Cost Effectiveness and Complexity Assessment in Ship Design

within a Concurrent Engineering and "Design for X" Framework

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Summary

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Boundaries – Where, What, How and Why?

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Where? – ANAST - University of Liège

- **University of Liège**
  - **ARGENCO** – ARchitecture, Geology, ENvironment and COnstruction department
  - **ANAST** – Naval Architecture and Transport System Analysis research team
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Boundaries – Where, What, How and Why?

What? – Selection of the best design alternative

- Ship designer problem $\Rightarrow$ selection of the best design alternative
- Evaluation of design alternatives $\hookleftarrow$ many attributes (economic, technical, environmental, safety)
- Every design change $\Rightarrow$ impact on how much producing/maintaining the ship will cost
- Understand the impact every time the designer make a change

PhD research questions

- How much will it cost (or save) to implement this change?
- How will the complexity of the whole structure be affected?
- How will the ship's performances be affected?
- How will the productivity/maintenance of the ship be impacted?
- What risk is involved?

$\Rightarrow$ **Apply to the shipbuilding industry**

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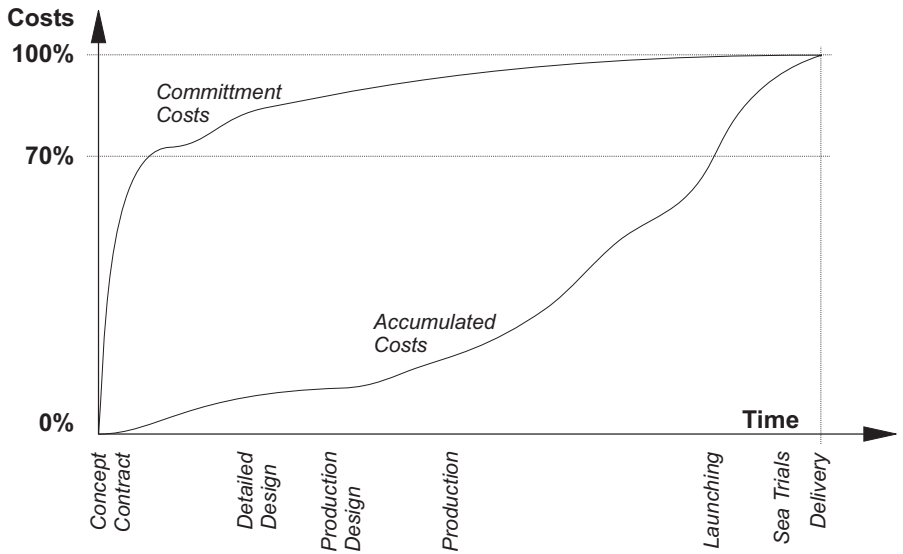
Boundaries – Where, What, How and Why?

How? – Reduction of costs and complexities

- Product design stage influences nearly 70% of the final product costs even if only a small amount of expenditure is incurred
- Design is the primary driver of quality, time and cost
- Main promising track to increase competitiveness
  - Better assessment of **cost and production delays**
  - Better assessment of **complexity**



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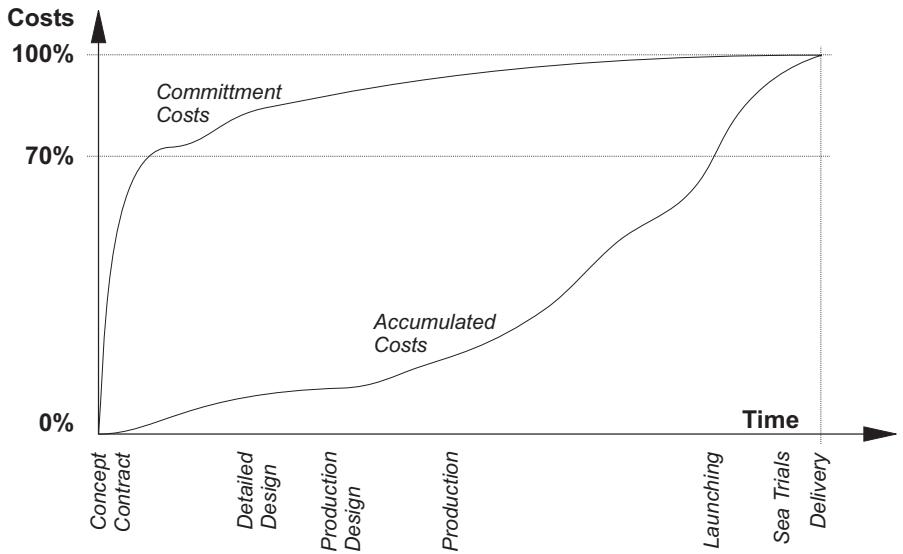

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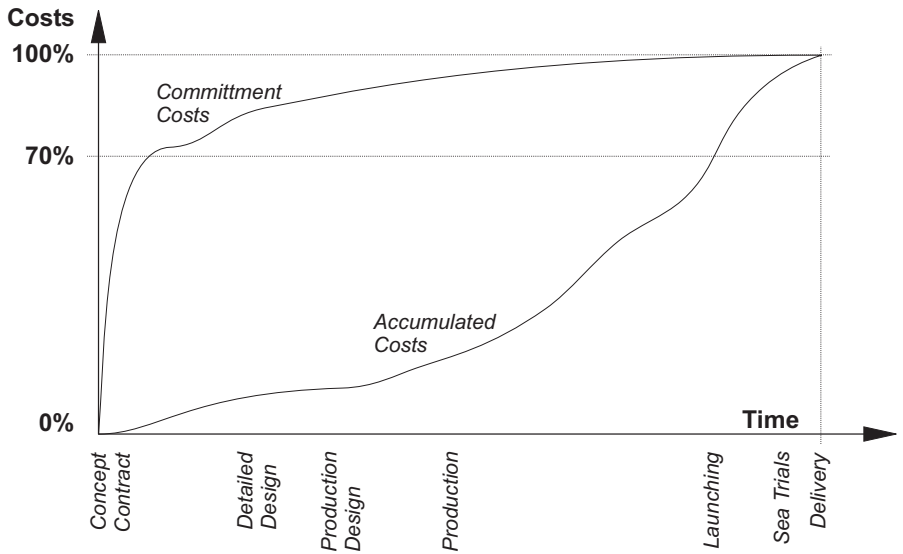

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Why? – Optimisation of the product design

- Shipbuilding = Industry of labour $\Rightarrow$ **Problem for EU shipyards**
  - Relocation of ship manufacturers
  - High added value ships or/and high technology ships
- Need to improve the shipyard *competitiveness*
- Solutions are the optimisation of:
  - The **industrial layout** – automation, mechanization, etc.
  - The **industrial process** – quality management, 6σ, lean manufacturing, CAD/CAM, scheduling, sequencing, etc.
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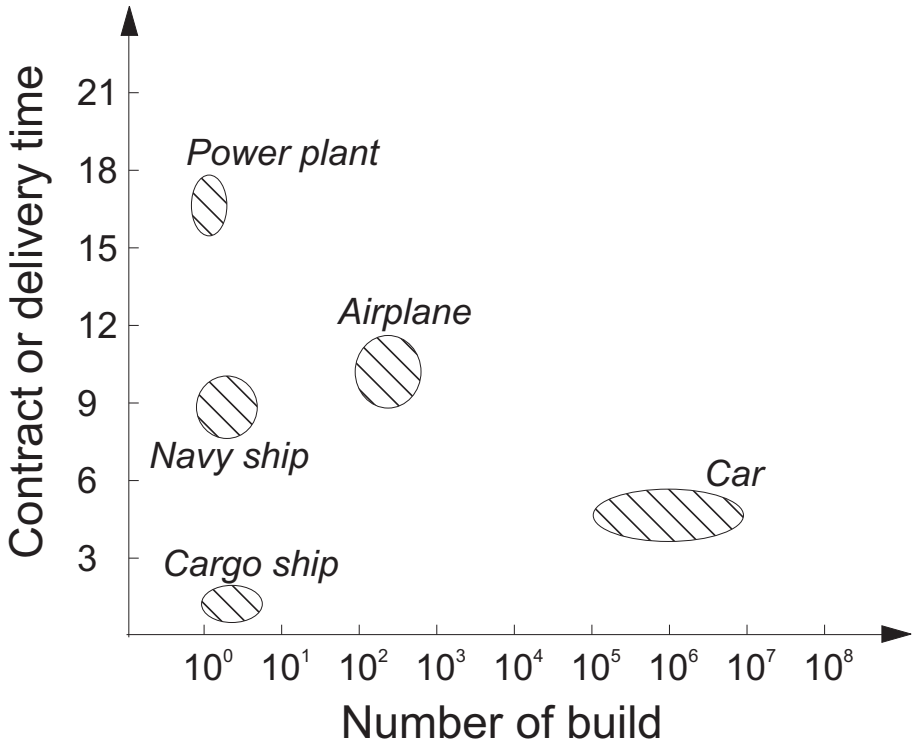
Shipbuilding industry $\neq$ other repetitive manufacturing industries

- Small series
- Short time to market
- High complexity
- Tripartite collaboration
- Bad working conditions
- Low standardisation
- Confined space and bad accessibility
- Increase of ship size



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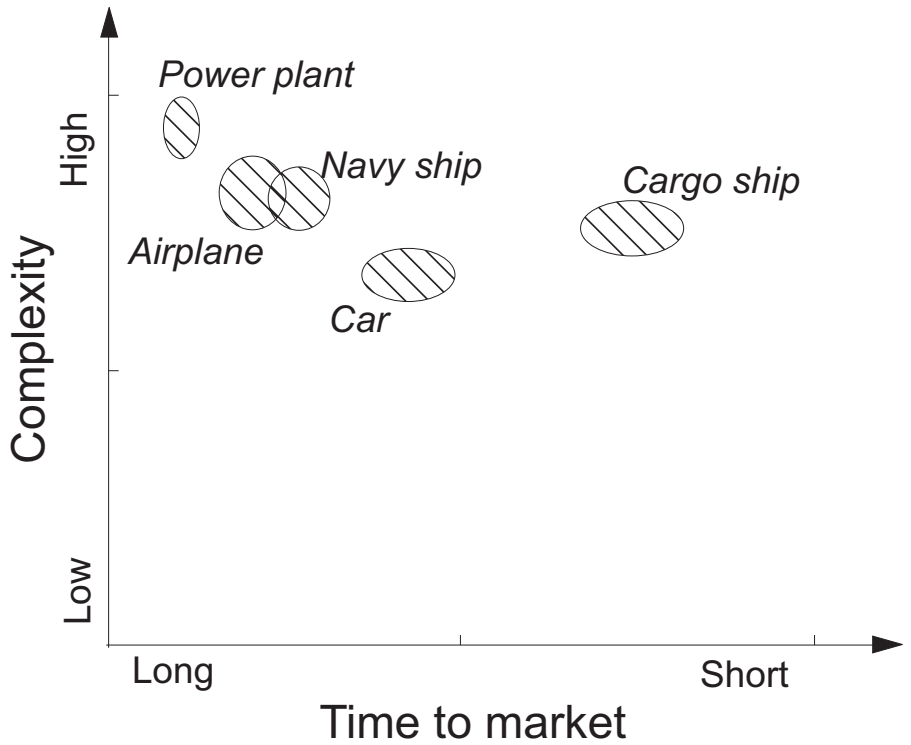

