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Simplification of steel truss design in fire - Optimization approach

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Steel trusses and optimization – Motivation and background

- Widely used light weight, cost effective and aesthetic structures
- By applying mathematical *optimization* techniques performance could be enhanced further

What is mathematical optimization?

- Find the *design* satisfying the *constraints* leading to minimal *objective* value

$$\min f(\mathbf{x})$$
$$\text{s. t. } g_i(\mathbf{x}) \leq 0 \text{ (inequality)}$$
$$h_j(\mathbf{x}) = 0 \text{ (equality)}$$

- Algorithms can be applied to many kinds of (engineering) problems

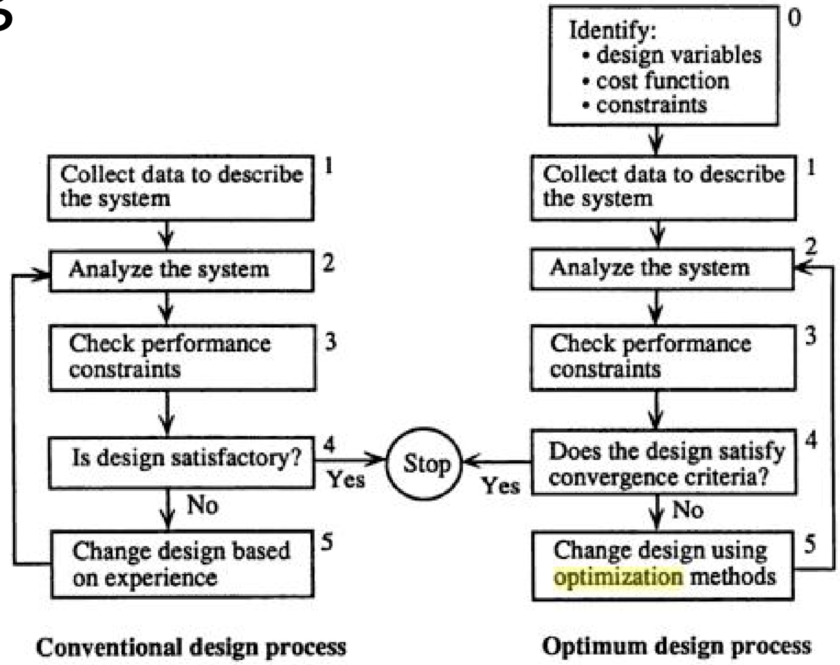


Figure above from: Arora, J. S., Burns, S. & Huang, M. W. (1997). What is optimization? In J. S. Arora (Ed.), Guide to structural optimization, ASCE Manual on Engineering Practice, No. 90 (pp.1-23). Reston, VA: American Society of Civil Engineers

Why optimize and why not?

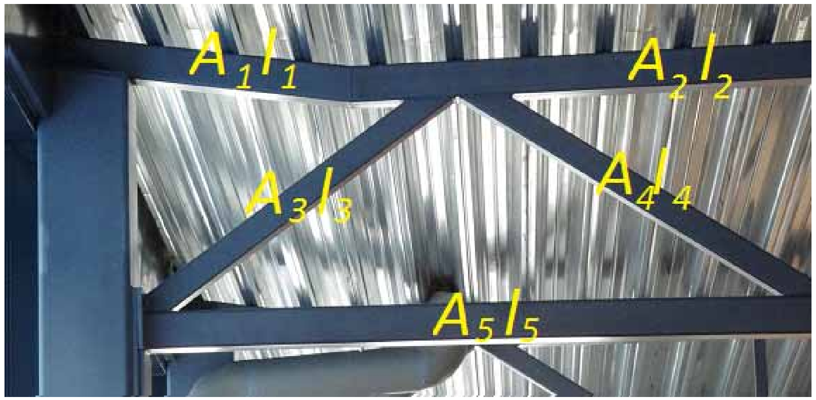
+ Design problem goals better defined
+ Transparency to decision making
+ Better desings
- Problem formulation takes time
- Setting up a system capable of doing necessary calculation takes also time

Truss problem formulation

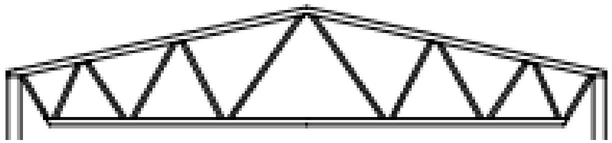
- Choise of *objective* function (weight, cost, enviromental impact etc.)
- Choise of *constraints*
  - Stresses and deformations
  - Building code requirements
  - Other (manufacturing, architecture etc.)
- Choise of *design variables*

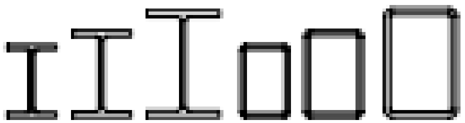
$$\min\ f(\mathbf{x}) = \sum A_i(\mathbf{x}) l_i$$

$$\text{s. t. } g_i(\mathbf{x}) = \frac{N_i(\mathbf{x})}{A_i(\mathbf{x})} - \sigma_{limit} \leq 0$$



