Multi-Criterion Scantling Optimisation of Passenger Ships

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Introduction

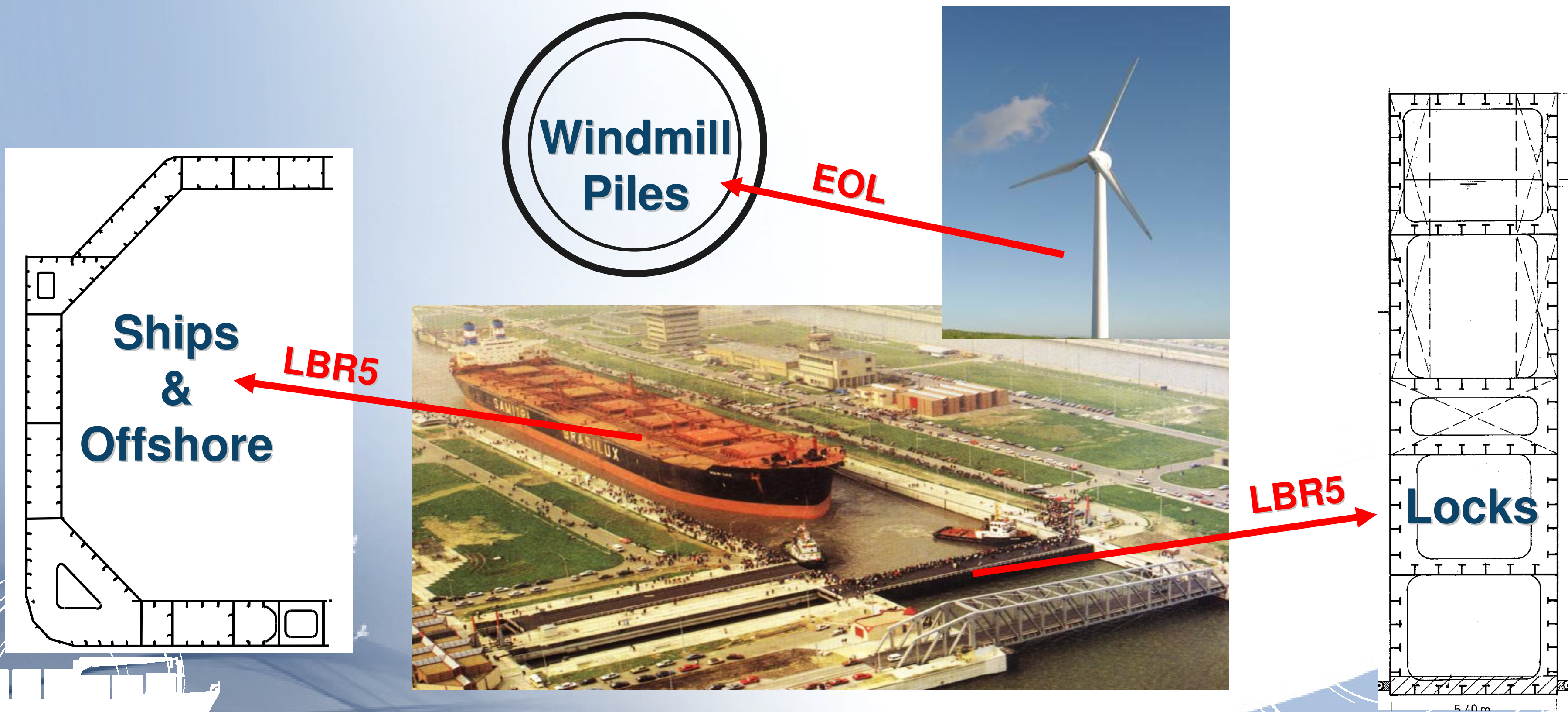
- Sustainability of technologies → Central focus
- Early technical requirement → impact on the entire ship life cycle
- Life cycle optimisation → Poorly applied
  - Long term task of decades
  - Take into account of overall Life Cycle aspects AEAP
    - Production, operation, safety, environment, disposal, etc.

- Scantling optimisation
  - Reduction of steel weight → Fuel costs reduction
  - Reduction of production costs

What is the LBR5 tools?

What is the LBR-5 tool ?