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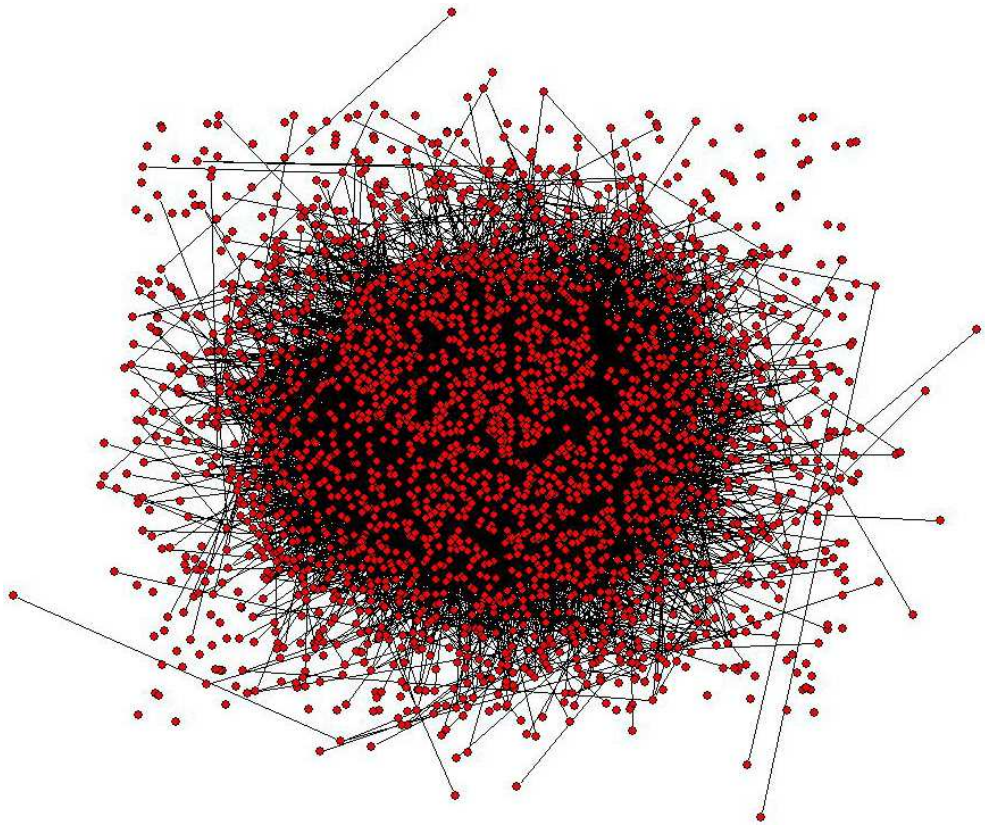

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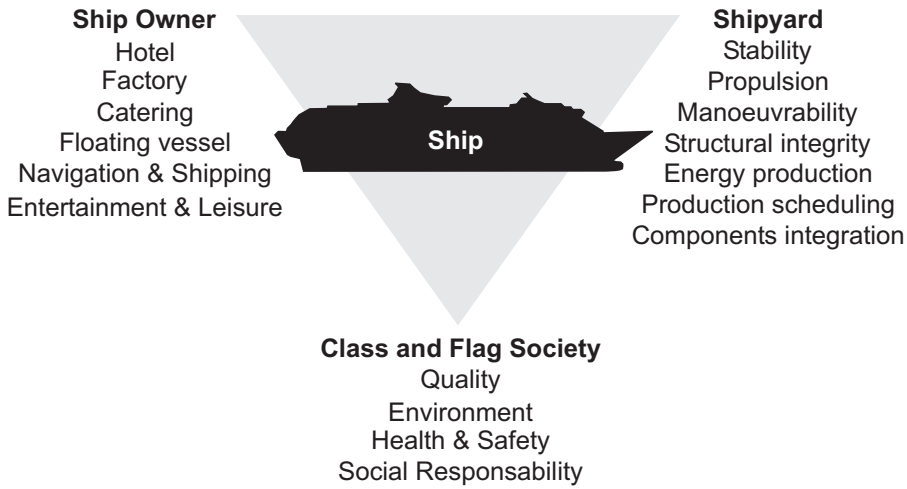

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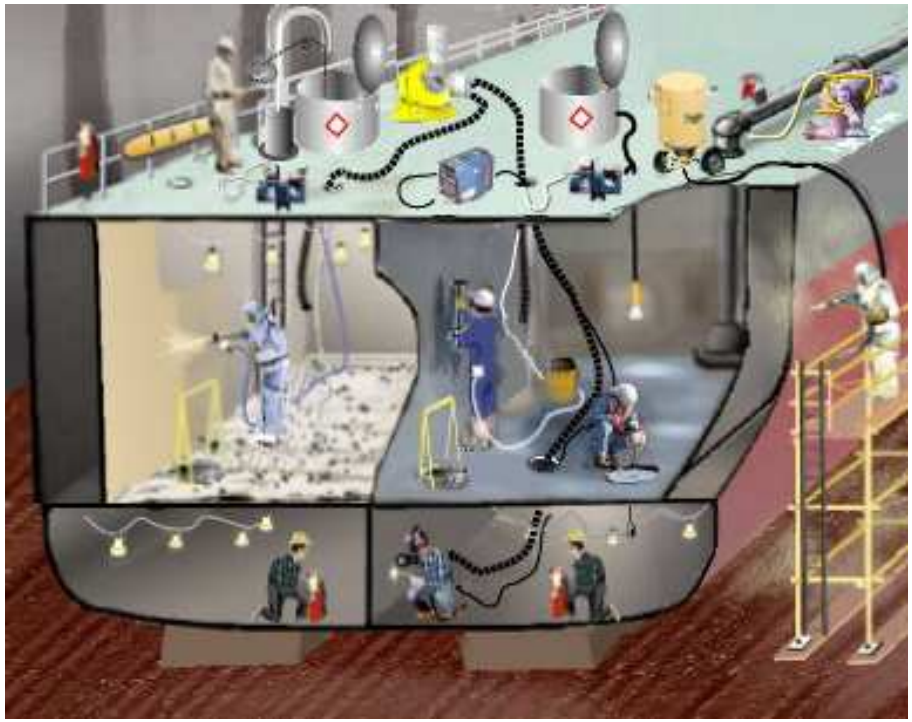

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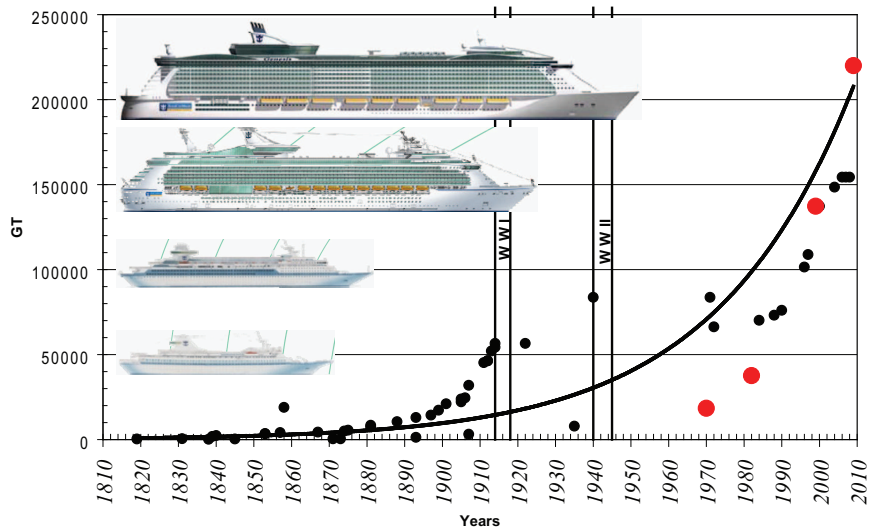

Challenge of cost and complexity assessment

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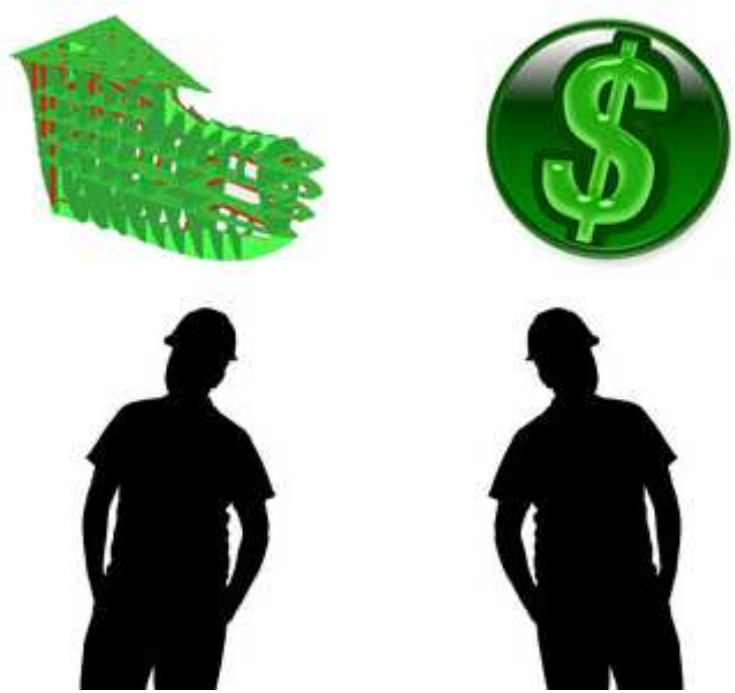
Uncoupling between design and cost engineering

