Risk & Safety
in
Civil Engineering

Jochen Köhler

Lecture overview

Organisation

Motivation

Risk & Decision Problems

Example

Outlook

Organisation

- Course webpage address is:
  http://www.ibk.ethz.ch/fa/education/ws_safety/index

- Available on course webpage:
  - ✓ Lecture notes (non-printable version)
  - ✓ Exercises
  - ✓ Exercise Solutions
  - ✓ PowerPoint presentations for each lecture

- Print edition of lecture notes for the entire course is available for a cost of CHF 45.

- Support will be available:
  Jochen Köhler → HIL E 24.1 / jochen.koehler@ethz.ch
  Gianluca De Sanctis → HIL E 23.3 / desanctis@ibk.baug.ethz.ch

Examination

- The exam for the course is an oral examination.
  The emphasis of the exam is to ensure that a fundamental understanding of the area of risk and safety in engineering is acquired by the students.
- The confirmation (or “Testat”) for admission to the examination is fulfilled by attending the lectures of the course.
- Doctoral students need to take the oral examination in order to get credit points for this course.

Risk & Safety
in
Civil Engineering

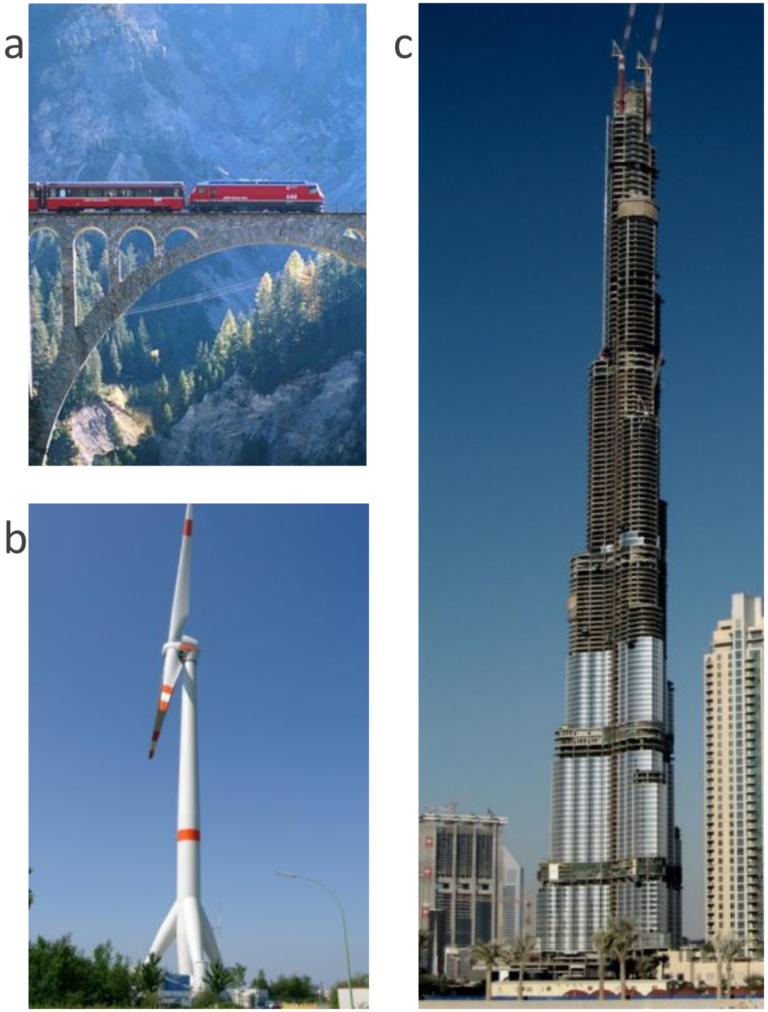
Why ??

Context and Motivation:

What Structural Engineers do:

- plan
- investigate
- design
- inspect
- maintain
- deconstruct

The build environment: e.g. dwellings, hospitals, schools, office buildings, industrial facilities , dams, bridges, tunnels.



a. Rhätische Bahn b. Multibrid M5000 c. Burj Dubai (800m)

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Constrains:

assure

- safety for personnel and
- safety for environment
- cost effectiveness

Context and Motivation:

What Structural Engineers do:

- Decision making or support

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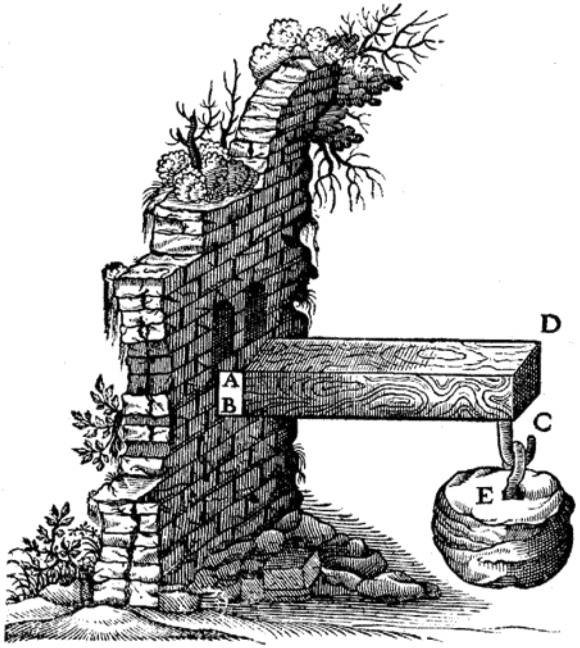
Context and Motivation:

What Structural Engineers do:

- Decision making or support, e.g.

  What is the proper cross section ?



Drawing: Leonardo da Vinci

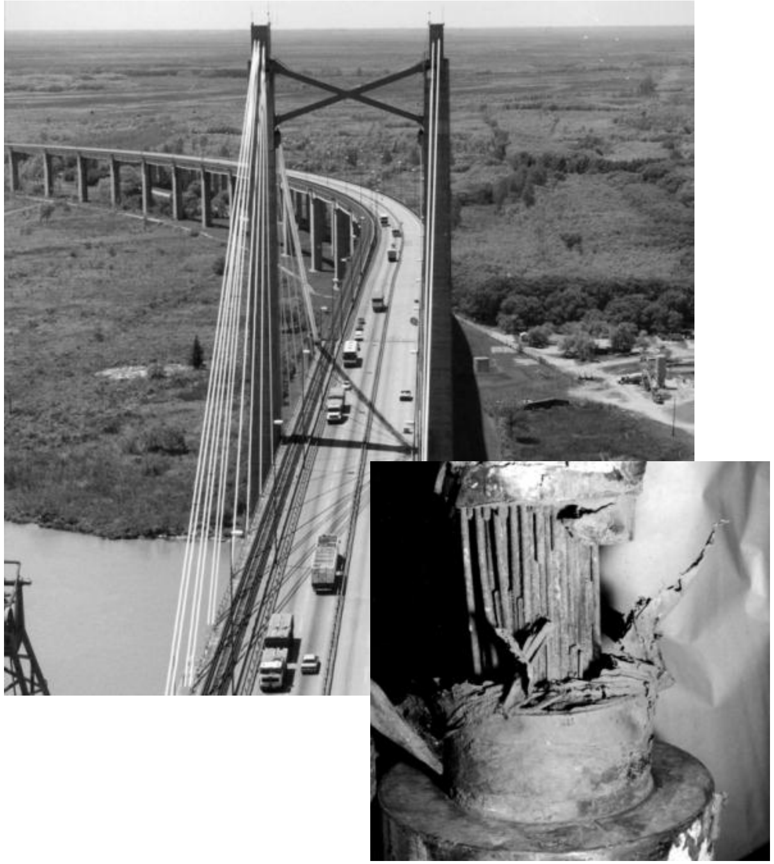
Context and Motivation:

What Structural Engineers do:

- Decision making or support, e.g.

  What is the proper cross section ?

  Should / can this bridge be repaired?



Lago Brazo, Argentinia

Context and Motivation:

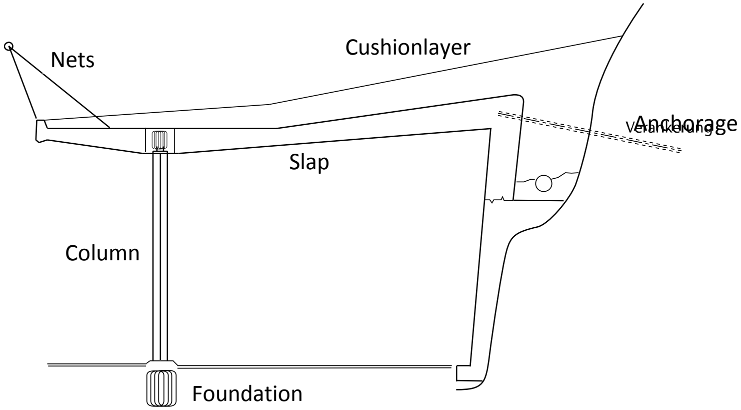
What Structural Engineers do:

- Decision making or support, e.g.

  What is the proper cross section ?