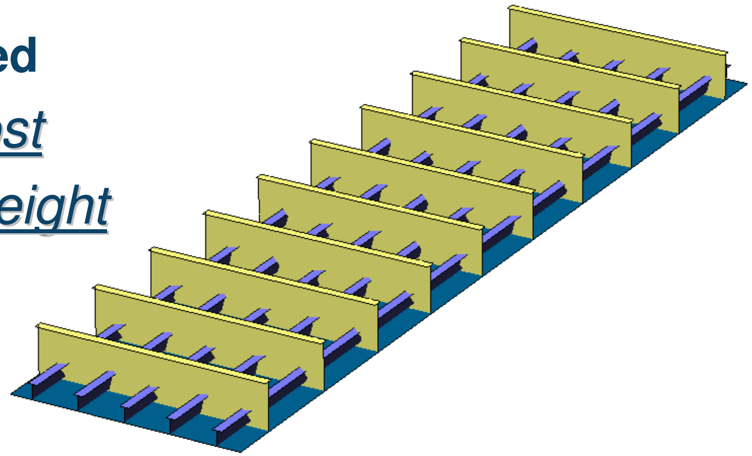
- Scantling optimisation tool for naval and hydraulics structures
- Dedicated to early conceptual design stage
- Ships and offshore, hydraulic (locks gates), windmills, etc.



What is the LBR-5 tool ?

- **3D structural analysis based on a extruded 2D mesh**
- **Analytic solution (Not FEM)**
- **Scantling optimisation of the structural elements**
  - *9 variables per strake*
  - *Spacing (frames & stiffeners)*
  - *Thicknesses & dimensions*

LBR5 strake element

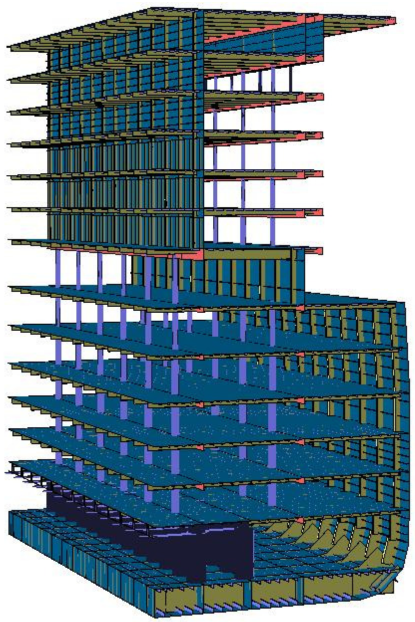


- **Different objectives are implemented**
  - *Minimize the manufacturing cost*
  - *Minimize the structural steel weight*
  - *Maximize the flexional inertia*

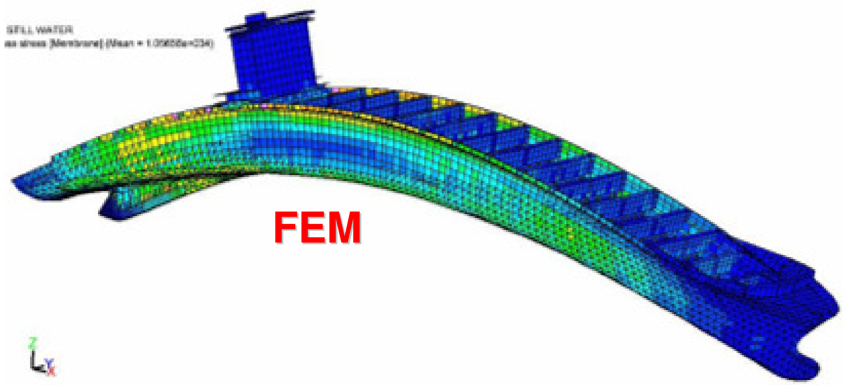
What is the LBR5 tools?

LBR5 or ship FEM ?

