse, reprocessing, waste disposal, storage

15. Transport

Lifting, clearance, transportation

16. Cost

Maximum permissible manufacturing costs, investment, depreciation

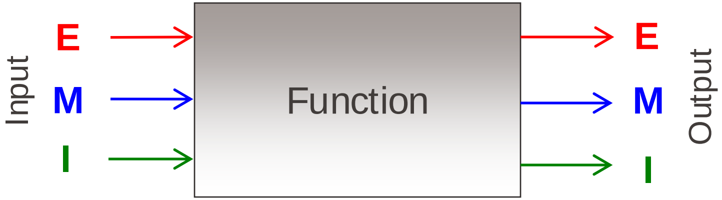
Problem Definition VI

- Example of specification document

The Power of Functions

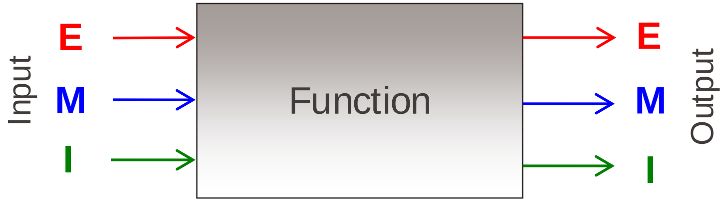
- Functions define actions that system needs to be able to fulfill

- Functions transform
  - Energy (E)
  - Material (M)
  - Information (I)



- Actions (hence function) always defined through a verb

How to Establish Functions?

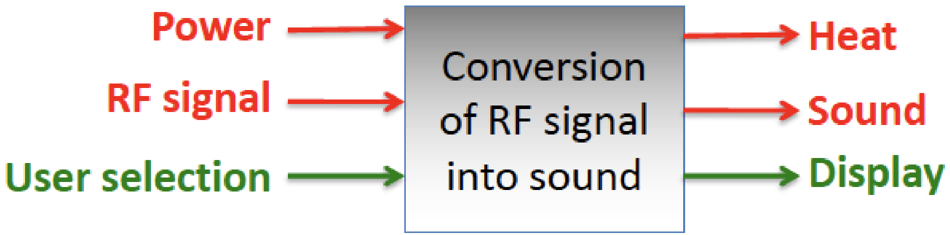


1. Identify key function
2. Define all entering and exiting flows
3. Open black box and identify flux transformations
4. Define sub-functions to achieve required flux transformation
5. Continue process of opening boxes until clear system understanding is achieved

