Selection of Engineering Materials

IM 515E

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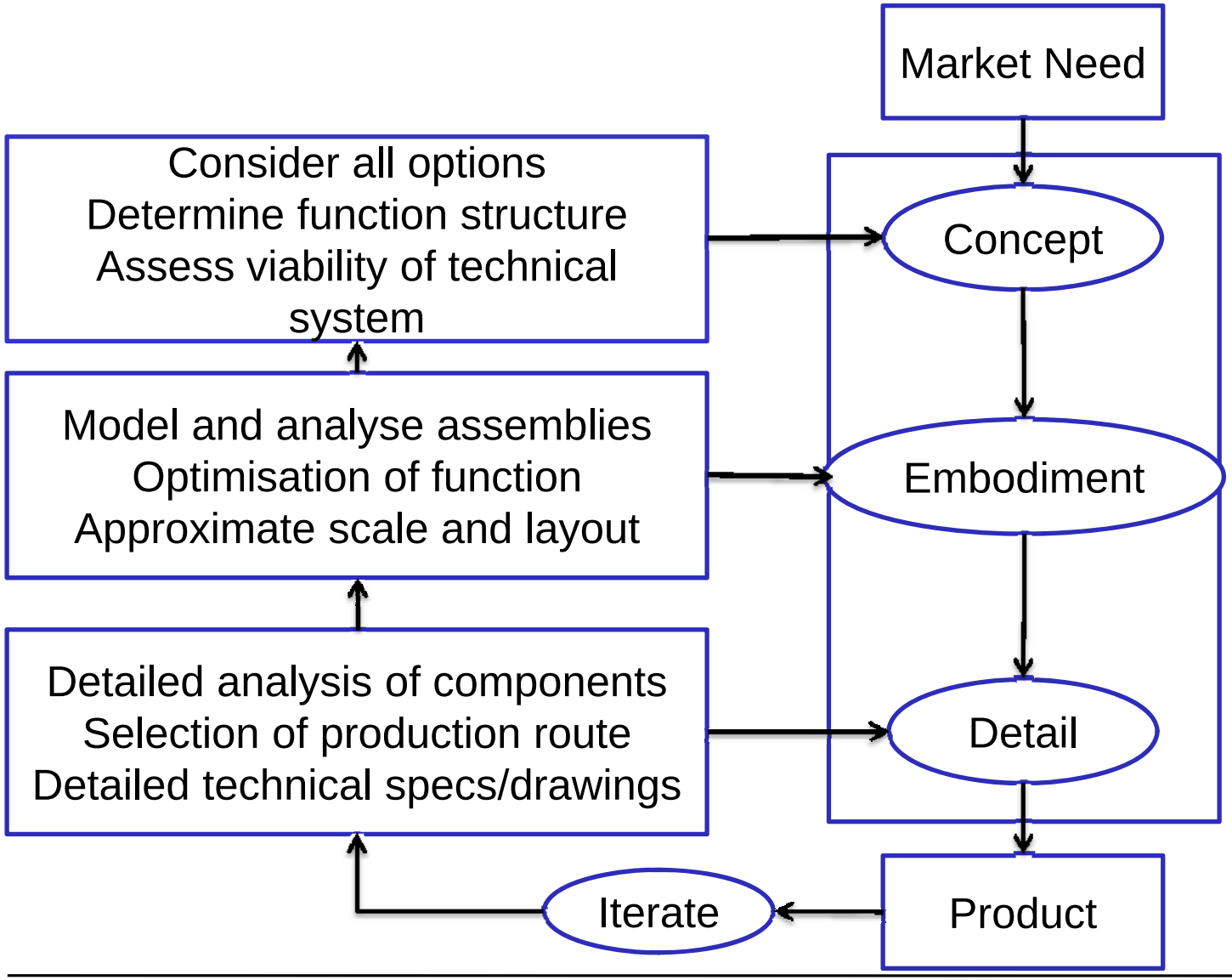
The Design Process

- Design is an iterative process.
- The starting point : a market need, an idea.
- The end point – a product which : fulfils the need, embodies the idea.
- Start $\rightarrow$ conceptual design $\rightarrow$ embodiment design $\rightarrow$ detailed design $\rightarrow$ production information, i.e. specifications – they define how the product will be made:

The Design Process



The Design Process

- **Conceptual Design**:
  - the designer considers the alternative working principles or schemes for the functions which make up the system.
  - the ways in which sub-functions are combined and separated.
  - the implications of each scheme for performance and cost.