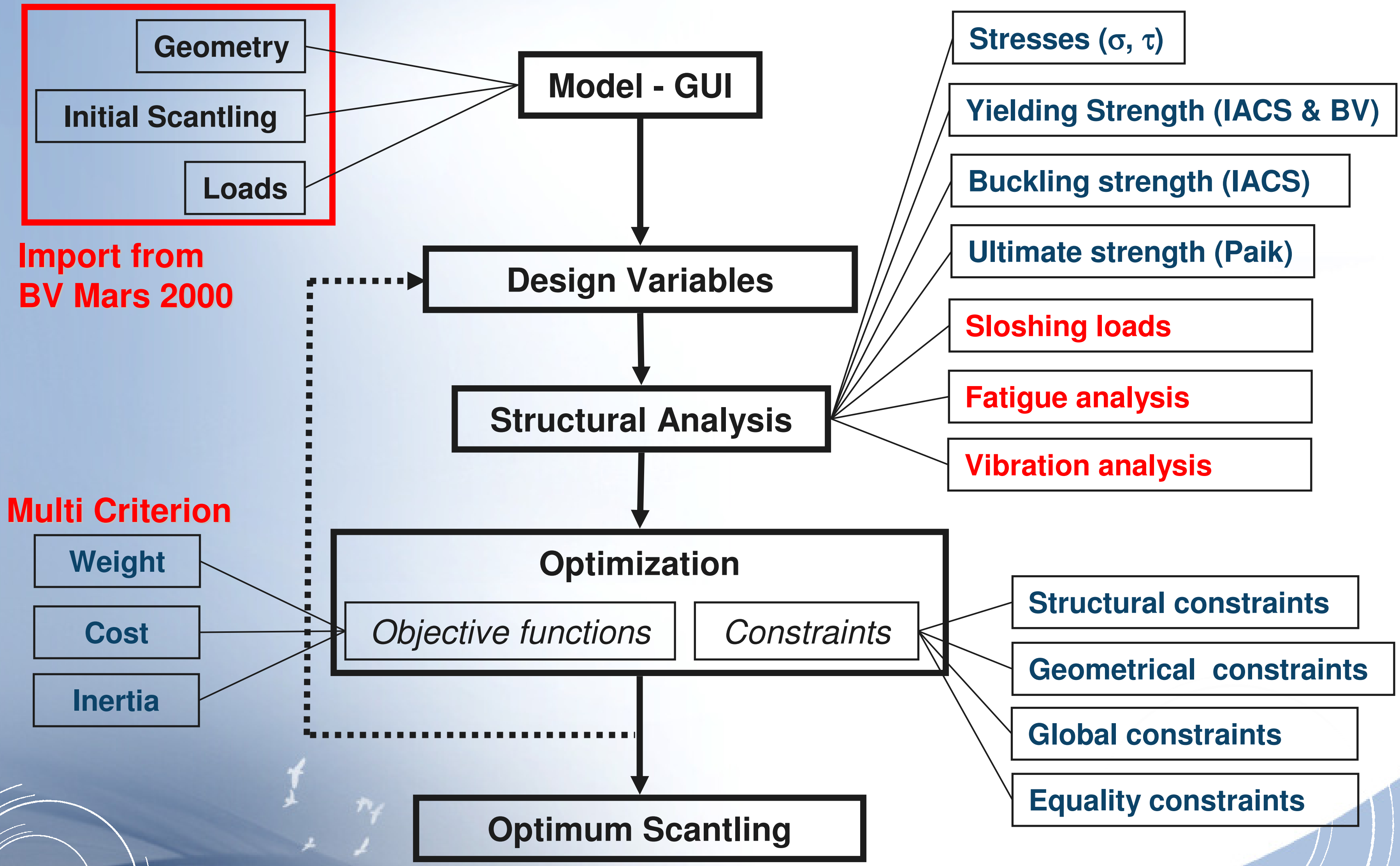
- LBR5
  - Early conceptual design
  - Quick analytical solution
  - Optimal solution in a couple of days
  - Difficult to take into account of local problems (Hot spots, fatigue, etc.)