→ Result is functional mode

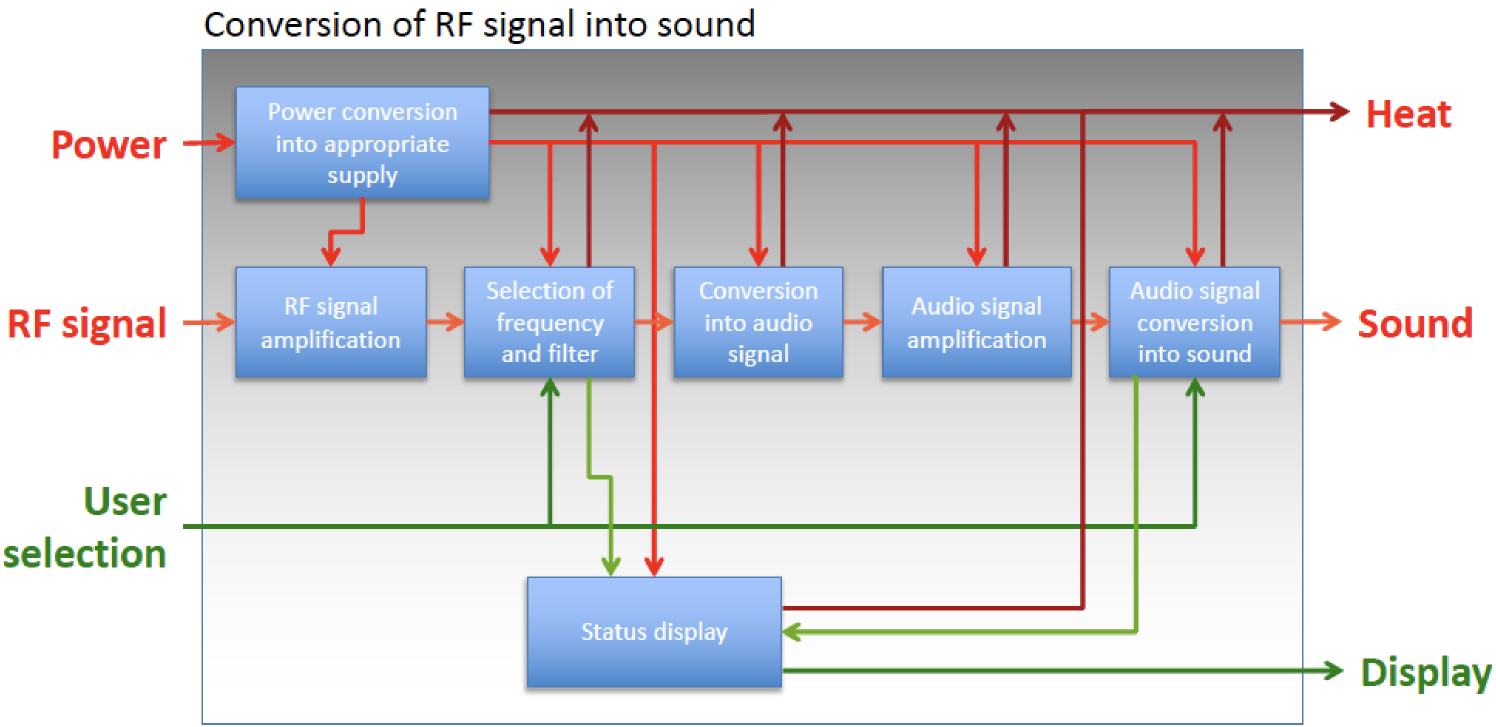
Example Radio I

- Principal function
  - Desired functions
  - Undesired functions



- Open cover of principal function to discover first layer of sub-functions

Example Radio II



Common Pitfalls

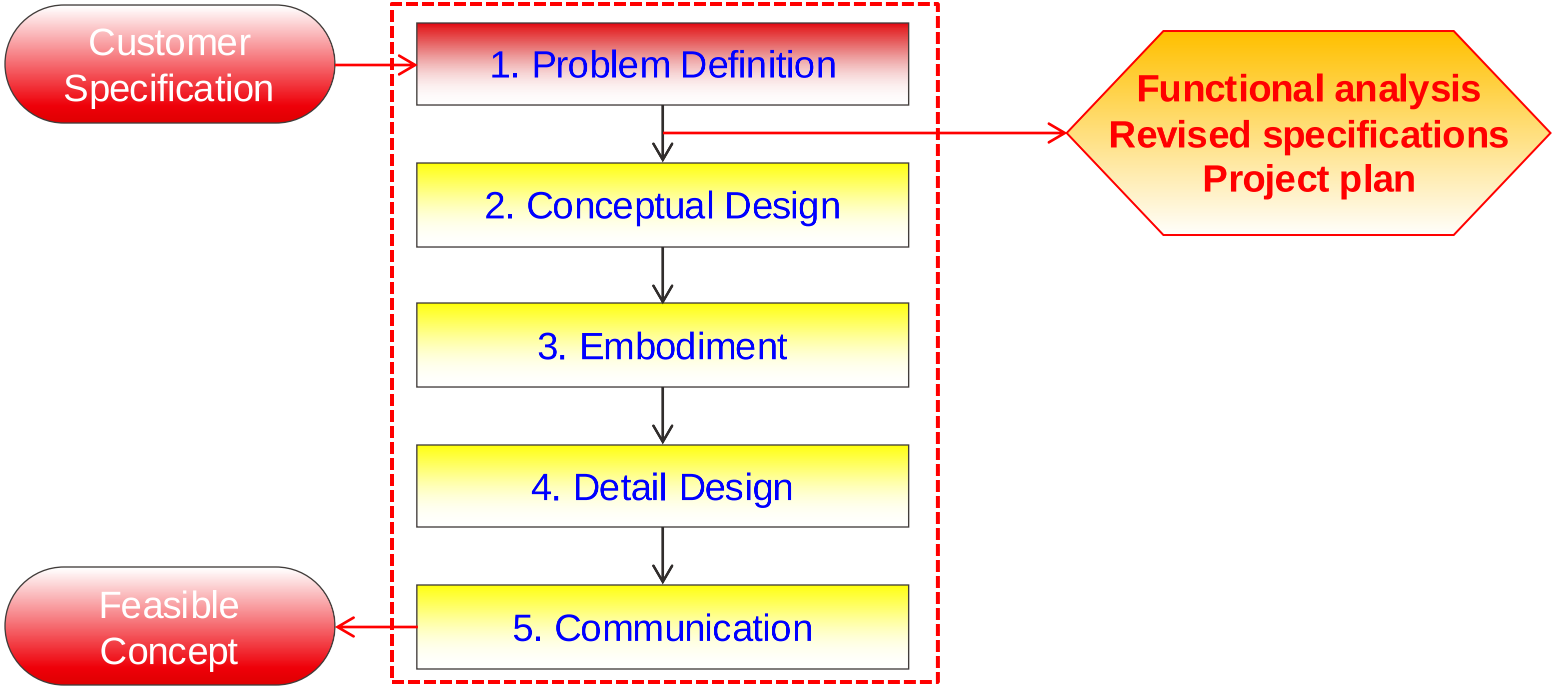
- Limit solution space by restrictive function definition
  - Example bookshelf: «carry books» vs. «carry objects»

