Strategic thinking: matching material to design

3.1 Introduction and synopsis
3.2 The design process
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3.5 Examples of translation

Images embodying the concepts described in the text: pull, geared pull, shear and pressure. (Image courtesy of A-Best Fixture Co., 424 West Exchange Street, Akron, Ohio 44302, USA)

Design-led Approach for Selecting Materials and Processes

Product Design

Identify Market Need

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Express as Design Requirements

↓

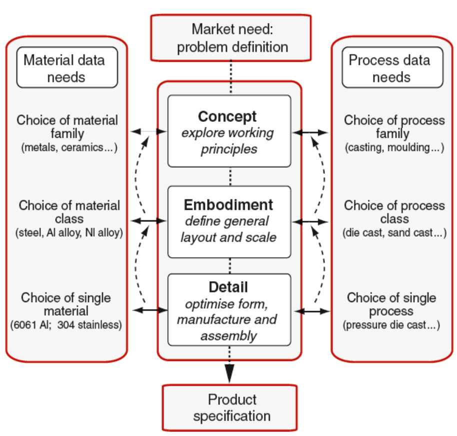
Develop Product Specification

Selection of materials and processes runs parallel with design process

Original Design

- New idea or working principle
- New material may suggest a new product
- New product may require a new material
- Market need is put in terms of a need statement – “Device is required to perform task X”
- Product specification – detailed plan for new design

Design Process



Three design stages between identifying the market need and developing a product specification

Information about materials is needed at each stage, but at very different levels of breadth and precision

Redesign

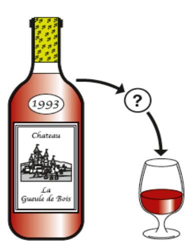
Improving a current design while keeping the working principle on which it operates and many of its components

Why?

- Product recall
- Poor value for money
- Inadequate profit margin
- Stay ahead of the competition

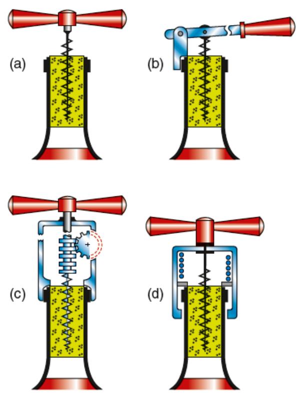
Design Process – Concept Stage

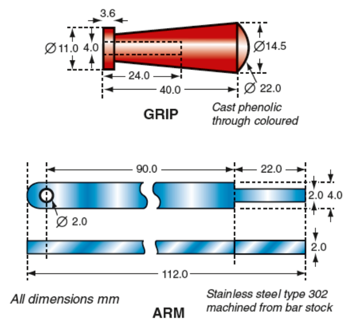
Need Statement: A device is required to allow access to wine in a corked bottle with convenience, at modest cost, and without contaminating the wine



Three concepts: Remove by axial traction (a); remove by torsional traction (b); push it out from below (c)

Embodiment and Detail



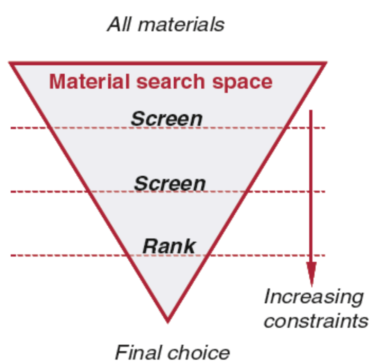


(a) – (d) show embodiment sketches based on concept of removal by axial traction – shows the layout, mechanism and scale

Detailed drawings of the lever mechanism of embodiment (b) shown – part dimensioned and the surface finish, material and manufacturing route defined

Material and Process Information for Design

The selection of a material begins with a catalog of all materials, which is narrowed by screening out those that fail to meet the design requirements



Concept stage: designer requires only approximate property values, but for widest range of materials

Embodiment stage: data needed for a subset of materials, but at a higher level of detail and precision

Detail stage: even higher level of detail and precision, but for few materials

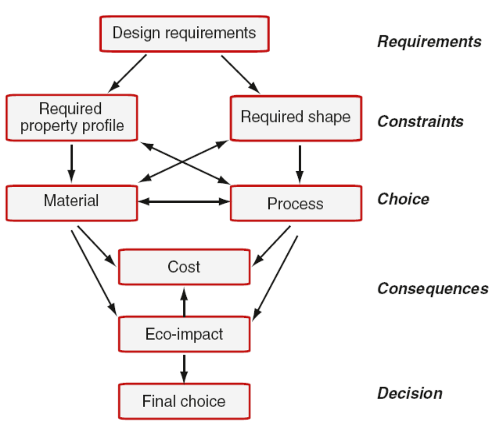
Material – Process- Shape

To make a shape, a material is subjected to processes that, collectively, are called *manufacture*