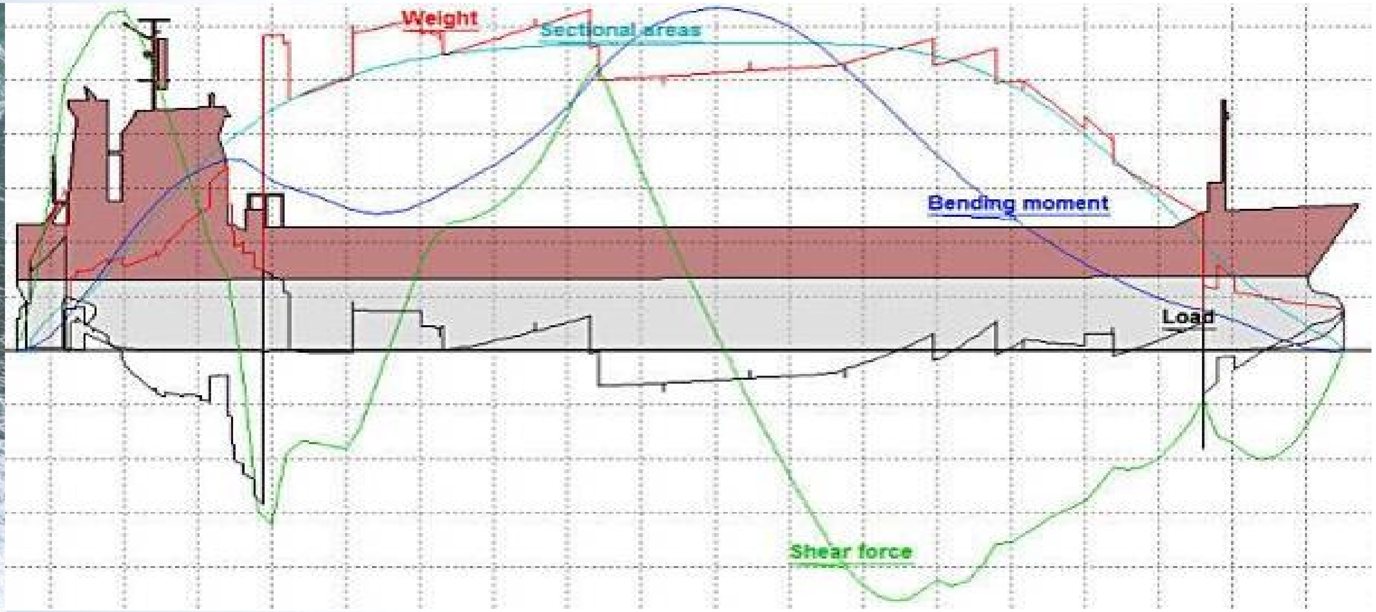
- FEM
  - Later on the design process
  - Long design process (3D design, meshing, solving, etc.)
  - Very difficult to optimise
  - Local problems can be modeling easily (Hot spots, fatigue, etc.)



What is the LBR5 tools?