- Secondary consideration for engineers
- Concentrating on delivering the technical aspects
- Cost evaluation $\Rightarrow$ only after technical details
- Possible update of design



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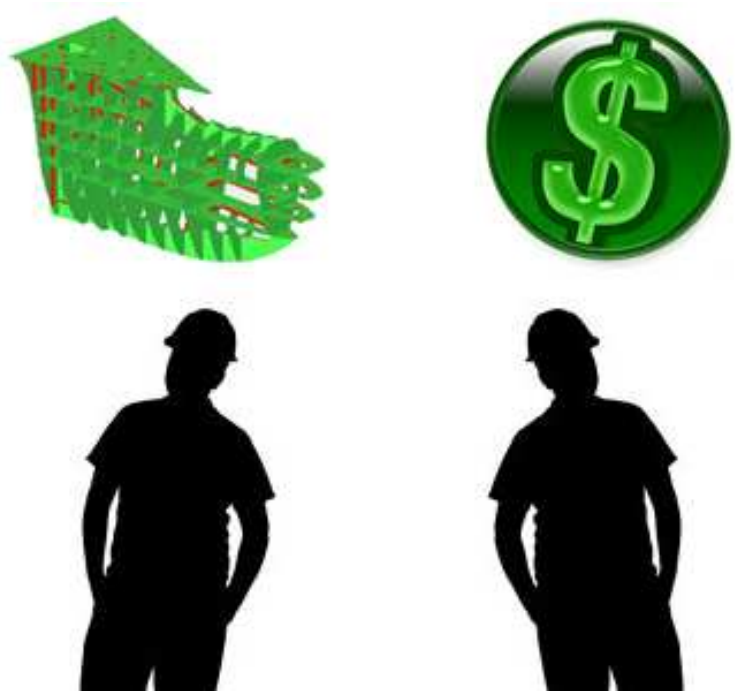

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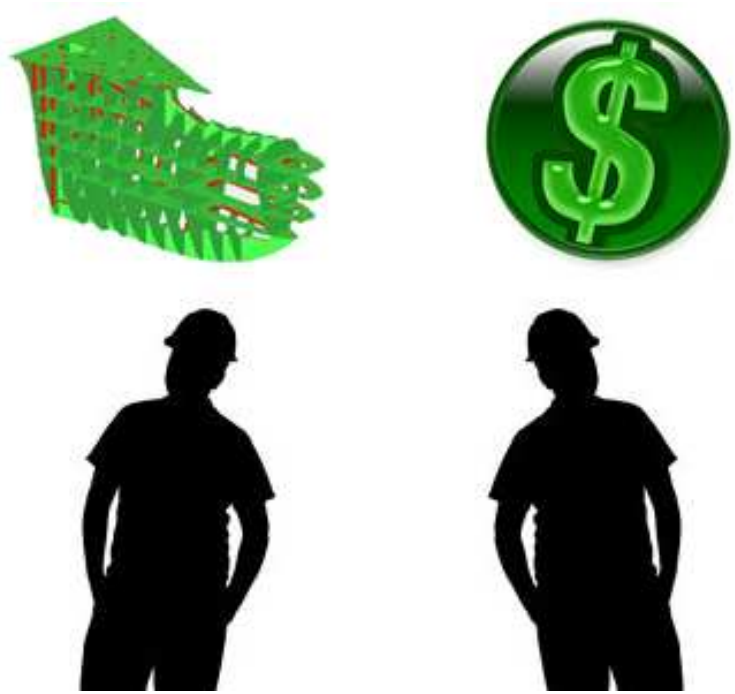

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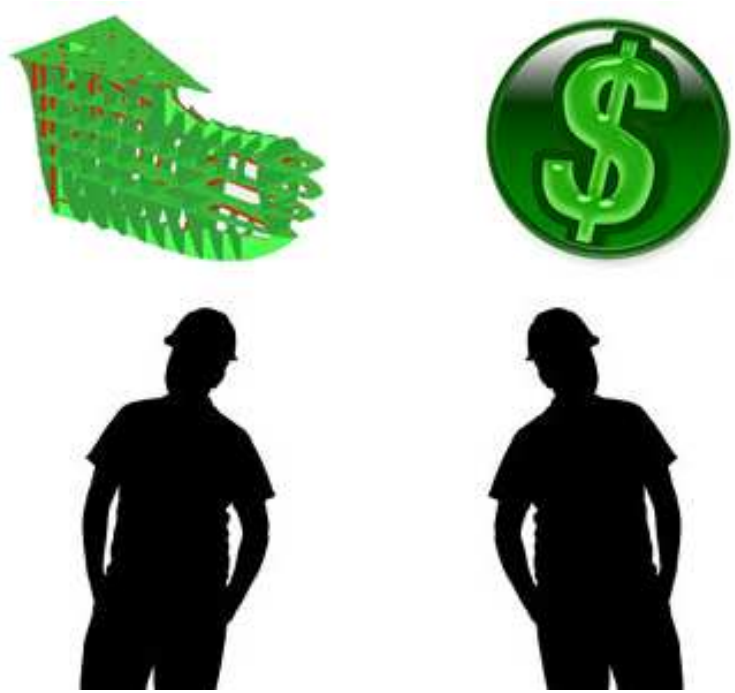

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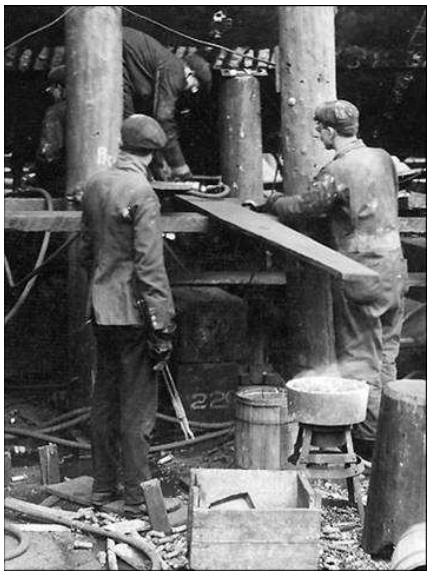
Cost and complexity variation factors

- Tracking of the cost during all the stage of the project
- Input factors are always changing
  - **Regulation** – new rules
  - **Labour rates** – different for each shipyard, effect of learning, unpredictable
  - **Technology change** – new process, new material, new design

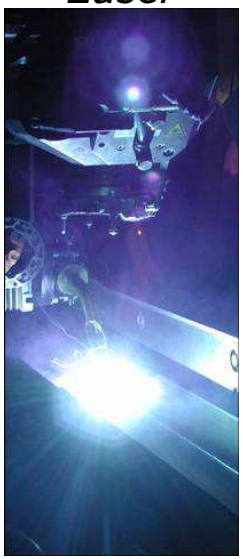
Riveting



Welding

Robot welding

Laser



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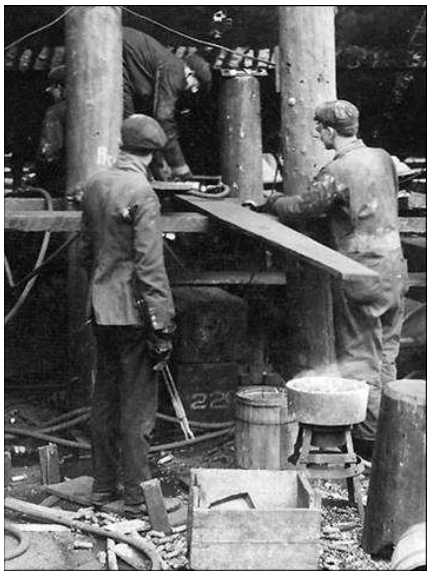

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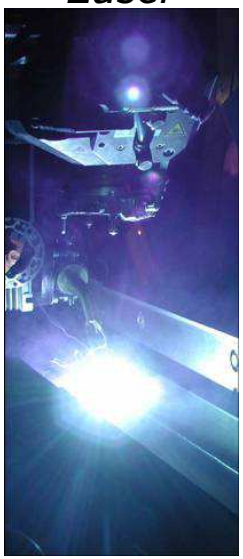

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Data and database management problems

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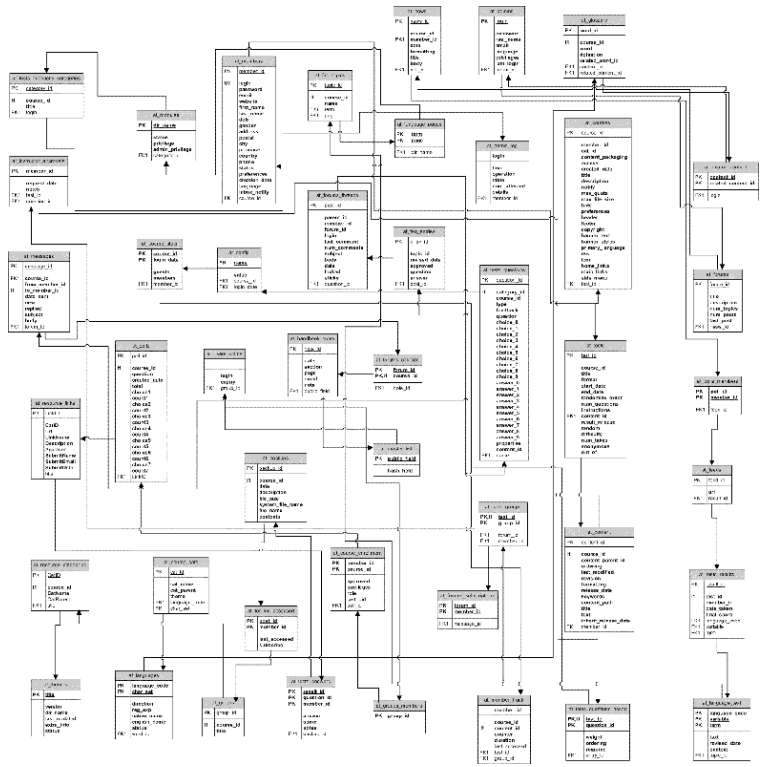