Process selection is influenced by the material – formability machinability, weldability, capacity for heat treatment, etc

Process selection is influenced by the requirement for shape – the process determines the shape, size, precision, and greatly contributes to the cost

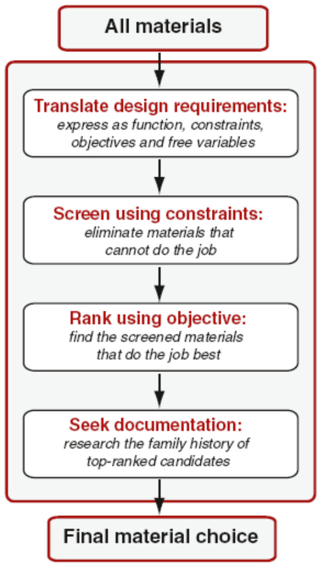
Interaction between design requirements, material, shape, and process



Two-way interactions:

Specification of shape restricts the choice of material and process, but equally the specification of process limits the materials you can use and the shape they can take

Selection Strategy



Select the best match between the attribute profiles of the materials and processes and those required by the design

4 step process:

1)Translation
2)Screening
3)Ranking
4)Documentation

Translation

Converting the design requirements into a prescription for selecting a material

This is accomplished by identifying the following:

Usually a variable that needs to be maximized or minimized

Function	• What does the component do?
Constraints	• What non-negotiable conditions must be met?
Objective	• What is to be maximised or minimised?
Free variables	• What parameters of the problem are the designer free to change?

Usually a range of a variable – as long as the variable is within the specified range, the design is ok. E.g. for purchasing a car, price vs. mileage vs. engine power…

Constraints vs. Objectives

Constraint: essential condition that must be met, usually expressed as a limit on a material or process attribute – for difference cases, a variable can be either constraint or objective, for which the materials selection processes and results are different.

Objective: quantity for which an extreme value is sought

Common constraints	Common objectives
Meet a target value of • Stiffness • Strength • Fracture toughness • Thermal conductivity • Electrical resistivity • Magnetic remanence • Optical transparency • Cost • Mass	Minimise • Cost • Mass • Volume • Impact on the environment • Heat loss Maximise • Energy storage • Heat flow

Translating Design Requirements

Bronson mountain bike: $8,000

Roadmaster shopping bike: $80

Super-light sprint bicycle
Objective: minimize mass
Constraint: upper-limit on cost

Cheap 'shopping' bike
Objective: minimize cost
Constraint: possible upper limit on mass

Screening

Eliminates candidate materials based on the constraints

<u>Constraint</u>: Component must function in boiling water
<u>Screening process</u>: All materials with a T_{max} < 100°C eliminated from consideration

Limits on material properties set by constraints are called *attribute limits* – in the above example, maximum service temperature is an attribute limit

Ranking

Screening isolates candidates that are capable of doing the job; ranking identifies those among them that can do the job best

The property or property group that maximizes performance for a given design is called its *material index*

Based on a single property: density (ρ), thermal conductivity (λ), strength (σ)

• Based on a combination of properties: specific stiffness (E/ρ), best materials for a spring (σ_y^2/E)

Documentation

- Detailed profile of the top ranked candidates
- Descriptive, graphical, or pictorial
- Helps narrow the short-list to a final choice
- Too labor intensive to do for more than a few materials

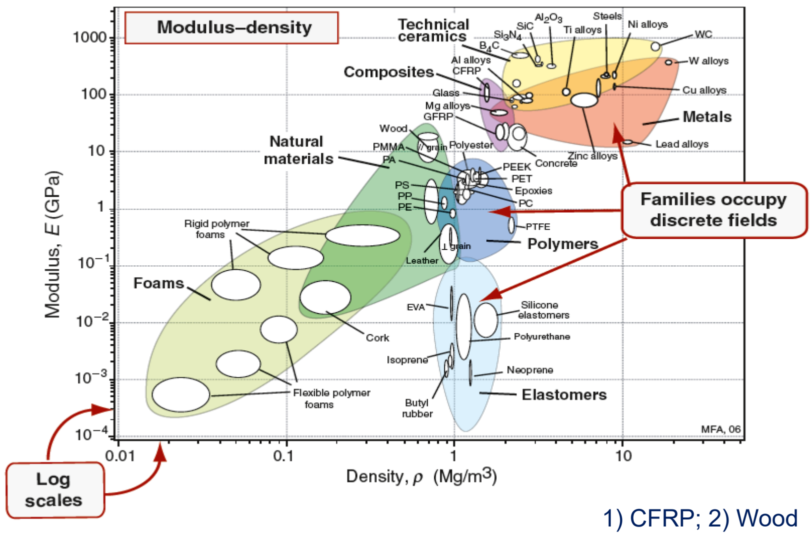
Examples

1) We are choosing materials for lightweight vehicles (e.g. electric cars). The mass density (ρ) must be below 2 ton/m^3 yet above 0.5 ton/m^3; the stiffness (E) must be as high as possible; the color does not matter.