The Design Process

- **Embodiment Design**:
  - takes a function structure and seeks to analyse its operation at an appropriate level.
  - sizing the components and selecting materials which will perform properly in the ranges of stress, temperature and environment suggested by the analysis.
  - the embodiment stage ends with a feasible layout which is passed to the detailed design stage.

The Design Process

- **Detailed Design**:
  - here specifications for each component are drawn up.
  - critical components may need precise mechanical and thermal analysis e.g. using finite element methods.
  - optimisation methods are applied to components (and groups of components) to maximize performance.
  - materials are chosen.
  - the production route is analysed.
  - the design is analysed in terms of cost.
  - the stage ends with a detailed production **specification**.

Design Tools and Materials Data

- The three mentioned design stages are achieved using design tools which are shown as inputs feeding in the main backbone of the design methodology.
- On the left are the tools of Engineering Science which allow the analysis, modelling and optimisation of the design.
- Increasingly, the routine aspects of design are made easier by:
  - The use of computer aided design (CAD) tools
  - The use of the databases which store information about standard components and configurations.

Design Tools and Materials Data

- Using these tools as the design evolves, we progress in the following manner:
  - Conceptual stage – approximate analysis and modelling
  - Embodiment stage – more sophisticated modelling and optimisation
  - Detailed design – “exact” analysis
- **Materials Selection** enters at each stage of the design process.
- The already large materials catalogue will increase further as better materials are developed.
- On the other hand, the increasing constraints as we progress through the three design stages will progressively limit the candidate materials.

Design Tools and Materials Data

- As the list of materials narrows the question is no longer “which material will do the job?” but “which will do it best?”.
- Additionally, the materials with the most desirable properties is seldom the one which is cheapest to shape, join and finish.
- So, we have a trade-off between performance and overall cost.
- **Detailed design** can only proceed when the list of candidate materials for each component is **reduced** to **one** (or a very few).