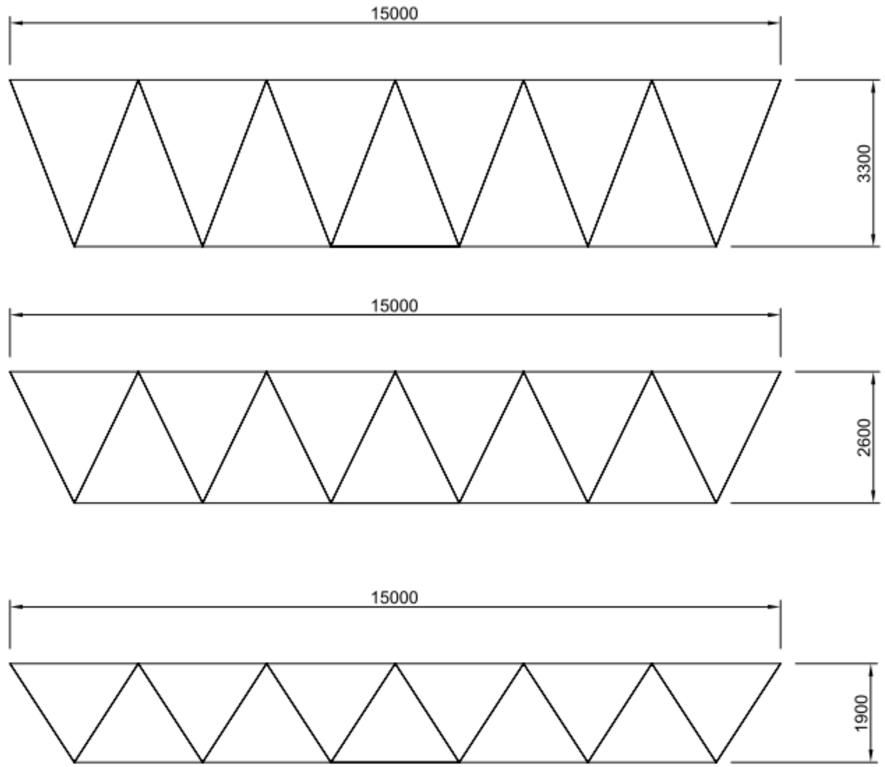
Truss optimization approaches (1/2)





Sizing

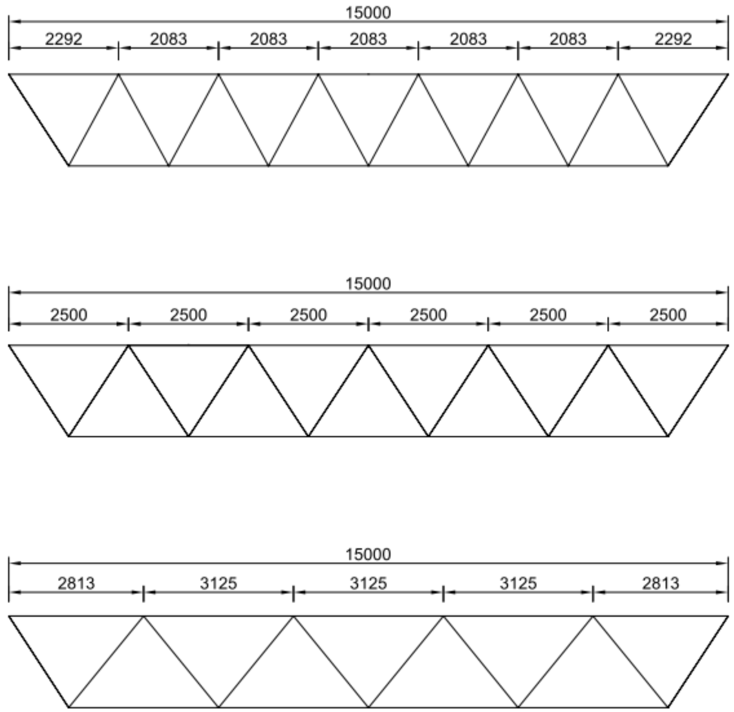
(Choice of
member profiles)



Geometry

(dimensions of truss)

Truss optimization approaches (2/2)



Topology

Other possible variables:

- -Connections (stiffness, resistance, cost)
- -Material strength (S355,S420 etc.)
- -Intumescent paint or other protection?