- Insinuate solution
  - Example lighter: «apply flame to tobacco» vs. «light flammable material»

- Avoid confusion between
  - objective (→ adjective / attribute)
  - function (→ verb)

Problem Definition VII

- Problem definition outcome



Course Organization and Setup

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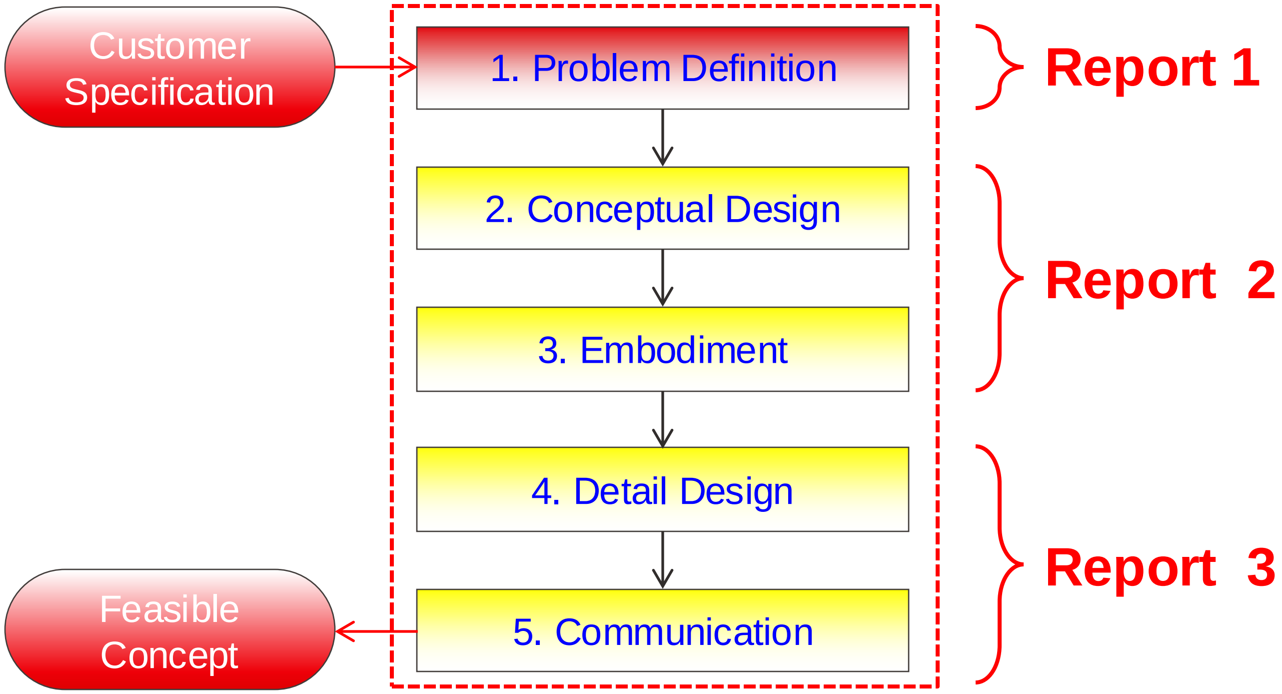
Deliverables

- Three reports



Deliverables

- Reports due on moodle
  - Report 1: 10 pages max, week 4, 04.10.2024 18h, weight 10%
  - Report 2: 20 pages max, week 8, 08.11.2024, 18h, weight 30%
  - Report 3: 30 pages max, 16.01.2025, 18h, weight 40%

- Handling of delays
  - Up to 30 minutes: Mark – 0.5 point
  - Up to 1 day: Mark – 1 point
  - Up to 2 days: Mark – 2 point

Deliverables

- Presentations
  - Weekly presentation to coach
    - Contains results, updated project plan, time sheets, next steps, questions
  - Final presentation (week 14)
    - Presentation of final concept to the class (weight 20%)

Deliverables

- Grading
  - One mark per group
  - Reports (10%, 30%, 40%)
  - Weekly presentations
  - Final presentation (20%)
  - Operation of group

  - Based on evaluation sheets filled by coaches
  - Discussed and adjusted within coaching team

Organization

- Groups
  - Composed of 4 students
  - One coach attributed per group
  - Weekly meeting with coaches organized individually

- Q&A, course , and general information offered during first hour (please be present)

- Documents on moodle

Literature

- Engineering Design Methods,
  N. Cross, Wiley 2008
- Konstruktionslehre,
  G. Pahl / W. Beiz, Springer, 2007
- The Mechanical Design Process,
  D. Ullmann, McGraw-Hill, 2003
- Principles of Optimal Design,
  Y. Papalambros, Cambridge Press, 2017