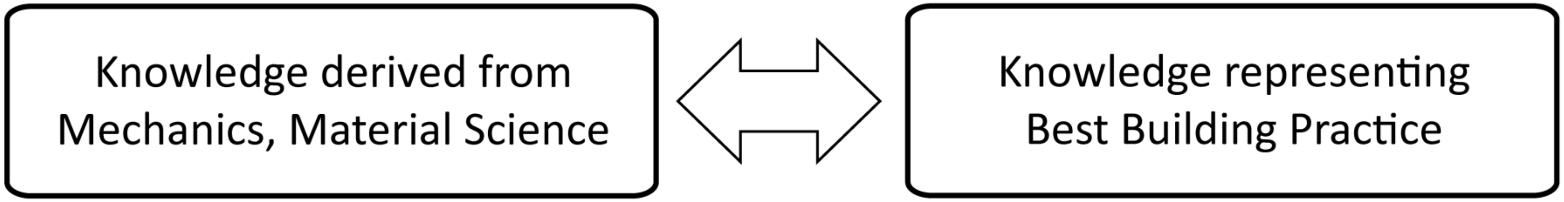
  Should / can this bridge be repaired?

  Is a rockfall gallery needed?
  If yes, what is the proper design for the slap?



Context and Motivation:

Structural Engineering knowledge basis for these decisions:



Knowledge derived from Mechanics, Material Science

Knowledge representing Best Building Practice

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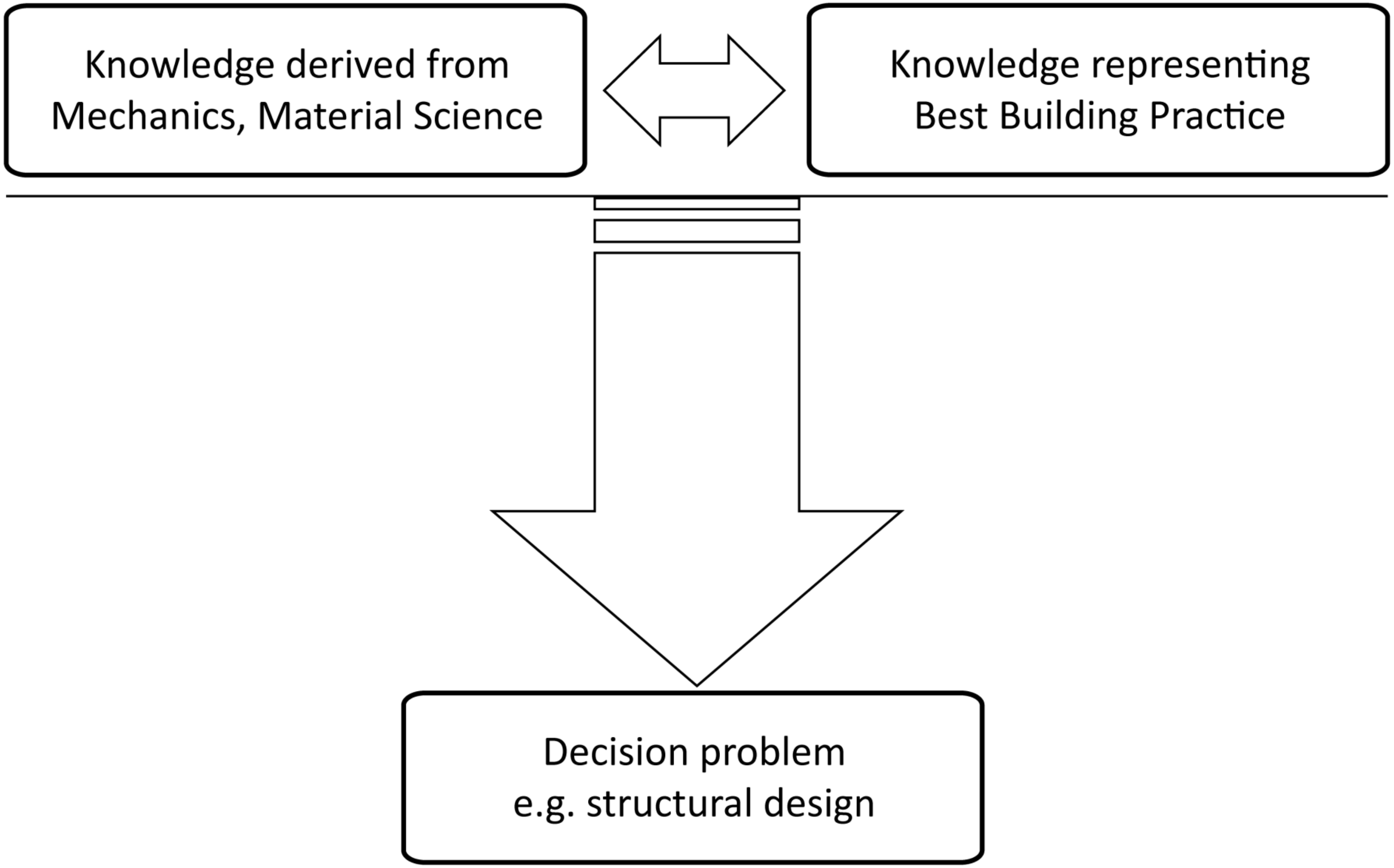

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Decision problem e.g. structural design

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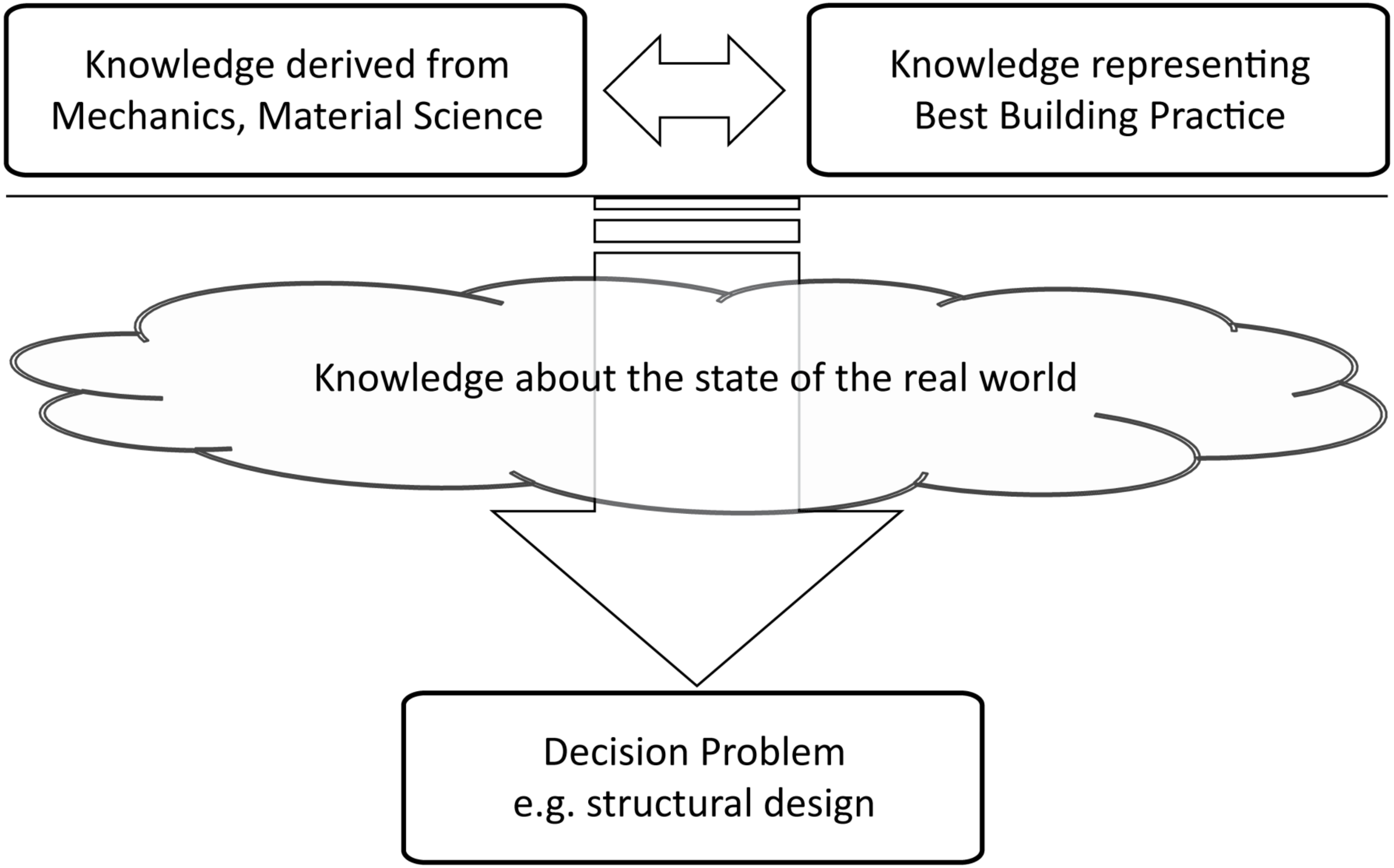

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Knowledge about the state of the real world