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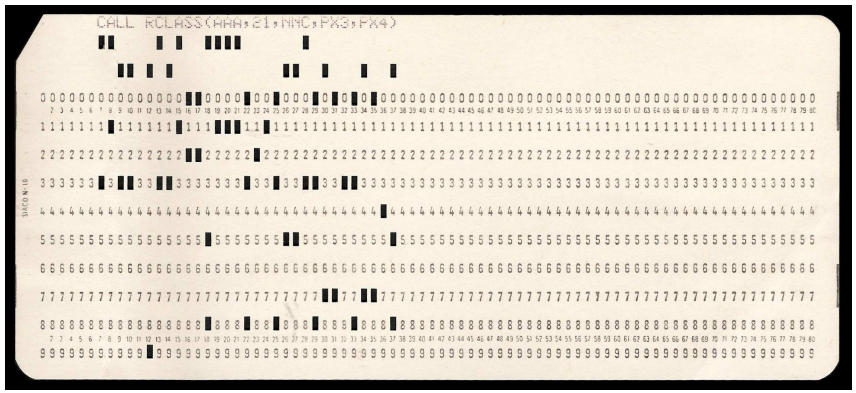

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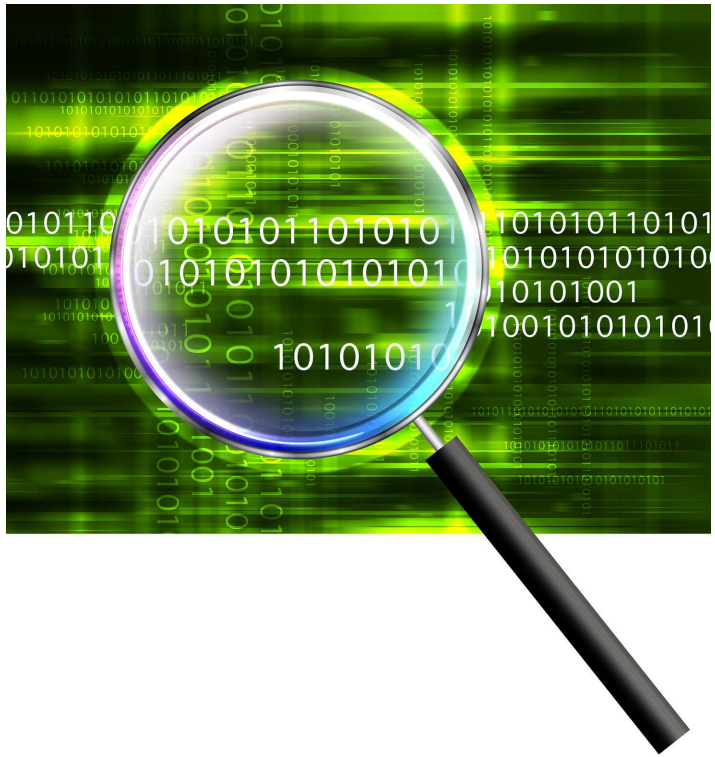

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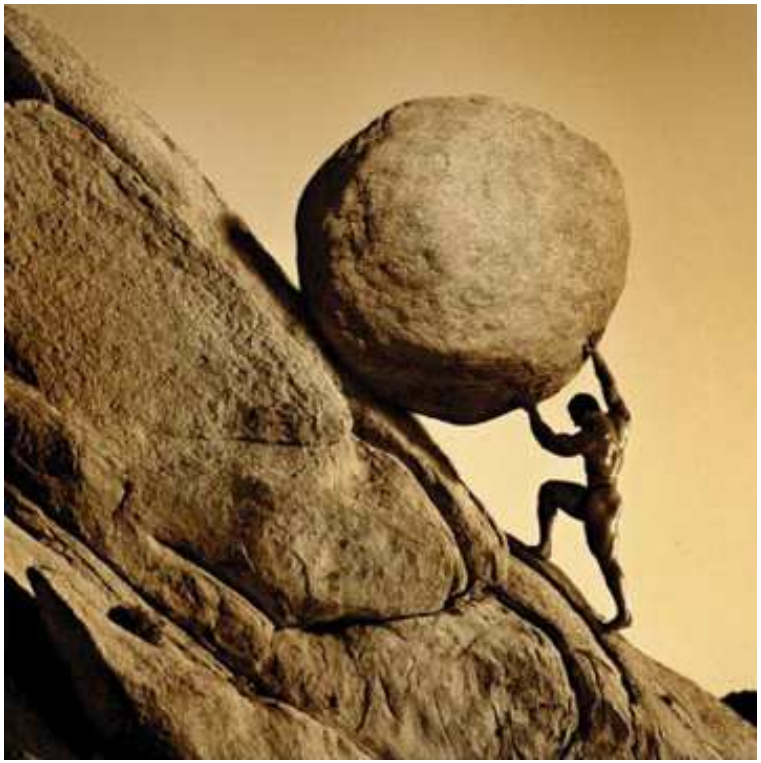
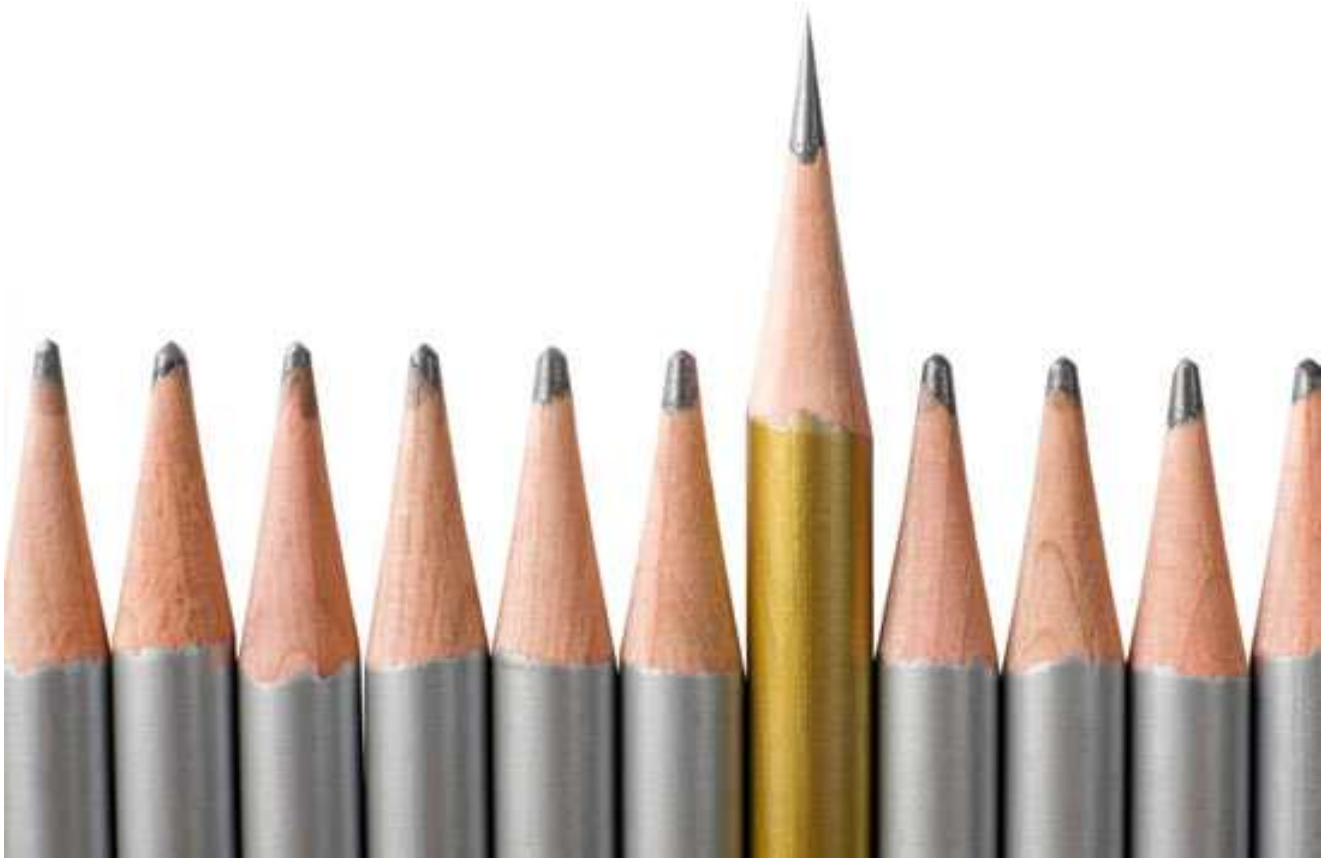


DB problems $\Rightarrow$ very **cumbersome**, **tedious** and **time consuming** to solve

Methodology

Summary

Paradigm



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Designing for sustainability

- Sustainability of technologies ⇒ central focus
- Early technical requirements ⇒ impact on the entire ship life cycle
- **Design for X** ⇒ optimise total benefits
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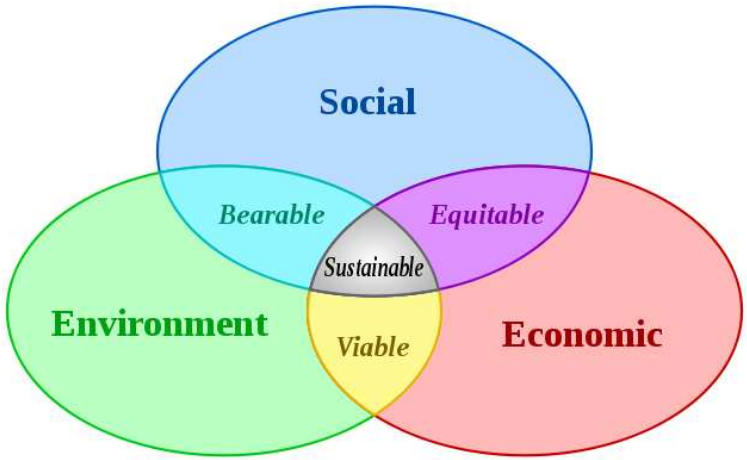

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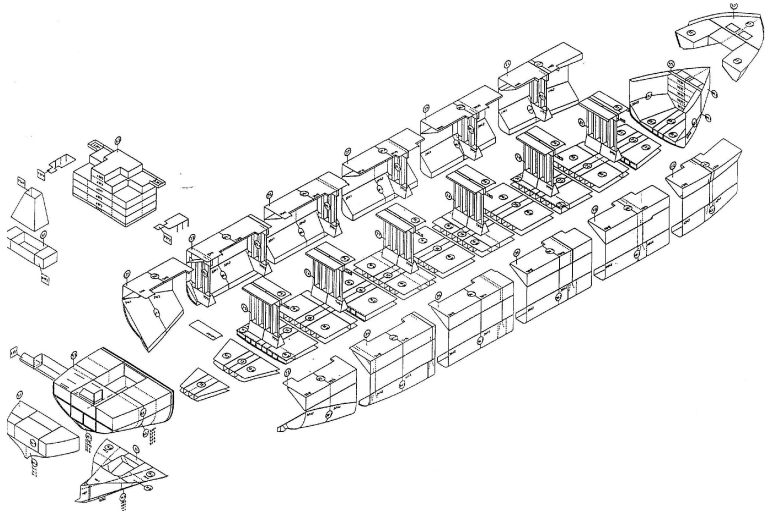