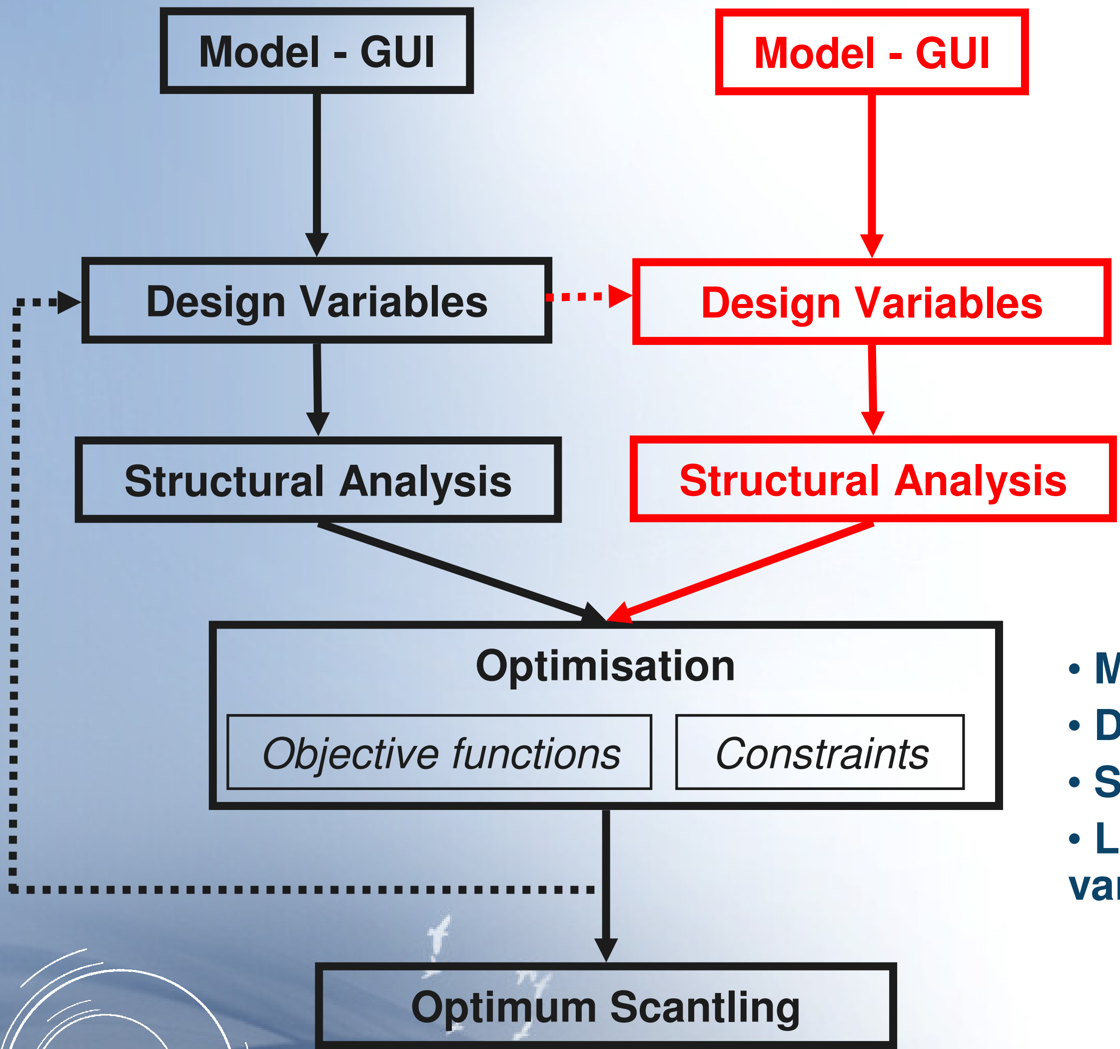


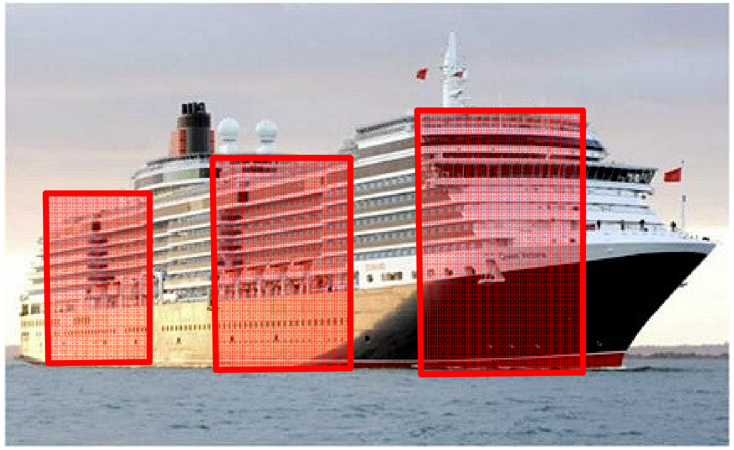
The new multi-structures module



- Cruise ship unlike a cargo ship
  - Cargo ship → Prismatic part = 70-85% of LOA
  - Passenger ship
    - Theaters, cinemas, swimming pools, lifts and stairs, agoras, restaurants, openings, funnel, etc.
    - Each amidships section are different
  - Loading conditions different at each section (shear forces and bending moment)

The new multi-structures module





- **Multiple cross sections**
- **Different loading condition**
- **Simultaneous scantling optimisation**
- **Link between several design variables**
    - *Deck plate thickness*
    - *Stiffener spacing*

Single Criterion Optimisation

$$\min_x F(x) = F_1(x)$$

with $h_i(x) = 0, \quad i = 1, \ldots, I$
$g_j(x) \geq 0, \quad j = 1, \ldots, J$

where $F_1(x)$ = *single optimisation criterion (objective function)*
$x = [x_1, \ldots, x_N]^T$, *vector of the N unknown design variables*
$h_i(x)$ = *equality constraint*
$g_j(x)$ = *inequality constraint*

Multicriterion Optimisation

$$\min_x F(x) = [F_1(x), \ldots, F_K(x)]$$

where $[F_1(x), \ldots, F_K(x)]$, *vector of the K multiple optimisation criteria*

Global Criterion Optima

$$\min_x F(x) = \left\{ [w_k \,|(F_k(x) - F_k^0(x)) \,/\, F_k^0(x)|\,]^\rho \right\}^{1/\rho}$$