Material Property Data

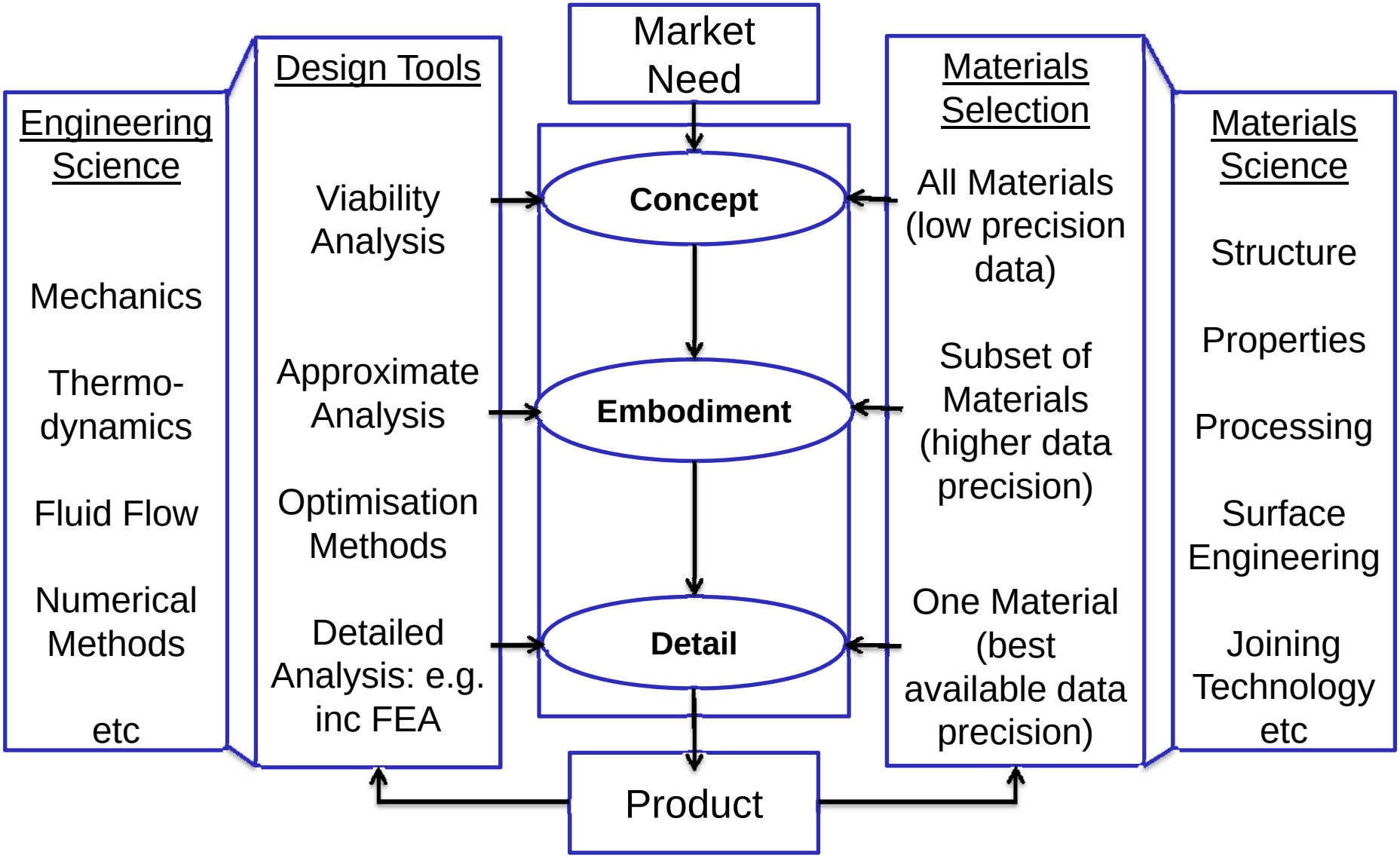
- Increasingly precise material property data is needed as we progress through the three stages of design:
  - **Conceptual design stage** – requires approximate data for a wide range of materials
  - **Embodiment design stage** – requires high level of precision and detail found in handbooks or computer databases which list, plot and compare the properties of a single class of materials e.g. metals – allowing choice of material at a level of detail not possible from the broader compilations which include all materials.

The Design Flowchart

– **Detailed design stage** – requires a high level of precision and detail but for only one or very few materials. Such information is usually found in the produces data sheets.

- The design flowchart shows how design tools and materials selection enter the procedure.
- Information about materials is needed at each stage, but at very different levels of breadth and precision.

The Design Flowchart



Material Property Data

- For some materials, e.g. polyethylene, we can get different properties in materials obtained from different producers.
- If the particular component is critical (i.e. a failure would be catastrophic), then we would be prudent to in-house test in order to measure the critical property.
- We must learn from failures in service, failure analysis prompting component redesign or material reselection.