Decision Problem e.g. structural design

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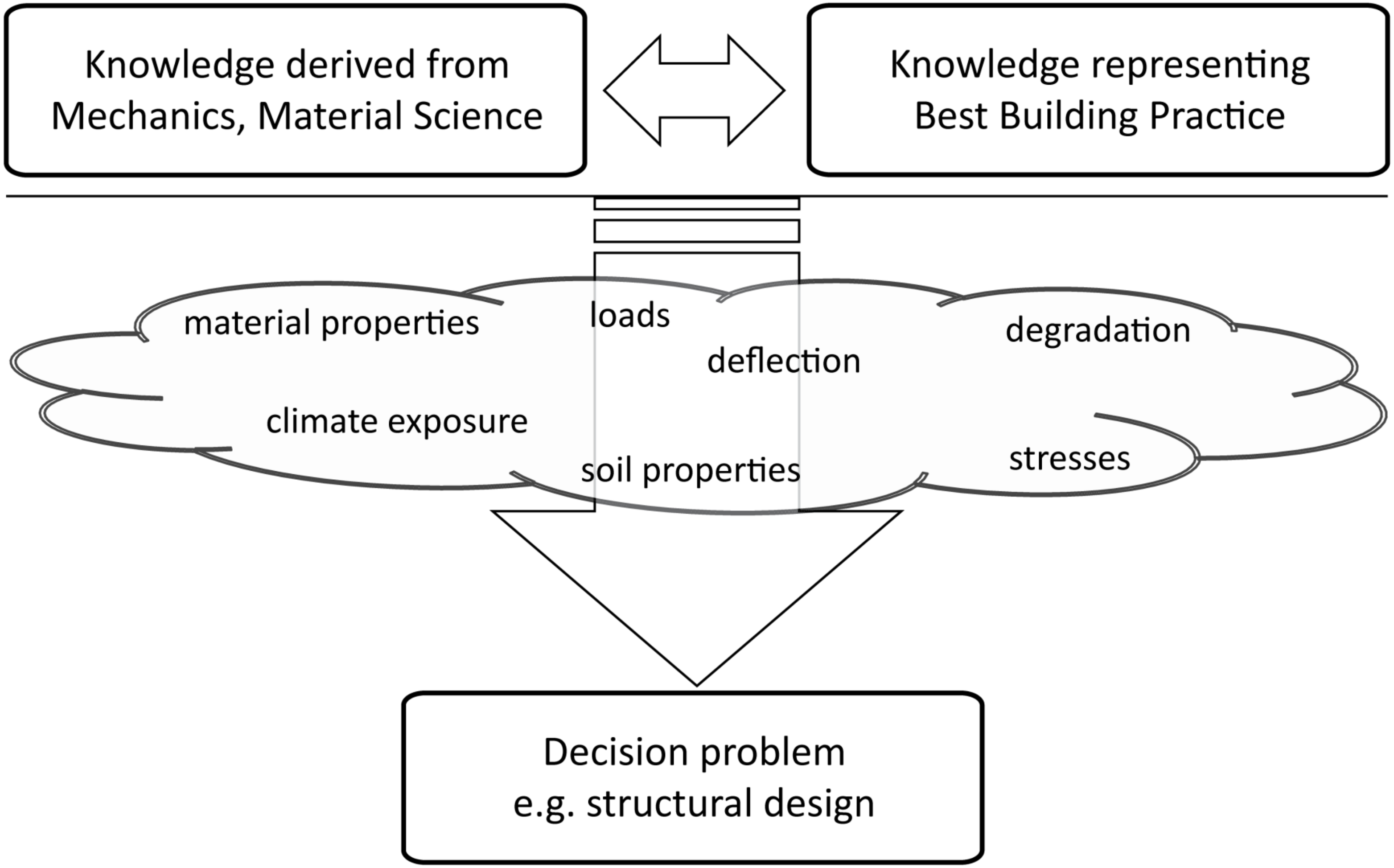

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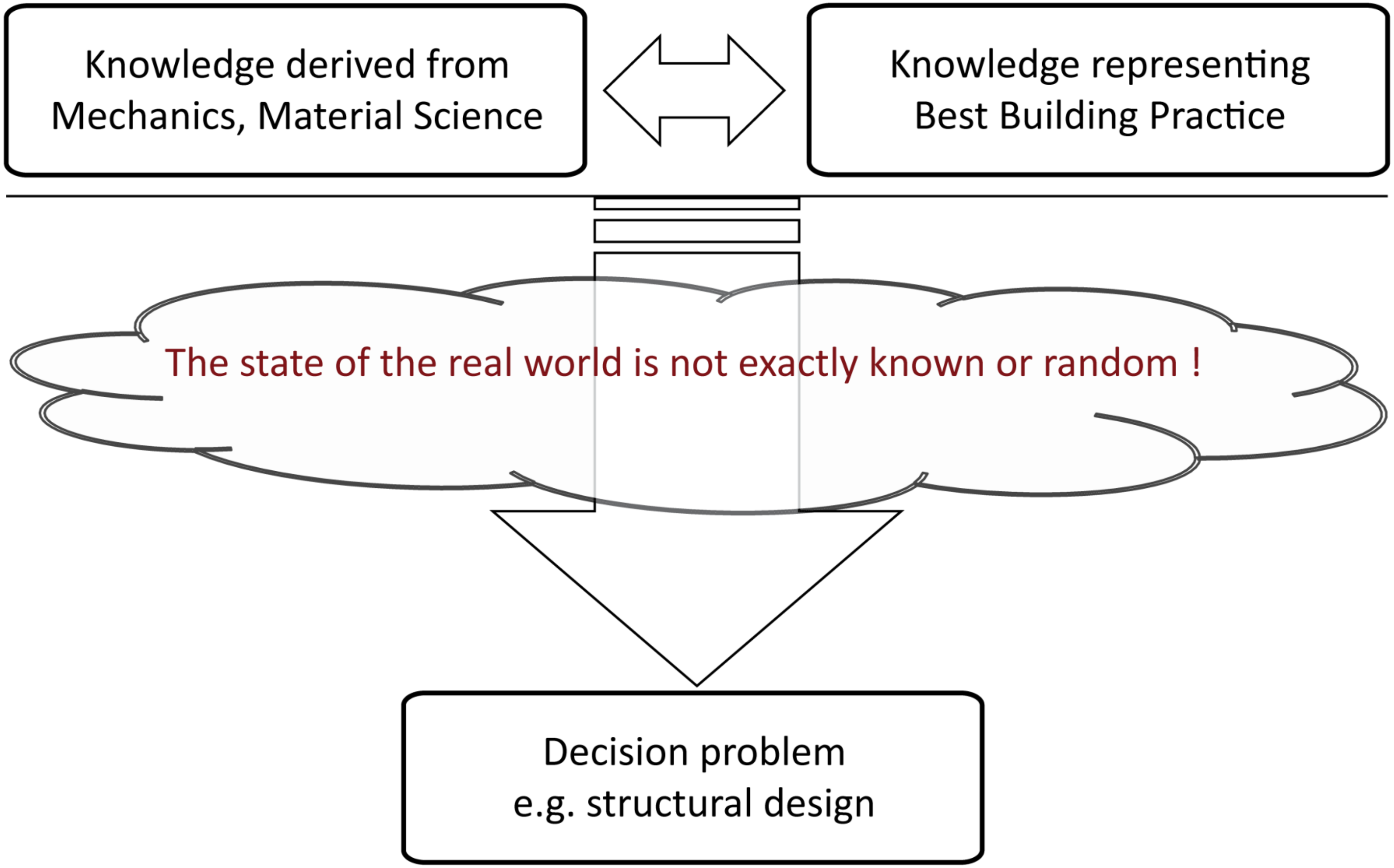


Knowledge derived from Mechanics, Material Science

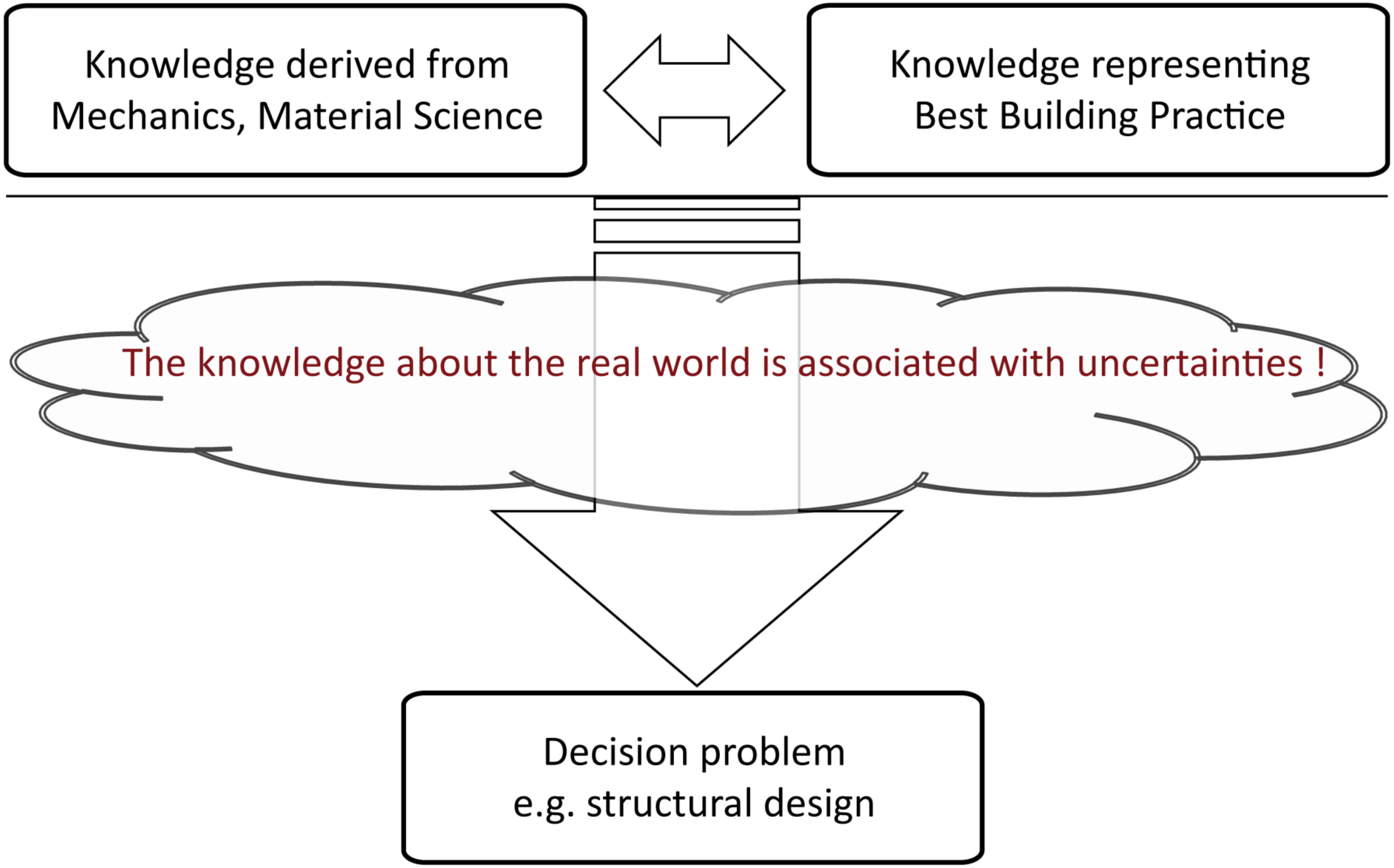
Knowledge representing Best Building Practice