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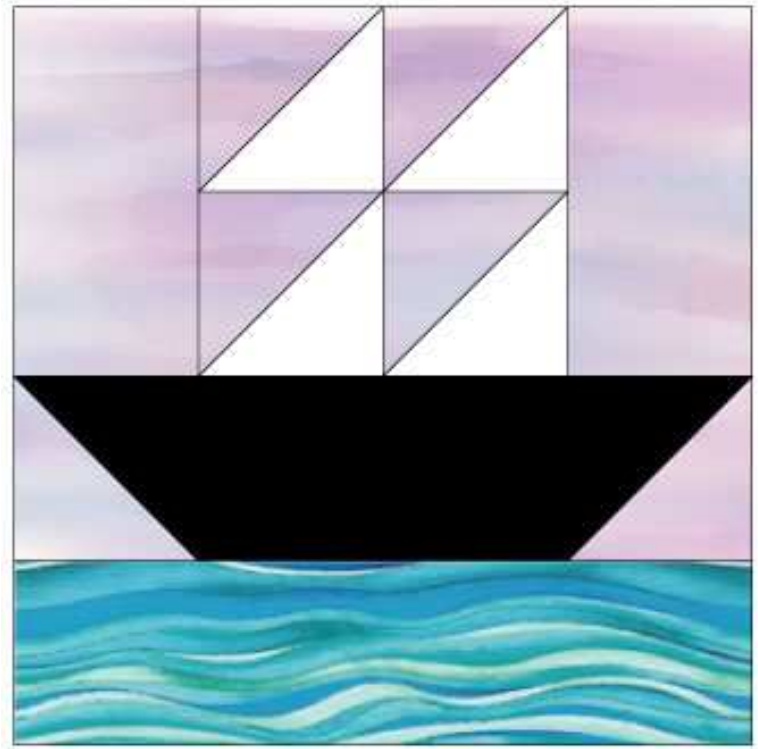

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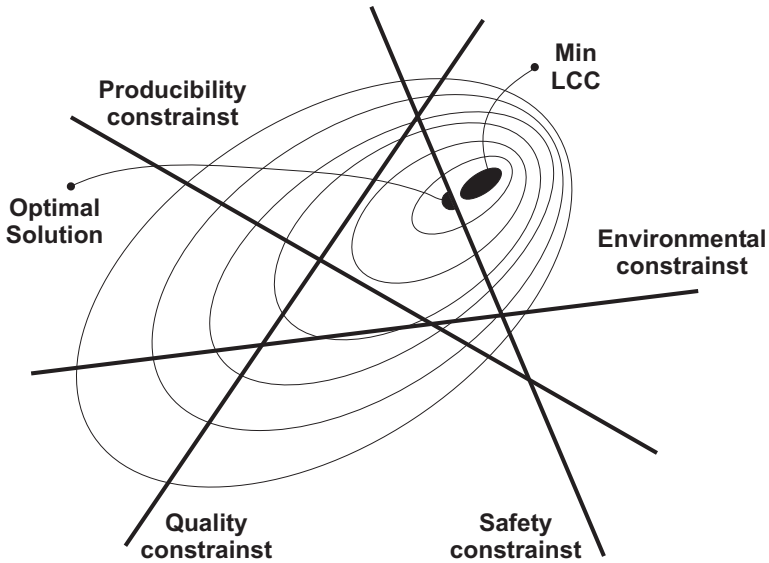

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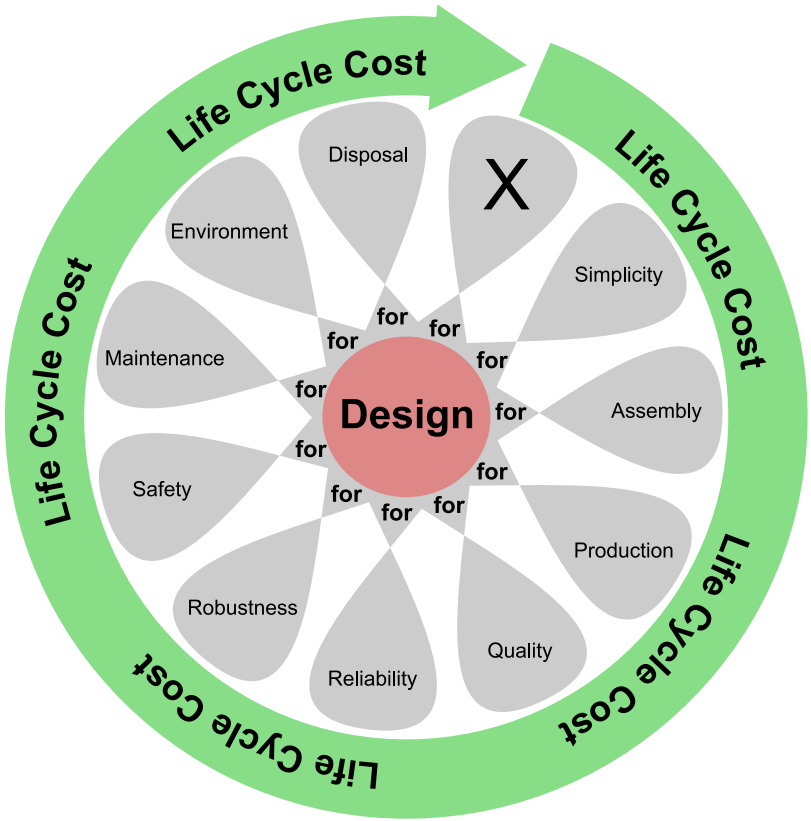

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Good assessment of LCC during all design stages lead to the improvement of the sustainability and competitivity ⇒ **Need to improve cost evaluation tools**

Paradigm

Designing for sustainability

- Sustainability of technologies ⇒ central focus
- Early technical requirements ⇒ impact on the entire ship life cycle
- **Design for X** ⇒ optimise total benefits

Paradigm

Good assessment of LCC during all design stages lead to the improvement of the sustainability and competitivity ⇒ **Need to improve cost evaluation tools**

Selection of cost estimation methods

Selection of cost estimation methods

An appropriate cost and complexity assessment method at each stage of the ship design

- Selection of the appropriate cost method (♯7)
  - **Intuitive method** (IM)
  - **Case based reasoning** (CBR)
  - **Parametric method** (PM)
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  - **Simulation method** (SM)
- Multiple Criteria Decision Making
  - PROMETHEE
  - Absolute ranking of the alternatives
  - Weighting factors scenarios (♯5)
  - W5 $\Rightarrow$ Survey

- Definition of 17 criterion in 5 families
  - Design Applicability (♯6)
  - Accuracy (♯3)
  - Data Needs (♯2)
  - Usability (♯4)
  - Cost (♯2)

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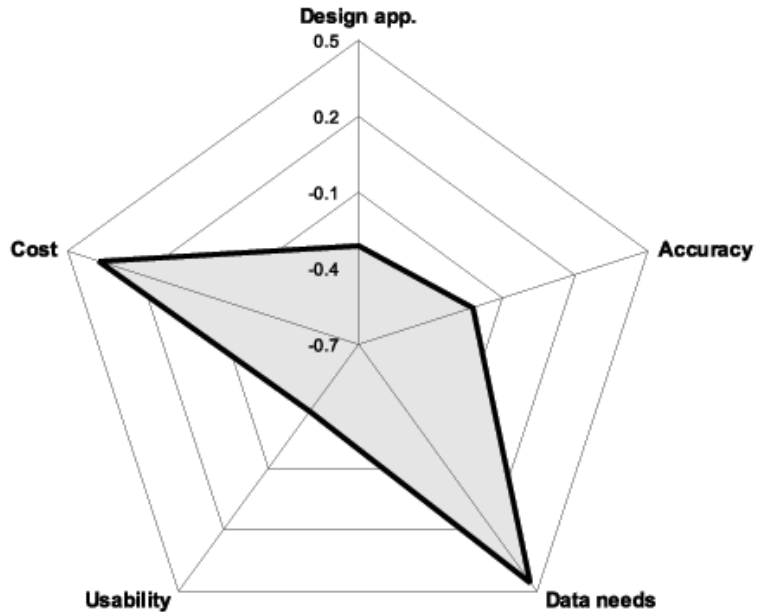

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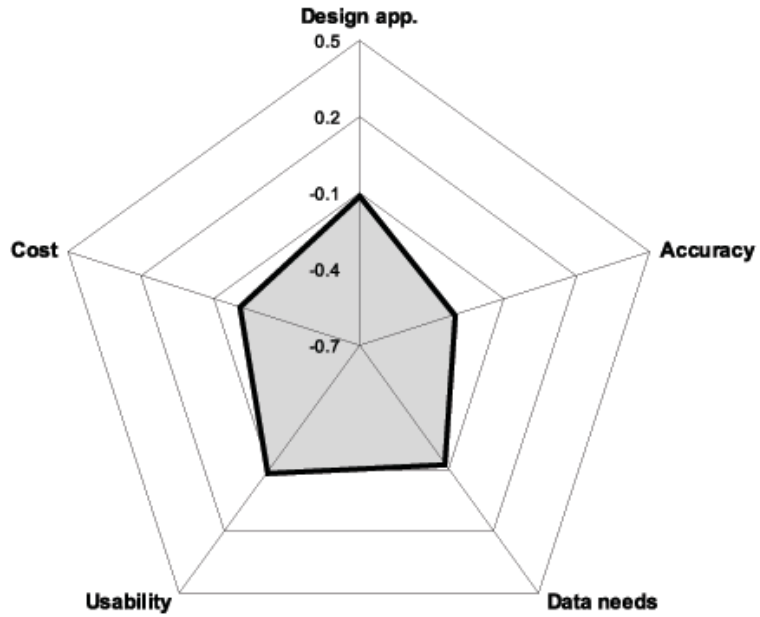