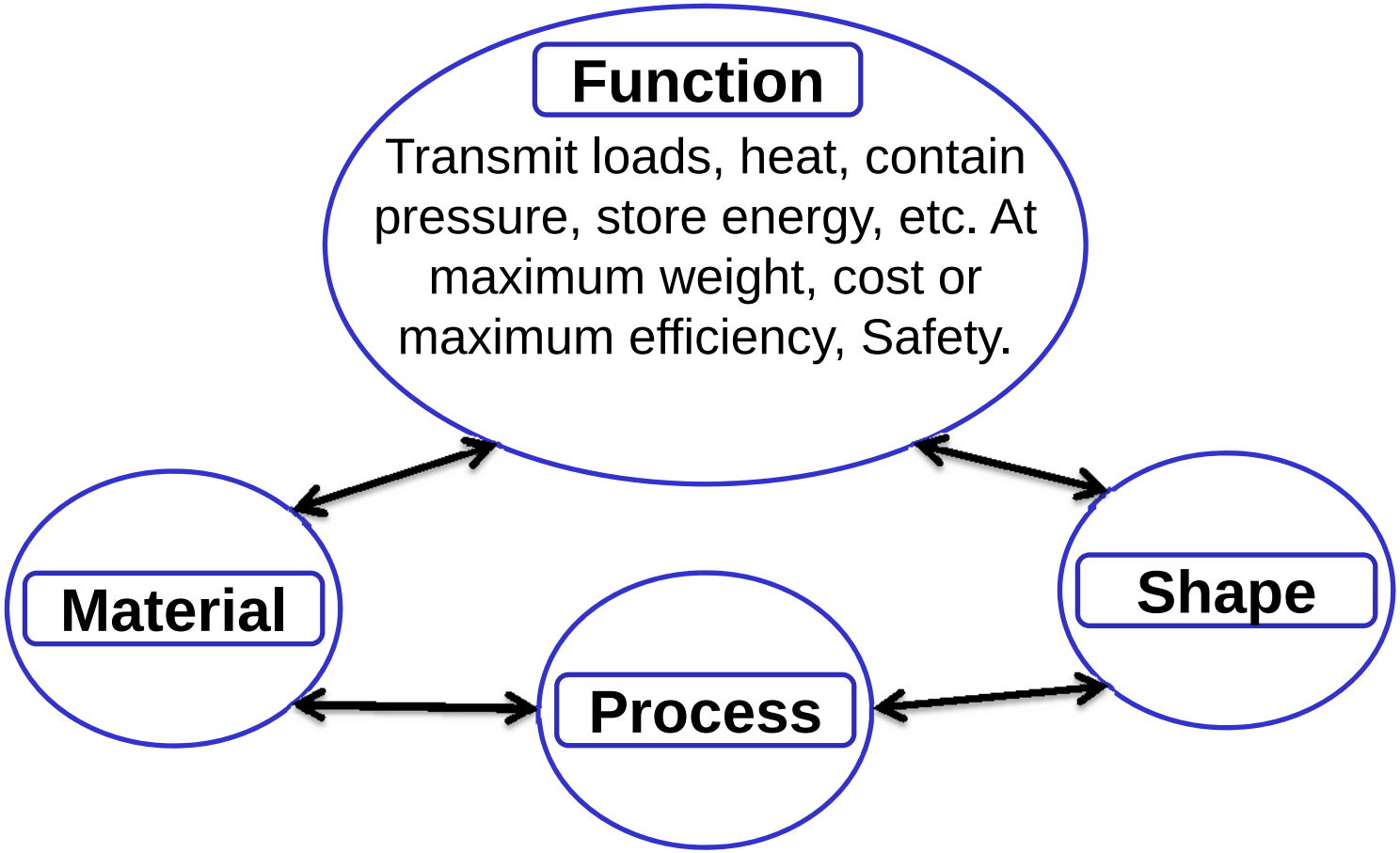
Function, Material, Shape & Processing

- The selection of a material cannot be separated from the choice of **shape**.
- Shape includes:
  - **External shape** – external shape and size (the macroshape)
  - **Internal shape** – e.g. a honeycomb or cellular structure (the microshape)
- In order to achieve the **final** product shape, the material is subject to various processes which collectively we call **manufacture**.

Function, Material, Shape & Processing

- Component manufacture may include the following:
  - Forming processes e.g. casting, forging, rolling, etc.
  - Material removal processes e.g. machining operations such as drilling.
  - Finishing processes e.g. grinding and polishing.
  - Joining processes e.g. welding.

Function, Material, Shape & Processing



The central problem of materials selection in mechanical design is : **the interaction between function, material, process and shape.**

Design Function

- Design statement of functions which the product must perform and is made up of:
  1. A basic function
  2. Several secondary functions
- Take for example a pair of scissors:
- Basic function - to cut thin sheets of material
- Secondary functions:

Function	Material Property Required
To stay sharp	Wear resistance
Resist plastic deformation	Yield strength
Resist corrosion	Corrosion property data
Resist elastic deflection	High Modulus, E
Minimise mass	Density, ρ
Permit processability into required shape	Formability, castability

Function, Material, Shape & Processing

They all interact as follows:

- **Function** – dictates the choice of material
- **Shape** – is chosen to perform the function using the material
- **Processing** – is influenced by:
  - Material properties such as formability, machinability, weldability, heat treatability
  - ➢ Processing interacts with shape
  - ➢ Processing determines the shape, the size, the precision and the cost.
- The interaction between function, material, shape and processing lies at the heart of the material selection process.