The state of the real world is not exactly known or random !

Decision problem e.g. structural design

Context and Motivation:

Structural Engineering knowledge basis for these decisions:



Knowledge derived from Mechanics, Material Science

Knowledge representing Best Building Practice

The knowledge about the real world is associated with uncertainties !

Decision problem e.g. structural design

Why Risk and Safety in Engineering?

Risk assessment, within the framework of decision analysis, provides a basis for rational decision making subject to uncertain and / or incomplete information

Thereby we can take into account, in a consistent manner, the prevailing uncertainties and quantify their effect on risks

Thus we may find answers to the following questions

- How large is the risk associated with a given activity ?
- How may we reduce and / or mitigate risks ?
- How much does it cost to reduce and / or mitigate risks ?
- What risks can we accept – what can we afford ?

Definition of Risk?

Risk is a characteristic of an activity relating to all possible events n_E which may follow as a result of the activity

The risk contribution R_{E_i} from the event E_i is defined through the product between

the event probability P_{E_i}

and

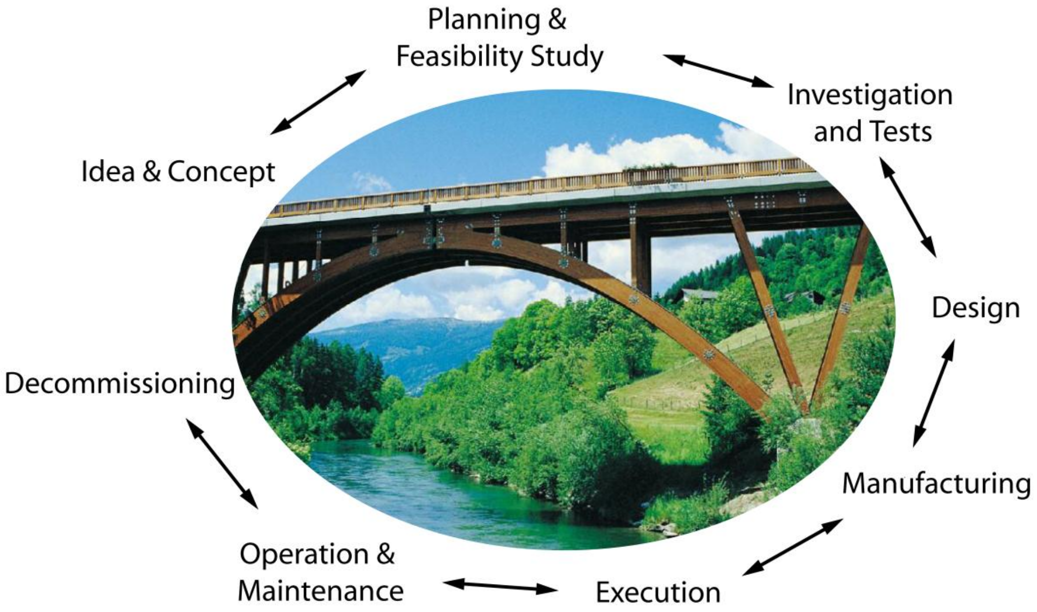
the consequences of the event C_{E_i}

The risk associated with a given activity R_A may then be written as

$$R_A = \sum_{i=1}^{n_E} R_{E_i} = \sum_{i=1}^{n_E} P_{E_i} \cdot C_{E_i}$$

Decision Problems in Engineering

Uncertainties must be considered in the decision making throughout all phases of the life of an engineering facility



<u>Decisions under uncertainties</u>

- Traffic volume
- Loads
- Resistances (material, soil,..)
- Degradation processes
- Service life
- Manufacturing costs
- Execution costs
- Decommissioning costs

Example – Classical Structural Engineering Decisions:

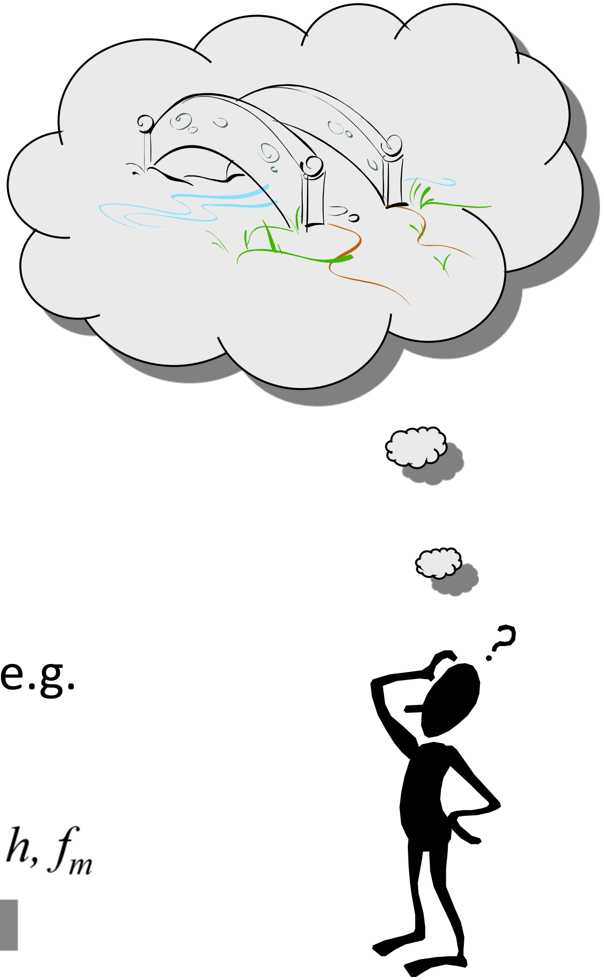
1. Idea and Concept

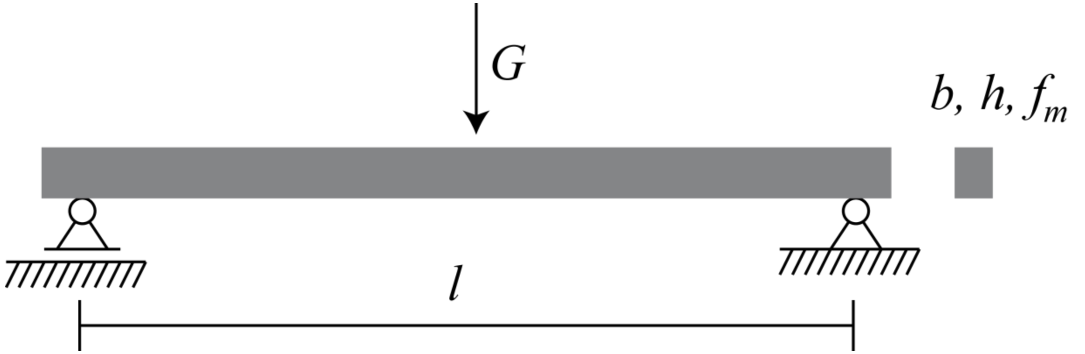
Definition of the structure and its purpose

Definition of expected loads and environmental conditions

Feasibility assessment of different structural layouts

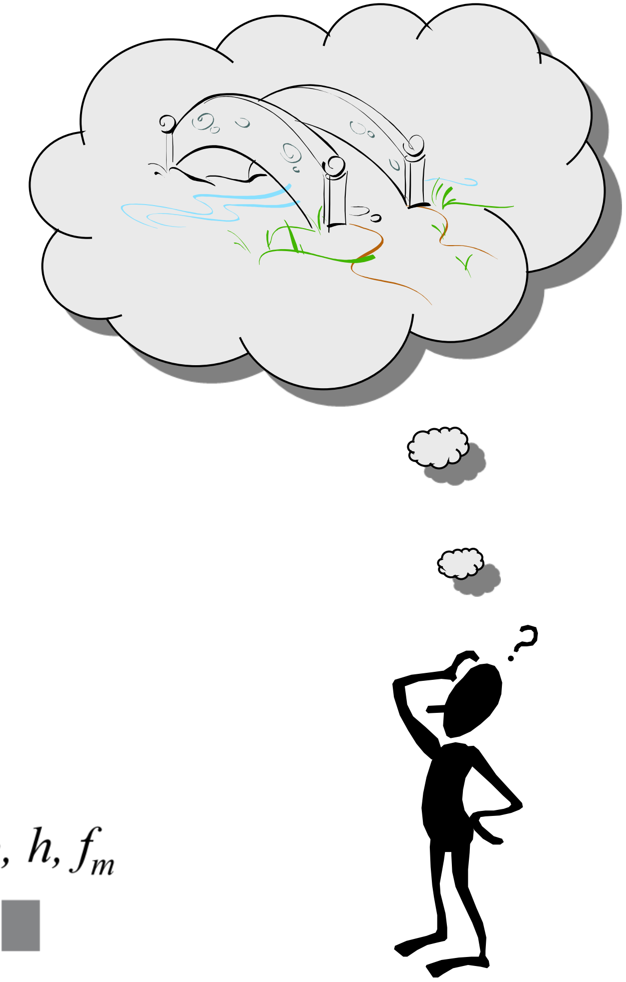
Abstraction of the different mechanical systems, e.g.