with $w_k = 1$, *weights*

where $F_k^0(x)$ = *value of* F_k *from single criterion optimisation*

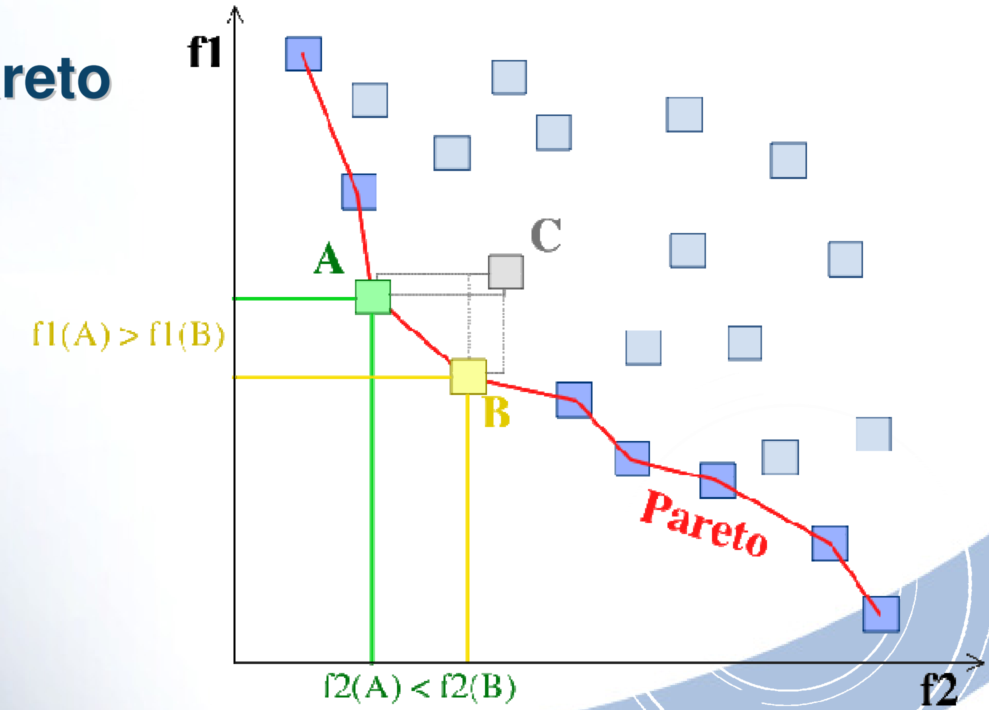
$\rho = 1$ ➔ weighted sum solution
$\rho = 2$ ➔ nearest to the utopian solution
$\rho = \infty$ ➔ min-max solution

Pareto Optimum Front

A solution is Pareto optimal if it satisfies the constraints and is such that no criterion can be further improved without causing at least one of the other criteria to decline (Edgeworth – Pareto optimality)

➔Pareto front is a set of optimal solutions

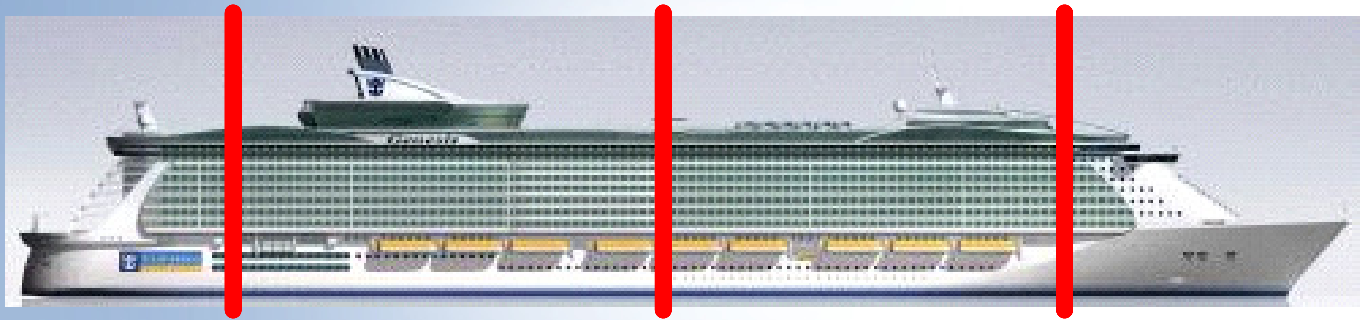
Mapping the entire Pareto front, by using, a.o. :