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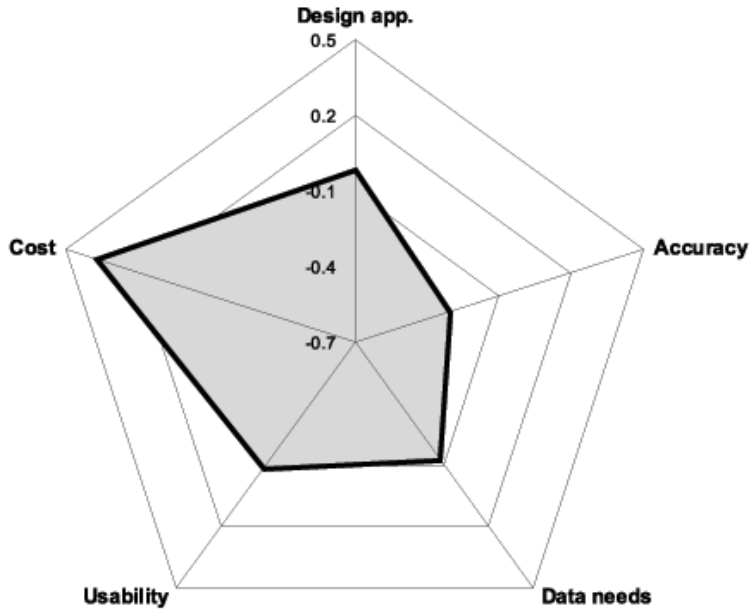

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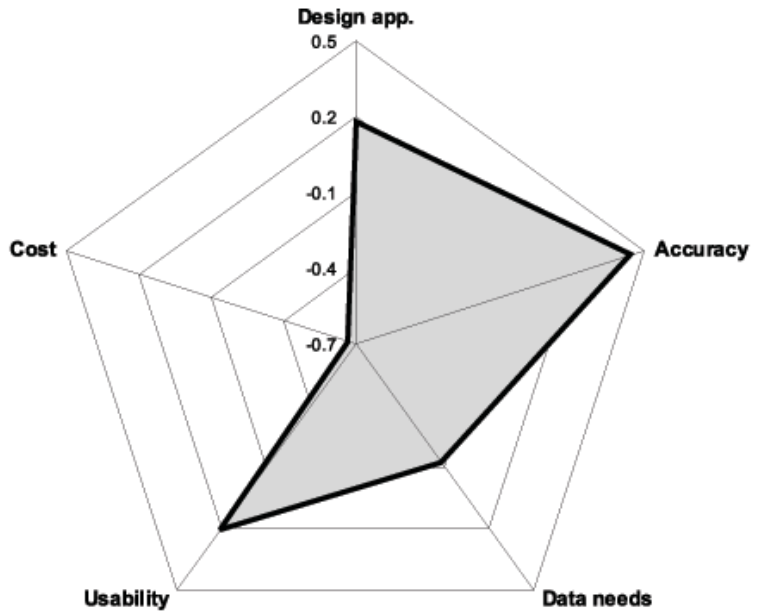

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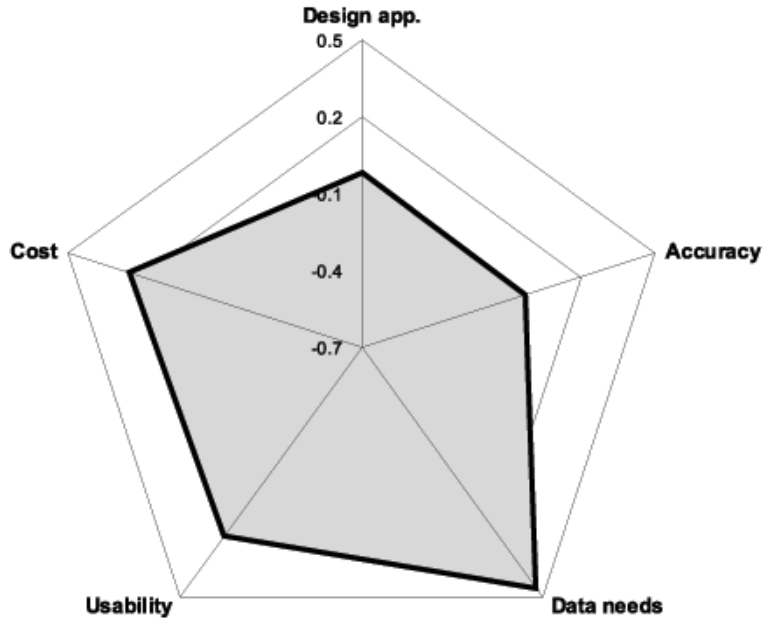

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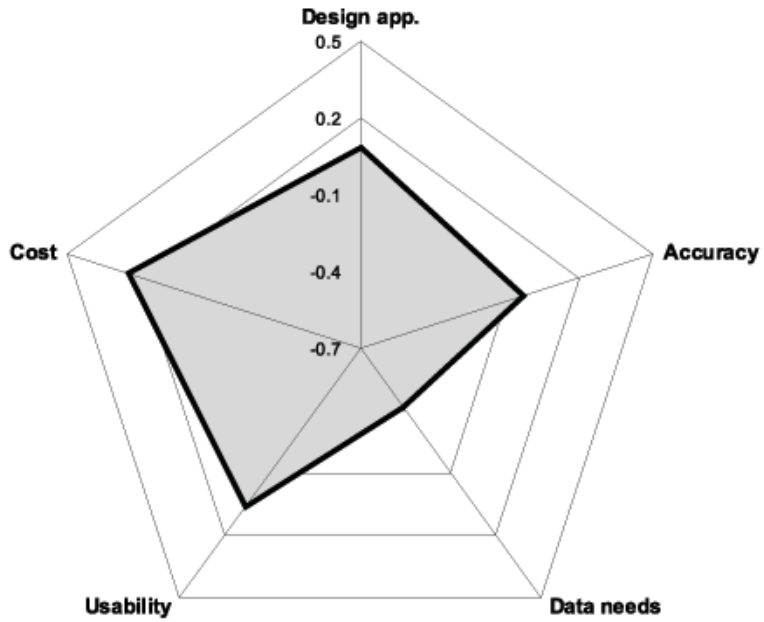

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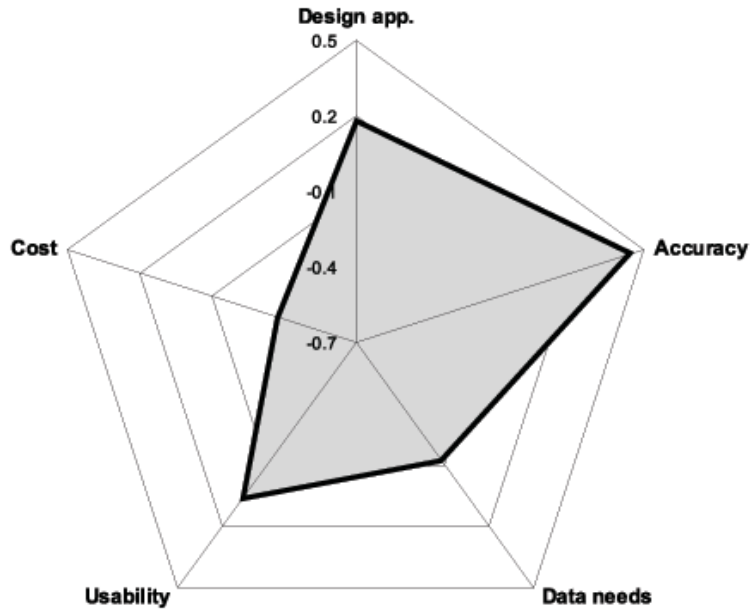

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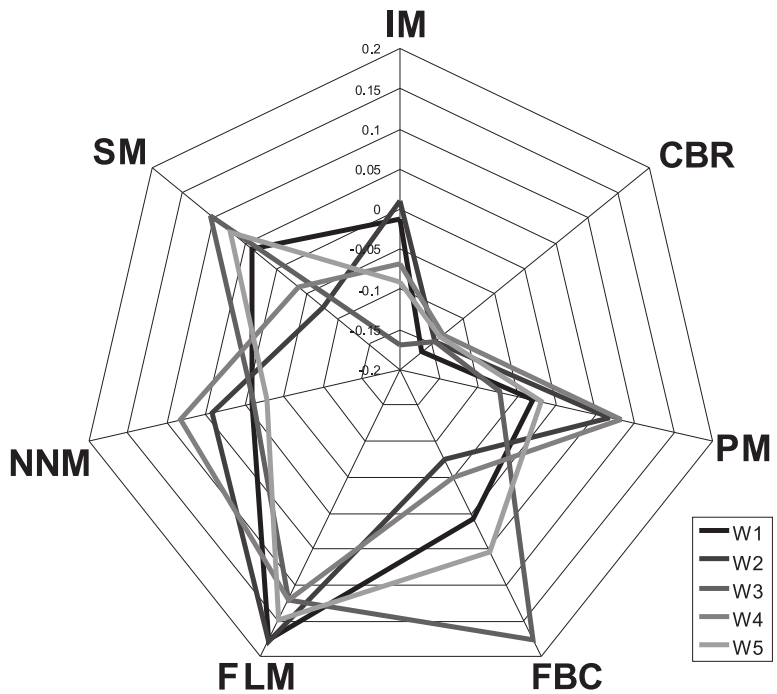