Example – Classical Structural Engineering Decisions:

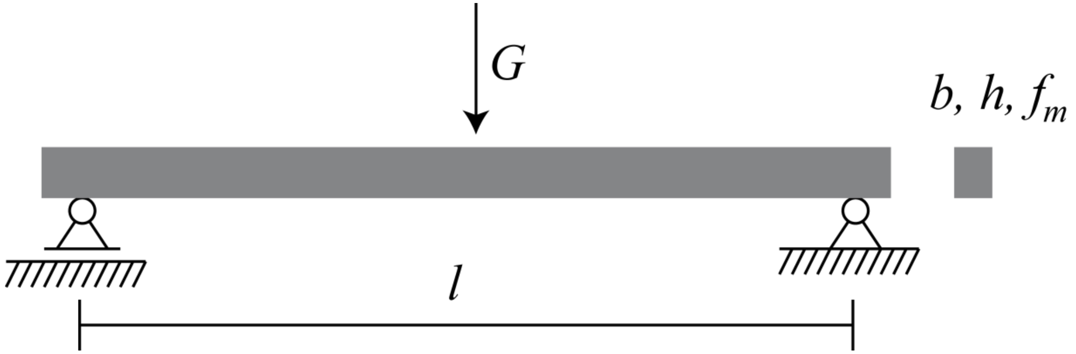
2. Formulation of Limit States



Limit States for the different requirements,
as e.g. load resistance

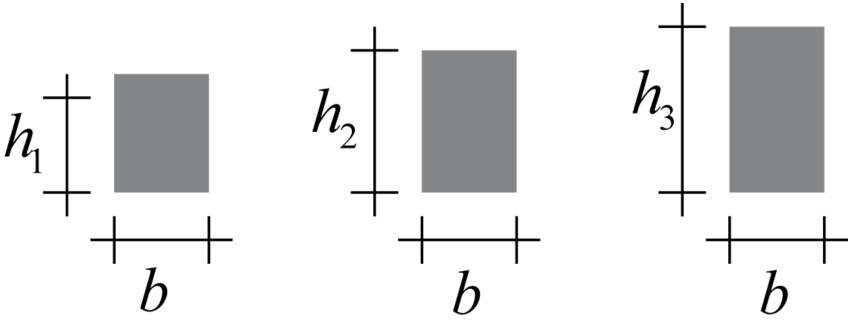
Capacity > Demand

$$f_m \frac{bh^2}{6} > \frac{Gl}{4} \quad [kNm]$$



Example – Classical Structural Engineering Decisions:

3. Design, e.g. of a proper cross section



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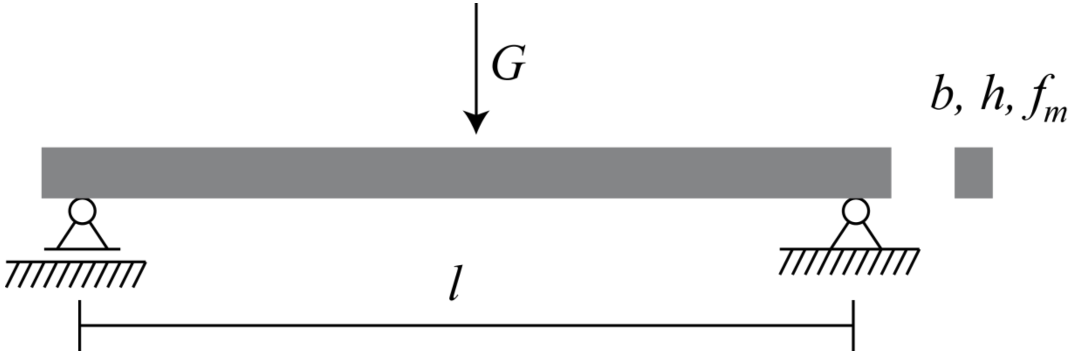

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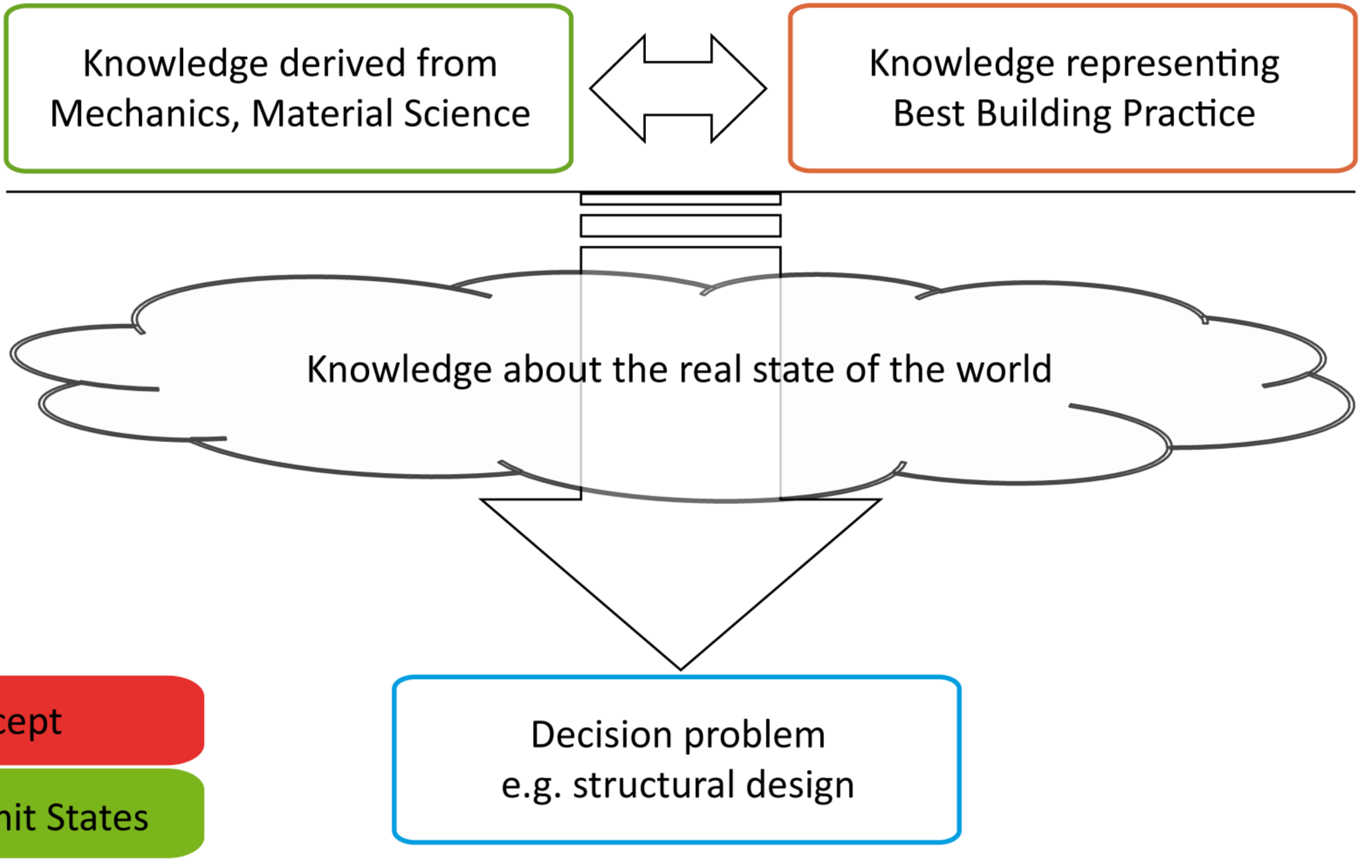

Knowledge derived from Mechanics, Material Science

Knowledge representing Best Building Practice

Knowledge about the real state of the world

Decision problem
e.g. structural design

1. Idea and Concept
2. Formulation of Limit States
3. Design

Example – Classical Structural Engineering Decisions:

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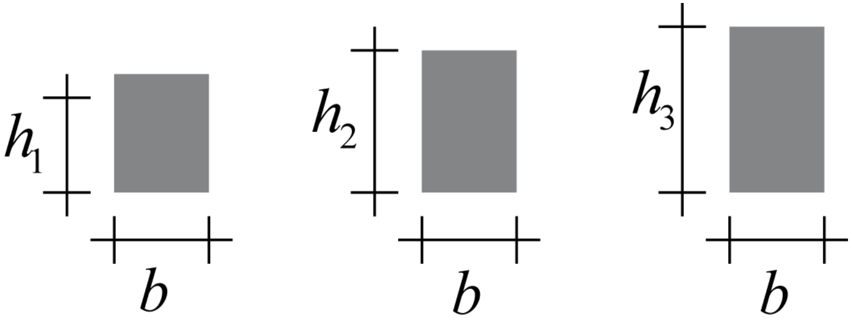

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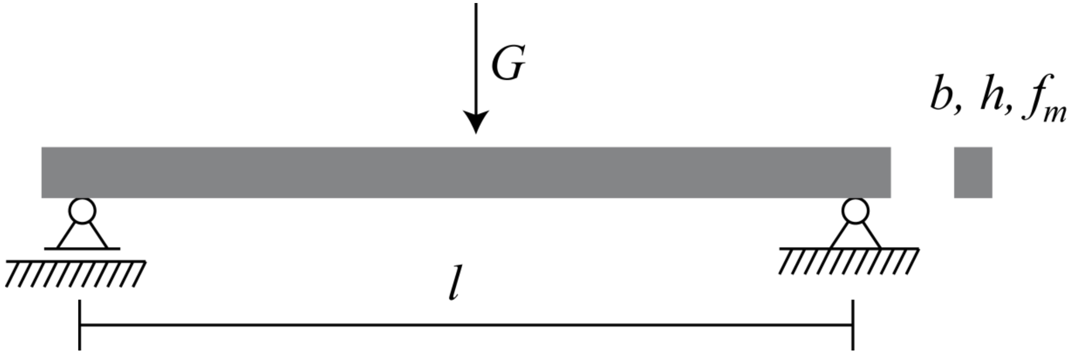

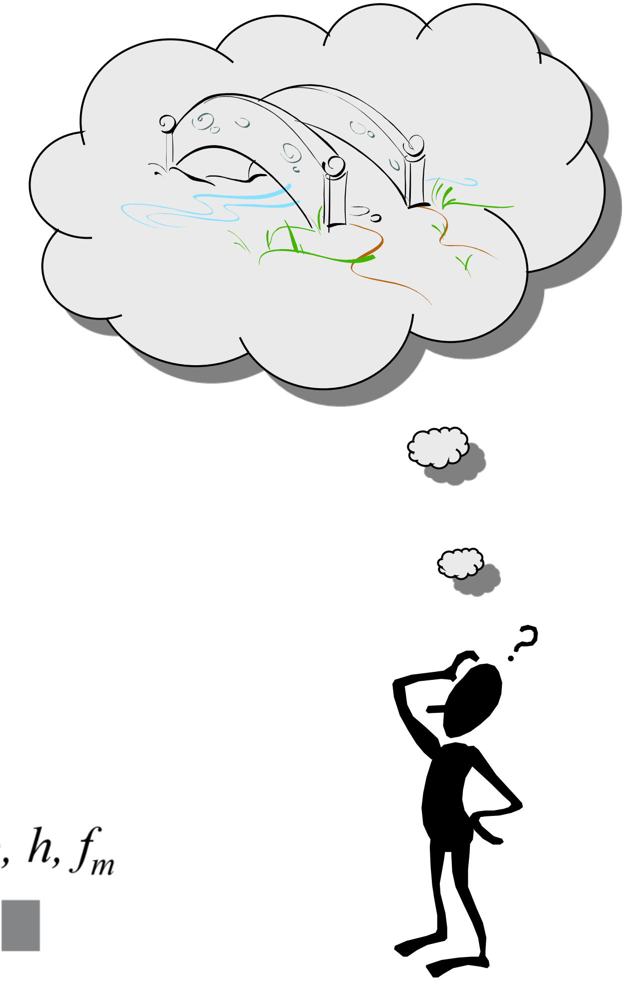

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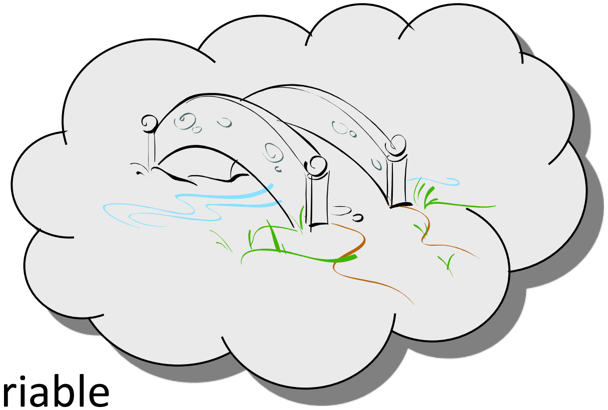
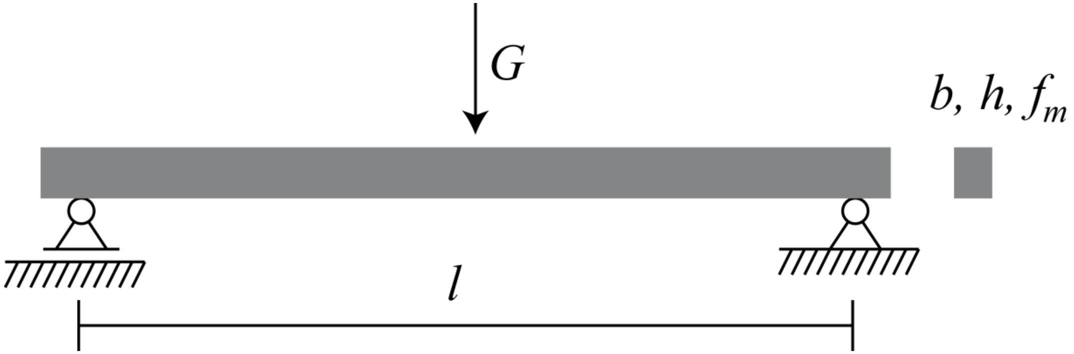


Classification of parameters:

G, f_m : **uncertain**

l, b : known (assumed to be) h : design variable

$$f_m \frac{bh^2}{6} > \frac{Gl}{4} \quad [kNm]$$



How to deal with uncertainties ?

1. Implicit
   - with conservative estimates for load and material resistance

MIN[Capacity] $>$ MAX[Demand]

$$f_{m,\min}\frac{bh^2}{6} > \frac{G_{\max} l}{4} \quad \left[kNm\right]$$

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Issues:

- minimum / maximum values are hard to justify
- model uncertainties are not accounted for
- poor workmanship is not accounted for

How to deal with uncertainties ?

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$$\phi \text{ MIN[Capacity]} > \text{MAX[Demand]}$$

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Short fix:

Multiply a safety factor ϕ to accommodate uncertainties in regard to the assumptions

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Remaining issues:

How can the safety factor be quantified?

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Conservative is not conservative in all cases !!

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How to deal with uncertainties ?

2. Explicit
   - considering load and material resistance as random variables

{Capacity} > {Demand}

$$R > S$$

$$X_{f_m} \frac{bh^2}{6} > \frac{X_G l}{4} \quad [kNm]$$

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Probability of failure:

$$P_F = \Pr(R \leq S) \ ; P_F \in [0,1]$$

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Cost effectiveness by maximization of the expected benefit:

$$E\left[B\right]$$

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Cost effectiveness by maximization of the expected benefit:

$$E[B]=\underset{\substack{\nearrow\\\text{benefit in service}}}{I}\left(1-P_F\right)-\underset{\substack{\nearrow\\\text{cost of design}}}{C_D}-\underset{\substack{\nwarrow\\\text{failure cost}}}{C_F}P_F$$

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Safety of personnel and environment might be related to the

corresponding acceptable

Reliability !!

Constrains:

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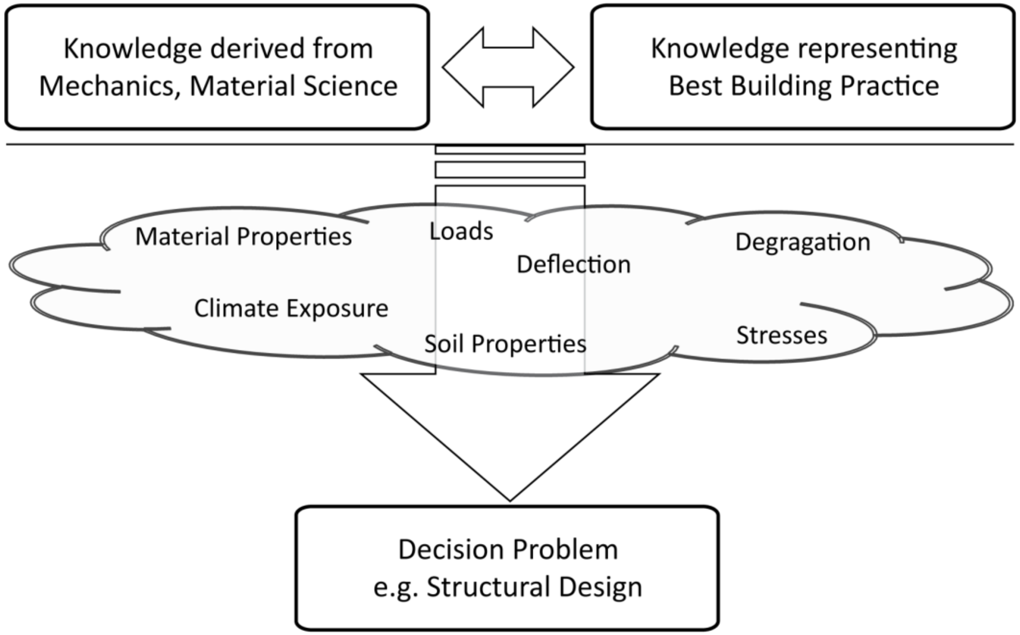
Structural Engineering Decision Problem

How does this relate to current engineering practice?