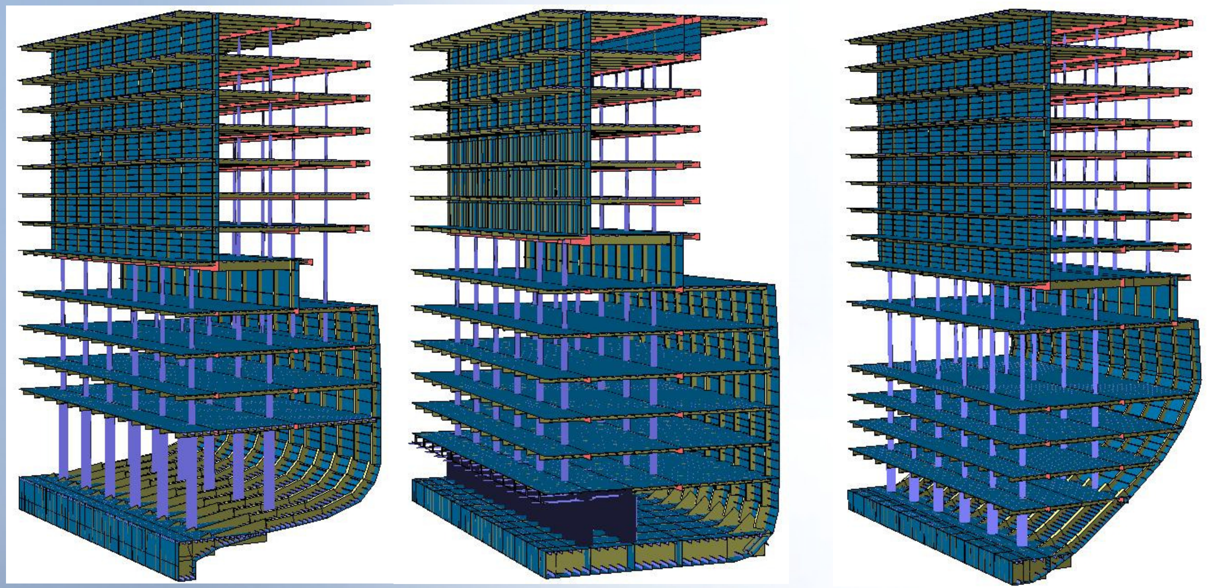


Repeated weighted

- **sum solutions**
- **min-max solutions**

Application on a cruise ship





- 81 panels
- 24 pillars
- 550 DV

- 78 panels
- 25 pillars
- 460 DV

- 93 panels
- 28 pillars
- 684 DV

Ship parameters

- LOA > 300 m
- Breadth ~ 40 m
- Height ~ 42 m
- 14 decks

Design Variables

- Plate thickness
- Longitudinal stif.
    - Web height
    - Web thickness
    - Flange Width
    - Spacing

Model Links

- Plate thickness
- Stiffener spacing

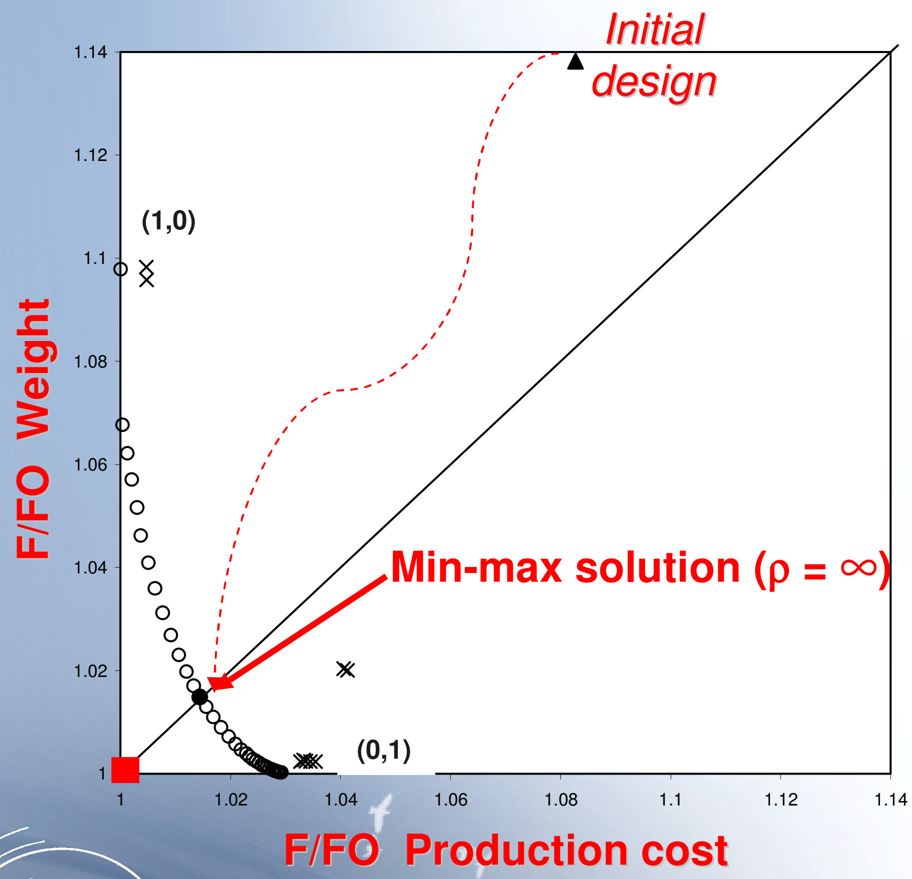
Loading cases

- Still water + Waves (Hog:10^{-8}) + Deck loads + Deadweight
- Still water + Waves (Sag:10^{-8}) + Deck loads + Deadweight
- Wrap pressures