Current situation

- Classical approaches of structural optimization have been researched widely from the 1960s
- Lately building code requirements have been replacing simple stress and deformation constraints and construction cost has become the objective instead of weight
- Still, performance at elevated temperatures is rarely considered in optimization literature

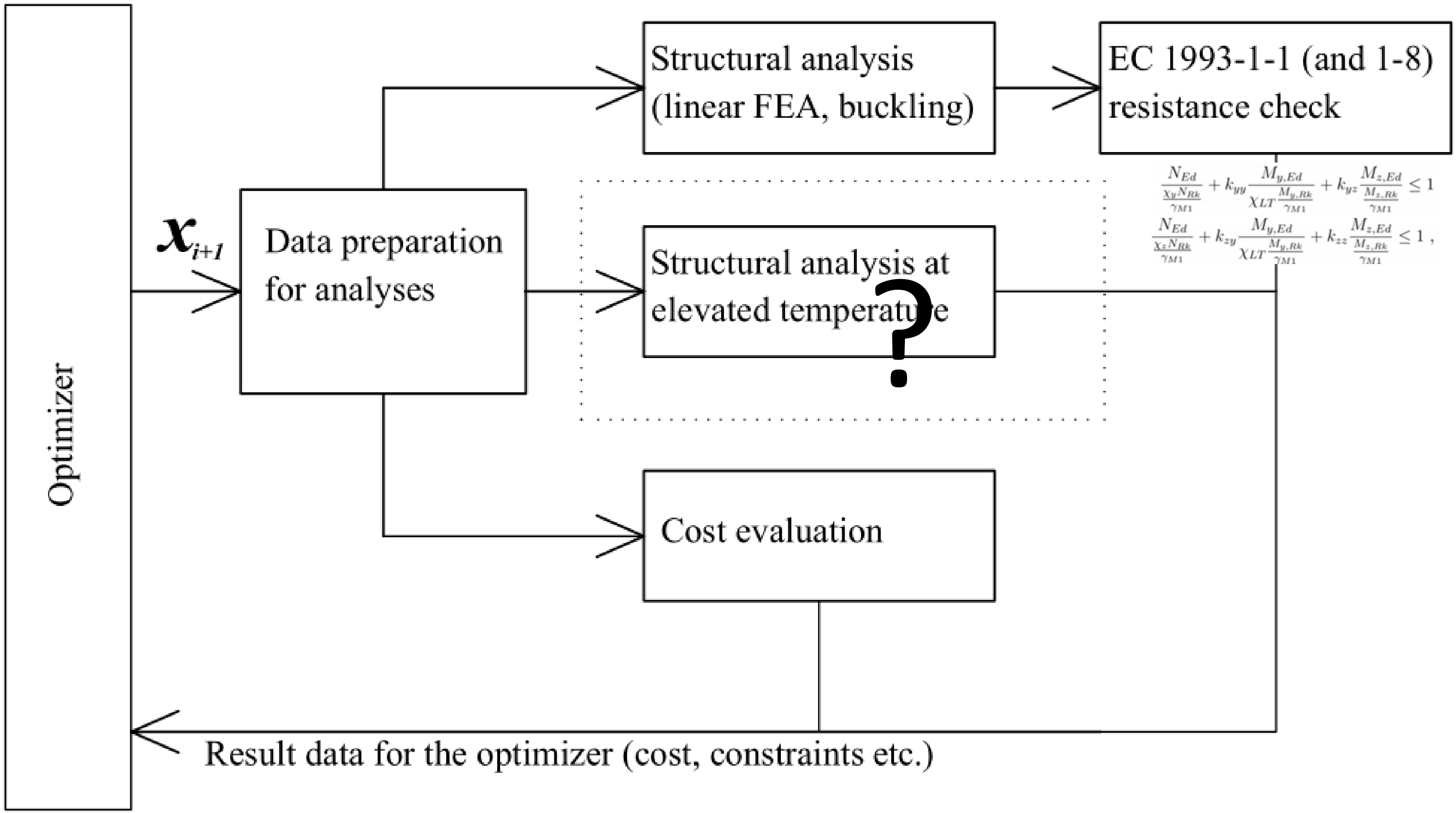
Main goals of the research

- Include fire design in steel truss optimization and see if it works
- If so, find out design guidelines leading to more cost effective or otherwise better designs

Truss optimization challenges

- The number of variables is high
- Optimization problems are most often non-linear mixed integer problems => method must be chosen carefully
- In a single optimization run, the truss has to be evaluated thousands of times => fast evaluation needed (seconds)

Truss evaluation in optimization



Elevated temperature design challenges

- Large deformations
- Elognation of members causes stresses and deformations (for hyperstatic trusses)
- Geometrical and material non-linearities
- Possible new buckling modes

=> Special methods must be utilized

Some possible approaches

- Advanced temperature and structural analyses
  - implementation laborious and requires commercial programs
  - accurate but analysis takes time
- Eurocode approach (weakened material properties, simplified temperature analysis, ISO fire) with linear beam FEA
  - implementation fairly easy
  - fast evaluation
  - accuracy with non-uniform temperature distribution?

Future studies, open questions

- Reliability of EC-based fire design?
- Multiobjective approach (safety vs. cost vs. sustainability)
- Connections?