Structural Engineering Decision Problem

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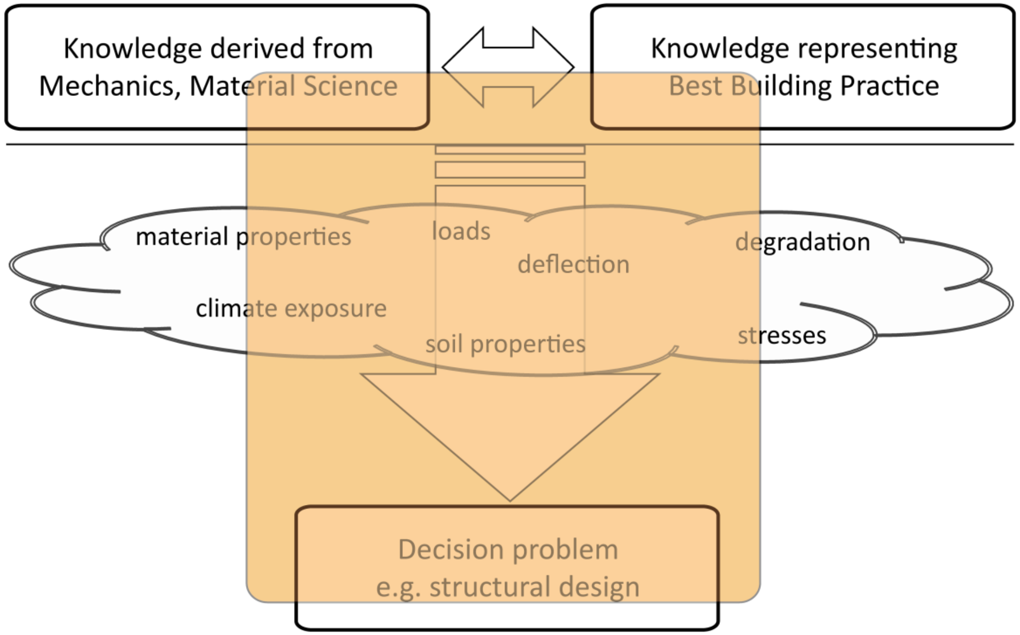
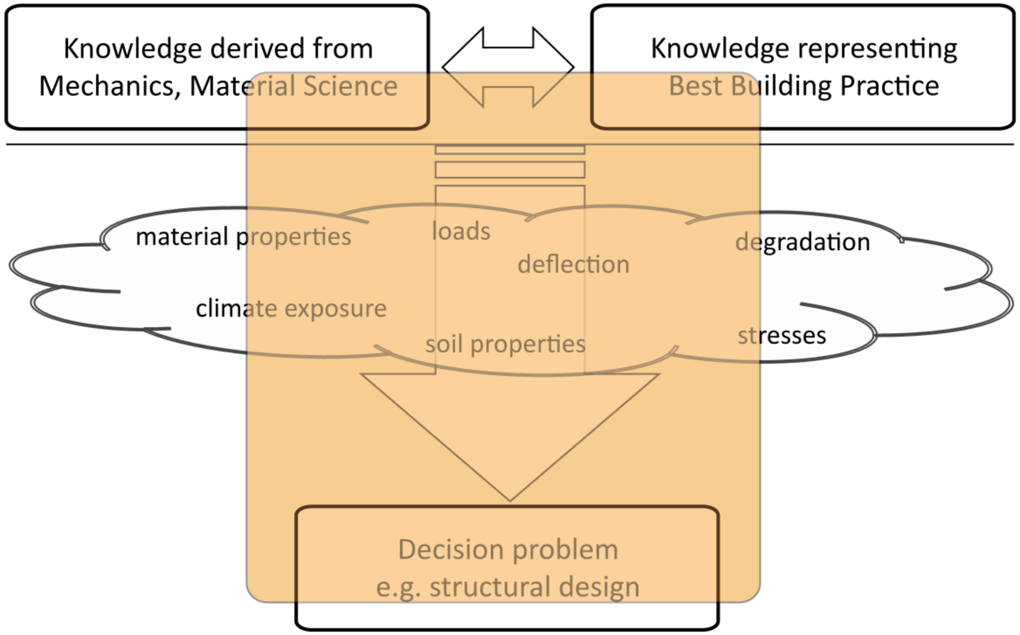


Structural Codes contain some regulations on “Mechanics” and “Building Practice”

Structural Engineering Decision Problem

How does this relate to current engineering practice?



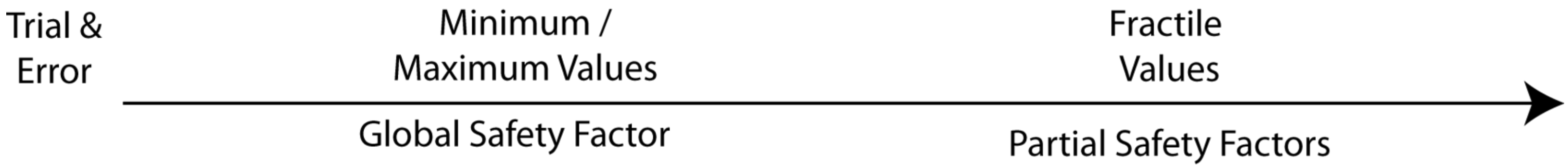
Structural Codes contain some regulations on “Mechanics” and “Building Practice”

- but mainly standardize a procedure on how to deal with uncertainties !

Codes and Standards

- Support the engineer for regular decision problems
- Contain standardized estimators for basic variables
- Contain a set of relevant limit states

- Represent the accumulated engineering experience
- Do not apply for extraordinary decision problems



Trial & Error

Minimum / Maximum Values

Global Safety Factor

Fractile Values

Partial Safety Factors

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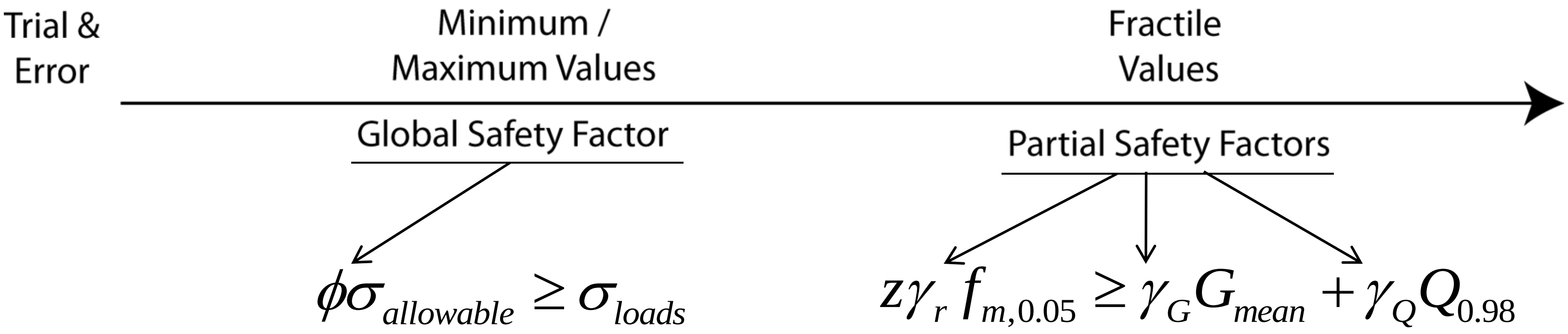

Trial & Error

Minimum / Maximum Values

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Global Safety Factor

Partial Safety Factors

$$\phi\sigma_{allowable} \geq \sigma_{loads}$$

$$z\gamma_r f_{m,0.05} \geq \gamma_G G_{mean} + \gamma_Q Q_{0.98}$$

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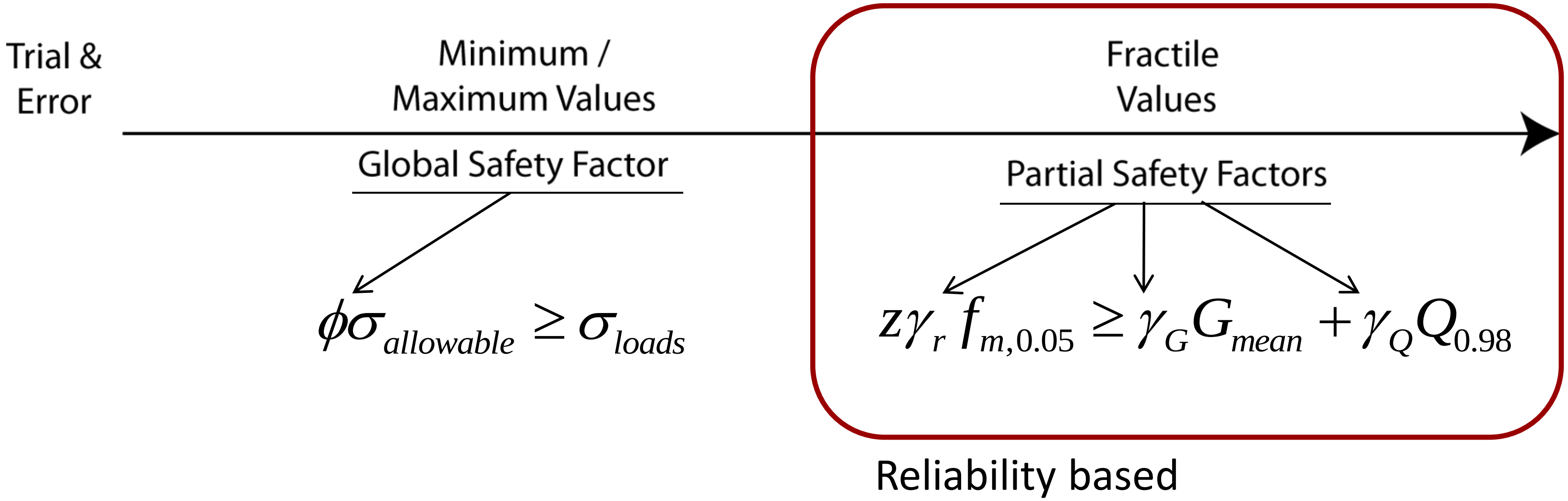