Constraints

- **Structural constraints**
  - Bending strength $\sigma \leq 175/k$
  - Compressive buckling/Yielding of plates
  - Compressive buckling of stiffeners
  - Limitation of total deflection
  - Limitation of deflection for each stiffener
  - Ultimate strength (Paik methodology)
- **Global constraints**
  - Upper bound value of the gravity center location (stability)

Pareto front (COST – WEIGHT)



- When the production cost is MIN the weight is MAX (1,0)
- When the weight is MIN the production cost is MAX (0,1)
- Array of Weights
    - W_1 = 1/nbr points
    - $W_2 = 1 - W_1$
- Min-Max solution ($\rho = \infty$) obtained for
    - W_1 = 0.41 for the weight
    - W_2 = 0.59 for the production cost
- ~ 50 points
- ~ 28 hours

	Cost Opti	Weight Opti	Min-Max
Cost	7.6%	*4.4%*	6.2%
Weight	*3%*	12.1%	6.4%

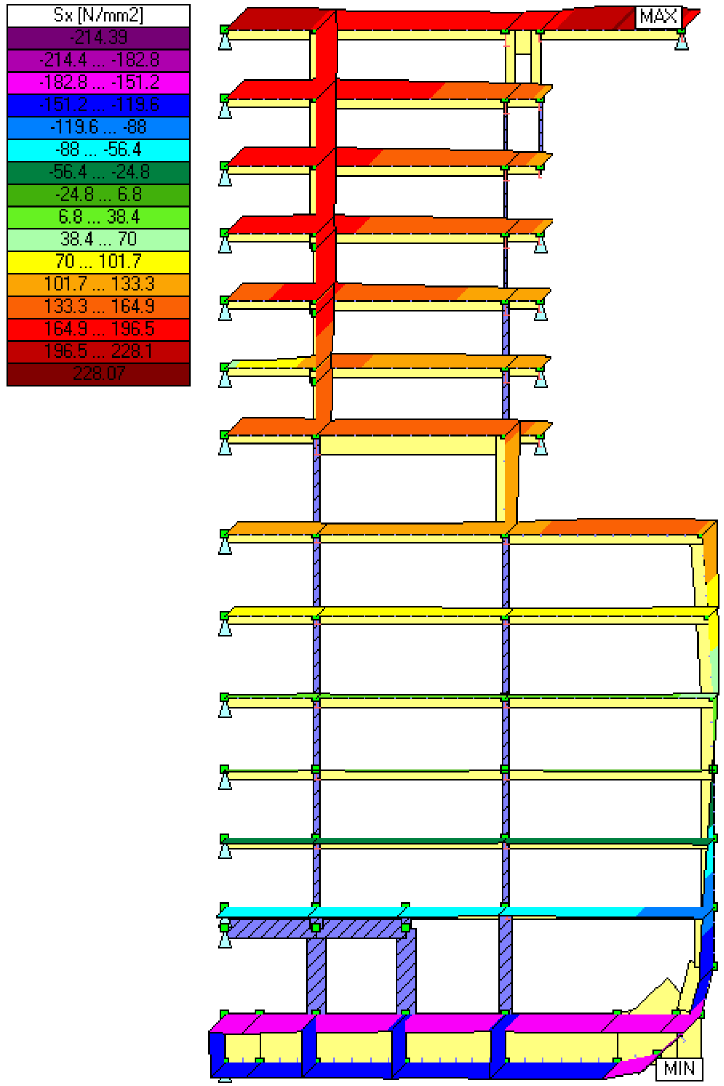
Conclusions

- Multi criterion optimisation
  - Min-Max
    - → 6% weight
    - → 6% cost
- Passenger ship
- 3 ship sections (Fore, Middle and Aft)

→Significant improvement of the ship scantling design at the early design stage

→ Reduce fuel costs

→ Reduce production costs



Thank you for your at