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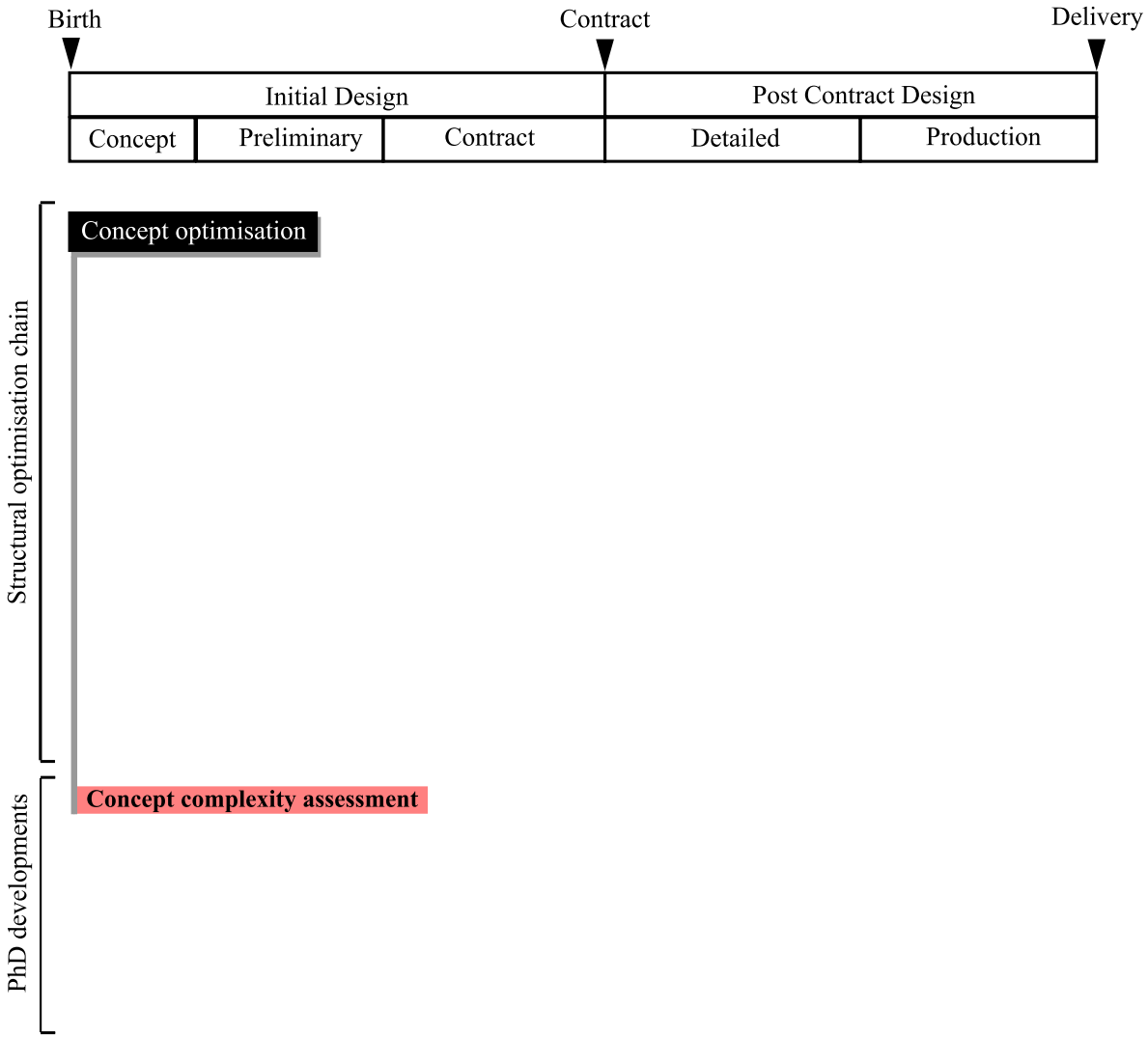
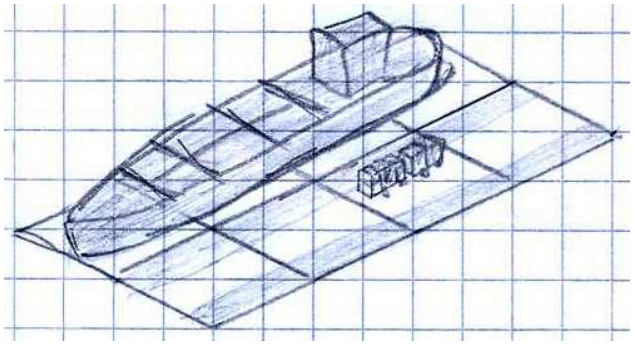
Analysis, developments and results

Summary

Presentation of the developments

The holistic ship design optimisation strategy



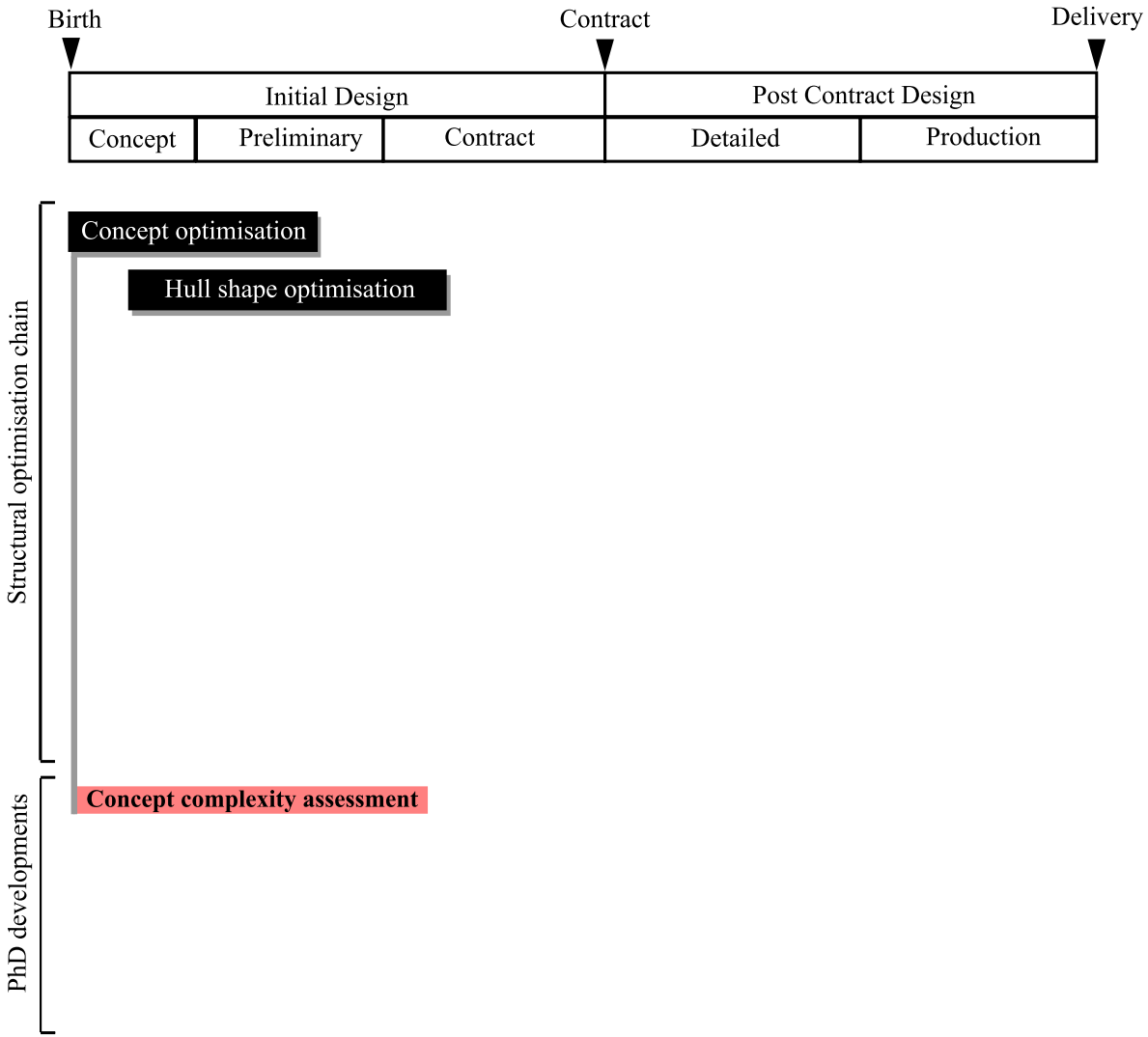


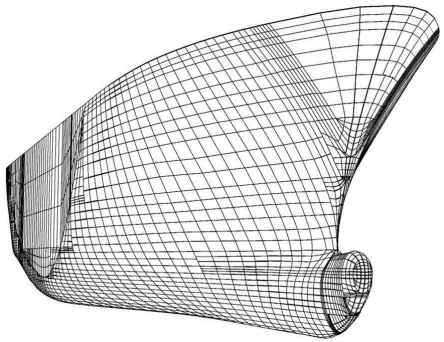
Concept optimisation

- Few degree of freedom
- ↗ impact on LCC
- Need for a subjective complexity metric