Trial & Error

Minimum / Maximum Values

Global Safety Factor

$$\phi\sigma_{allowable} \geq \sigma_{loads}$$

Fractile Values

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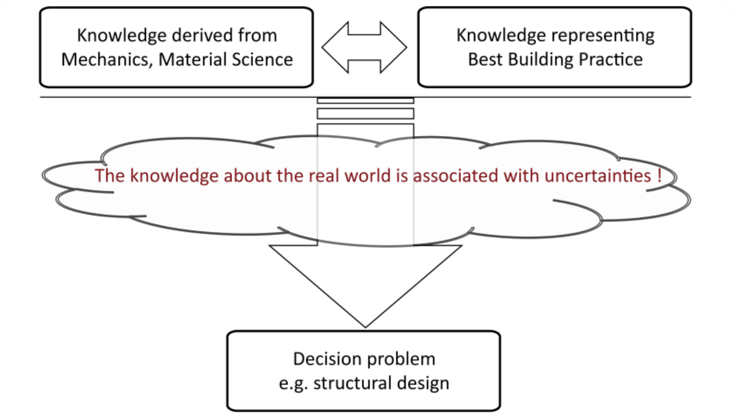
Reliability based

Summary


Knowledge derived from Mechanics, Material Science

Knowledge representing Best Building Practice

The knowledge about the real world is associated with uncertainties !

Decision problem e.g. structural design

- For structural engineering decisions uncertainties have to be considered

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- Implicit consideration through conservatism bears problems

ϕ MIN[Capacity] $\geq$ MAX[Demand]

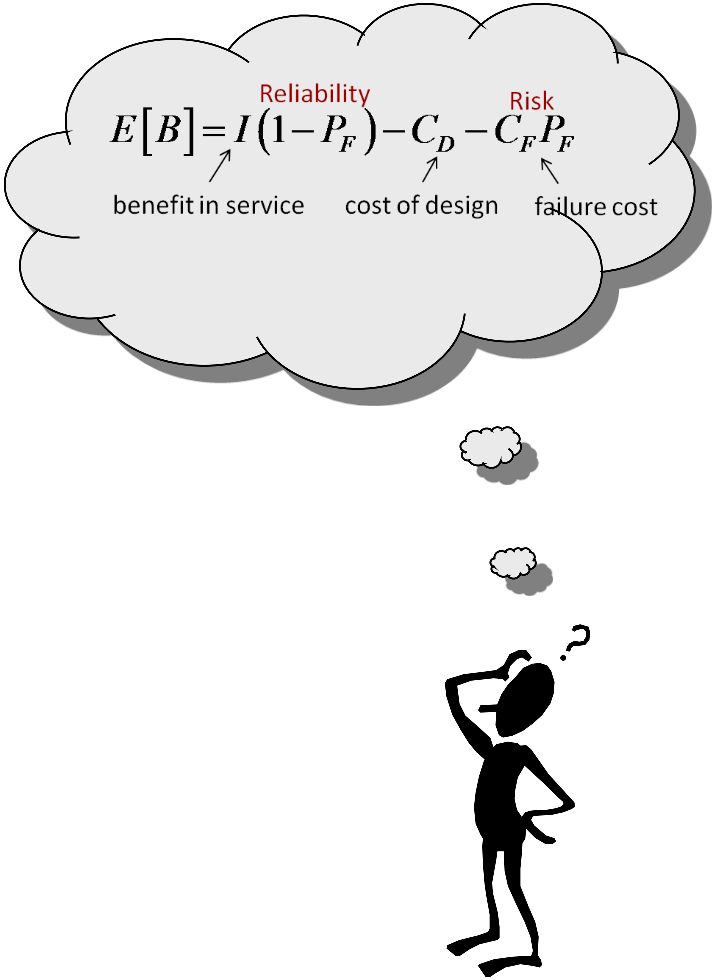
$$\phi f_{m,\min}\frac{bh^2}{6}\geq\frac{G_{\max}l}{4}\quad[kNm]$$

- Explicit consideration is possible, safety and efficiency can be assessed

$$E[B]=\underset{\substack{\nearrow\\ \text{benefit in service}}}{I}\overbrace{(1-P_F)}^{\text{Reliability}}-\underset{\substack{\nearrow\\ \text{cost of design}}}{C_D}-\overbrace{\underset{\substack{\nwarrow\\ \text{failure cost}}}{C_F}P_F}^{\text{Risk}}$$

Summary, continued

- Explicit consideration is possible, safety and efficiency can be assessed



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Summary, continued

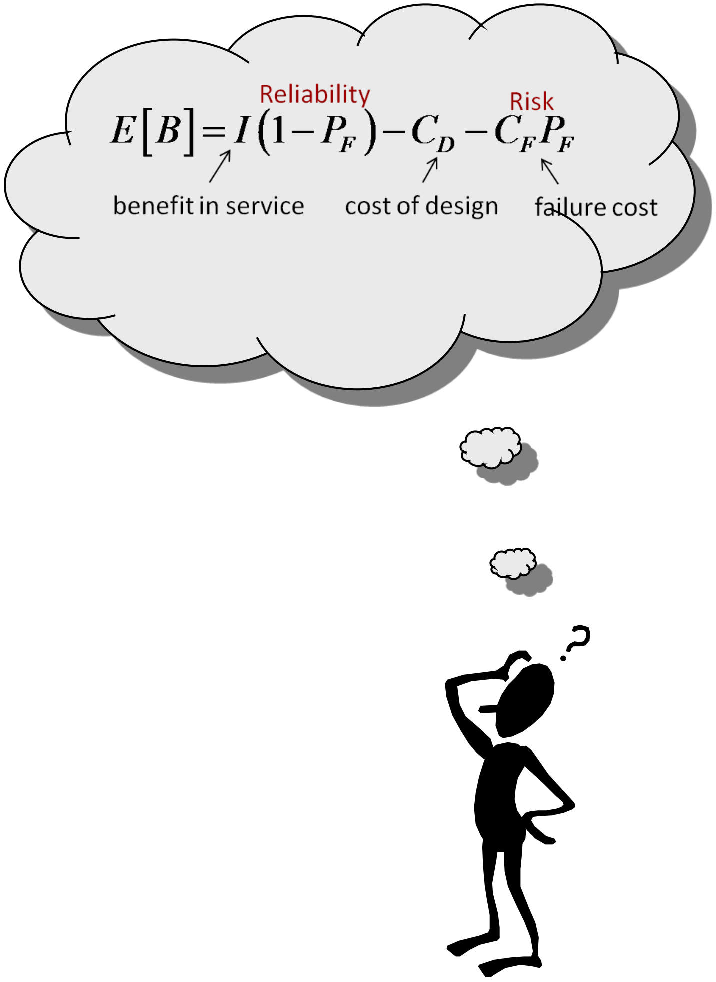
- Explicit consideration is possible, safety and efficiency can be assessed

Required knowledge:

What is the reliability ?
- failure criteria ?
- basic variables ?
- computation of failure probability?

What are the consequences ?

How to combine this information ?



$$E[B]=\underset{\text{benefit in service}}{\underset{\nearrow}{I}}\overset{\text{Reliability}}{(1-P_F)}-\underset{\text{cost of design}}{\underset{\nearrow}{C_D}}-\overset{\text{Risk}}{\underset{\text{failure cost}}{\underset{\nwarrow}{C_F}}P_F}$$

Date	Topic	Date	Topic
21.09.	Course Introduction	9.11.	Structural Reliability - Basic Principles
28.09.	Revisiting Probability Theory and Statistics I	16.11.	Methods of Structural Reliability
5.10.	Revisiting Probability Theory and Statistics II Basic Decision Theory – Concepts I	23.11.	System Reliability
12.10.	Basic Decision Theory – Concepts II	30.11.	Probabilistic Modelling of Loads and Resistances
19.10.	Basic Decision Theory - Examples	7.12.	Exercise - Software for Reliability Analysis
???? (26.10.)	Bayesian Probabilistic Networks	14.12.	Reliability Based Code Calibration
2.11.	Exercises	21.12.	Exercises