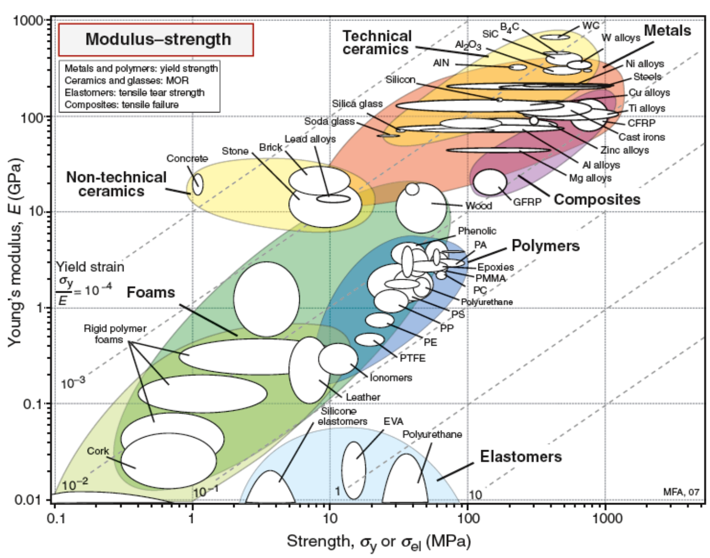
2) We are choosing materials for decks of pedestrian bridges. The stiffness (E) must be higher than 10 GPa; the material must be as lightweight as possible.

Constraints:
Objective:
Free Variable: Choice of material and …

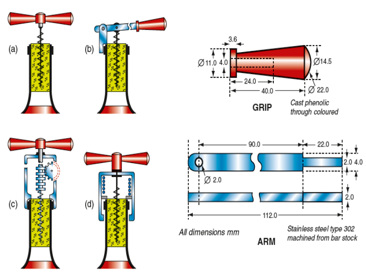
Examples



1) CFRP; 2) Wood



Examples of Translation: Corkscrew



The design limiting properties are those directly relating to the constraints:

Requirement on the structure/device

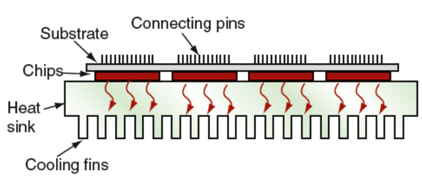
All functional requirements go to these 2 categories

Function	• Lever (beam loaded in bending)	
Constraints	• Stiff enough • Strong enough • Some toughness • Resist corrosion in wine and water	Functional constraints
	• Length *L* specified	A geometric constraint
Objective	• Minimise cost	
Free variables	• Choice of material • Choice of cross-section area	

Requirement on material

Everything else not listed as a functional requirement: color, mass density…

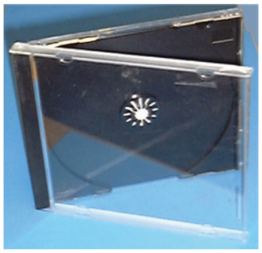
Heat Sinks for Microchips



Design limiting properties:

Function	• Heat sink	
Constraints	• Material must be good electrical insulator • Maximum operating temperature 200 °C	Functional constraints
	• All dimensions are specified	Geometric constraints
Objective	• Maximise thermal conductivity	
Free variable	• Choice of material	

Redesign of a CD Case



Original design called for polystyrene; these cases crack easily, jam shut, and the corners are hard and sharp enough to damage the cd

Potential limiting properties:

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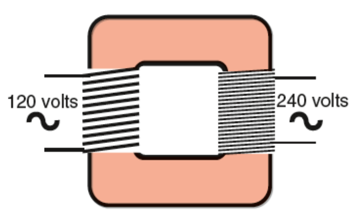
Function	• Contain and protect a CD	
Constraints	• Optically clear • Able to be injection moulded • Recyclable • Tougher than polystyrene	Functional constraints
	• Dimensions identical with PS case	A geometric constraint
Objective	• Minimise cost	
Free variable	• Choice of material	

HF Transformer Cores

Function	• HF transformer core	
Constraints	• Soft magnetic material • Electrical insulator	Functional constraints
	• All dimensions are specified	Geometric constraints
Objective	• Minimise cost	
Free variable	• Choice of material	



Translation of design requirements is the first step of selection

Constraints are used for screening

Objectives are used for ranking