Presentation of the developments

The holistic ship design optimisation strategy



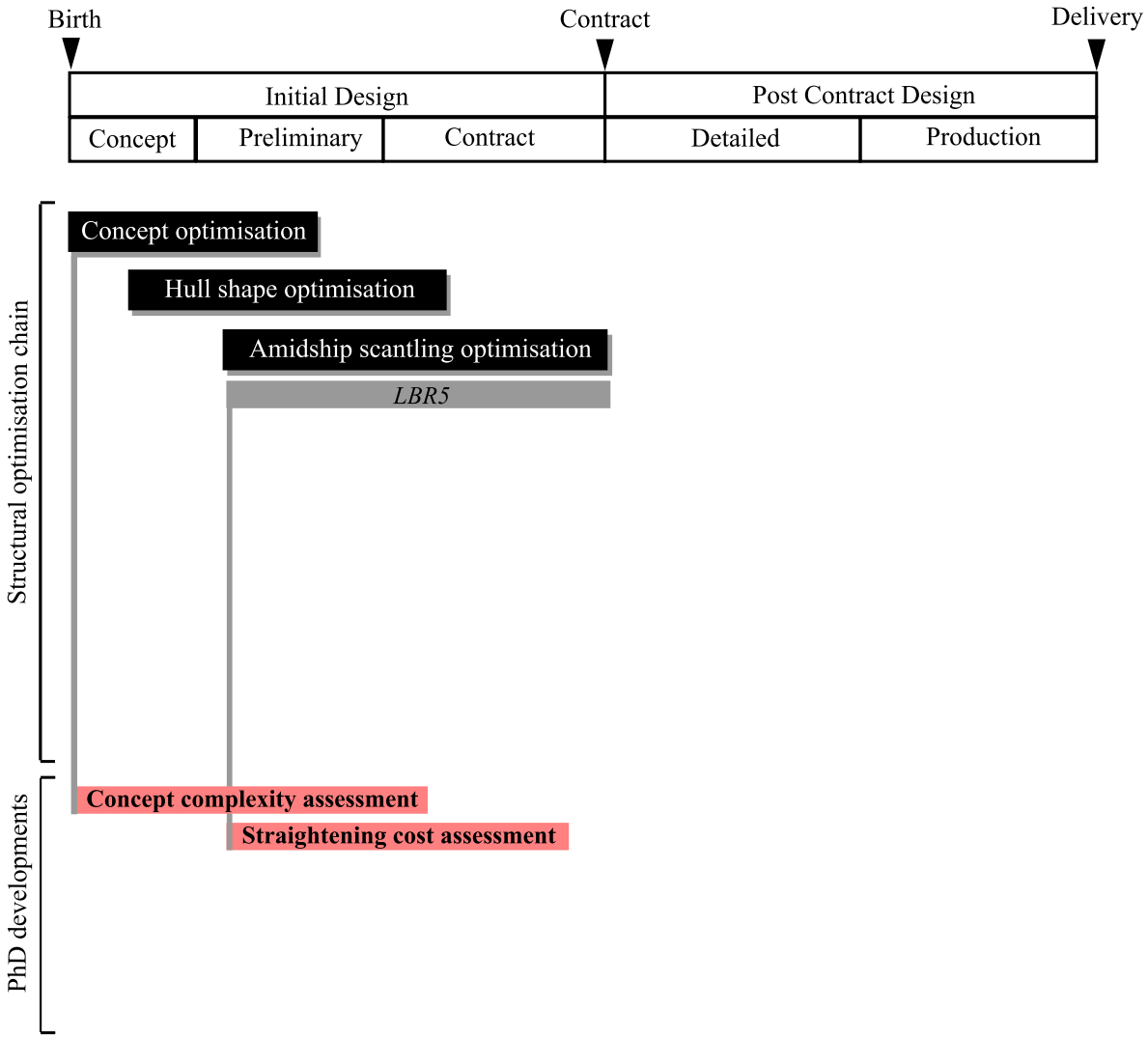


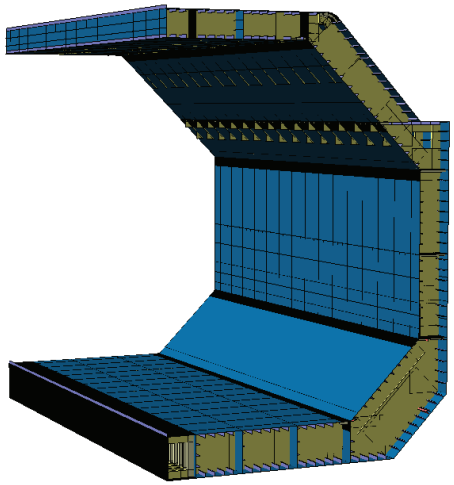
Hull shape optimisation

- Fuel savings = cost
- Very efficient solution are already available

Presentation of the developments

The holistic ship design optimisation strategy



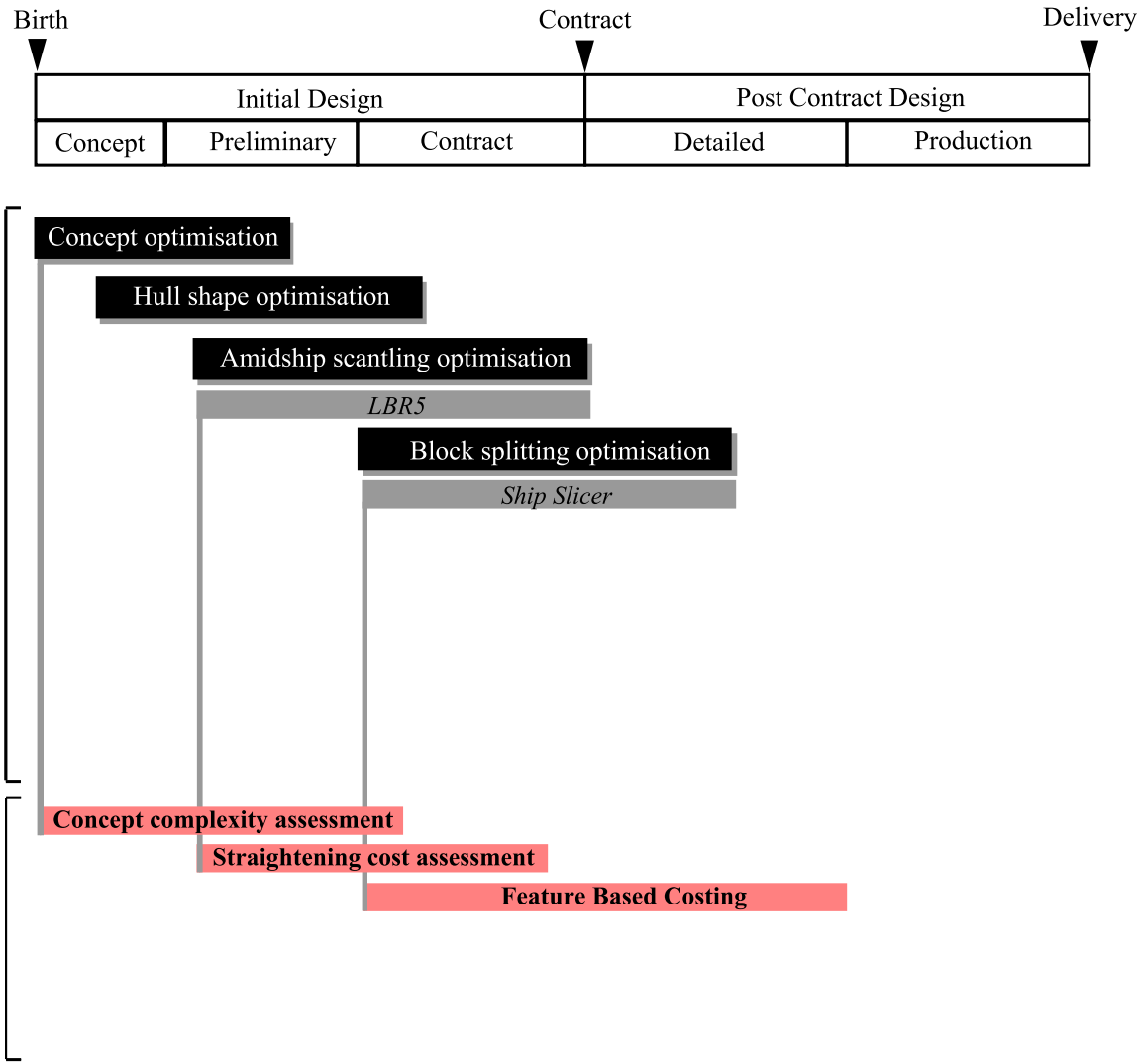


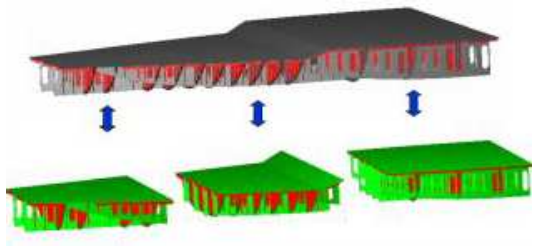
Amidships scantling opt.

- LBR5
- Need to assess straightening cost

Presentation of the developments

The holistic ship design optimisation strategy



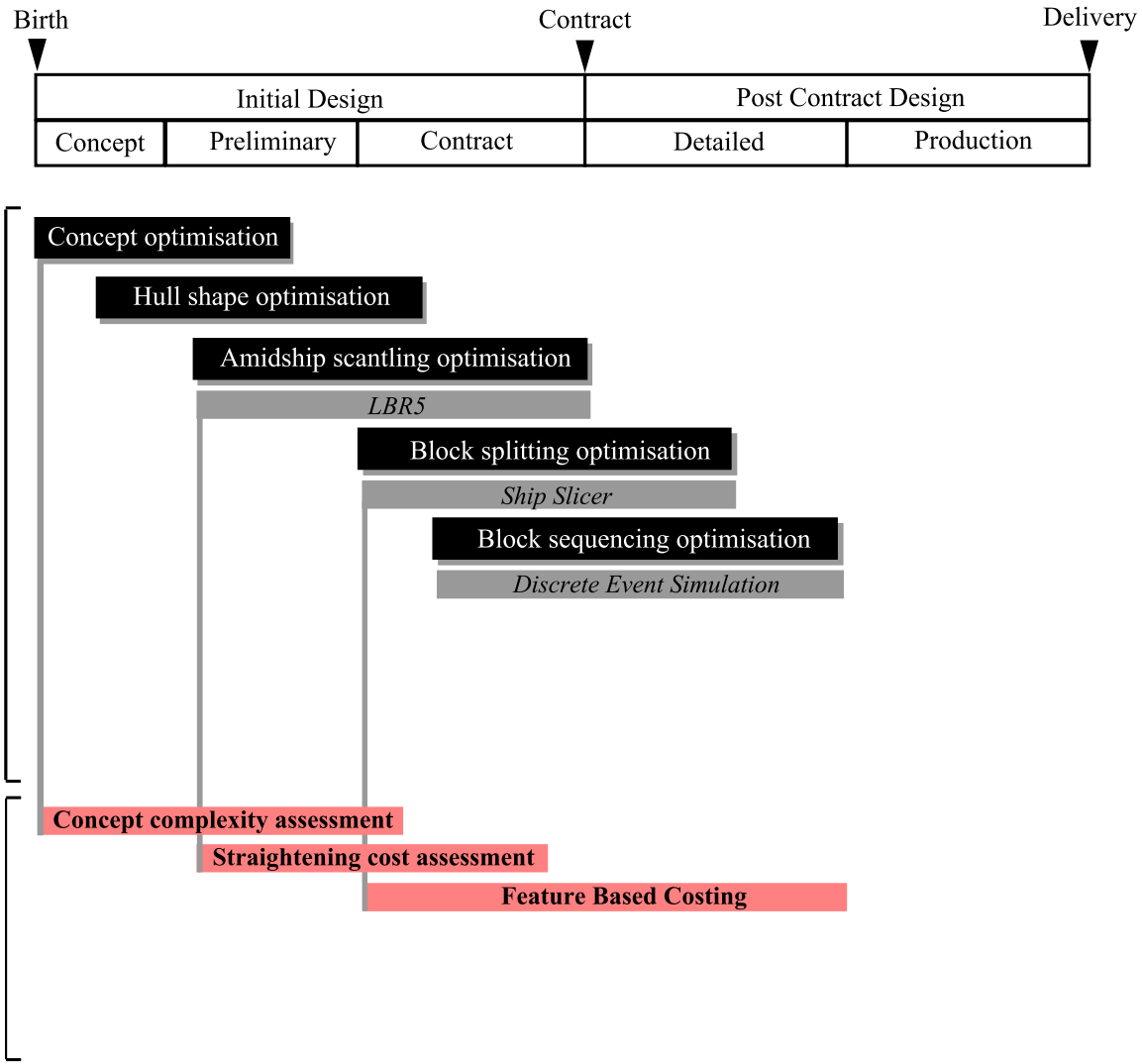


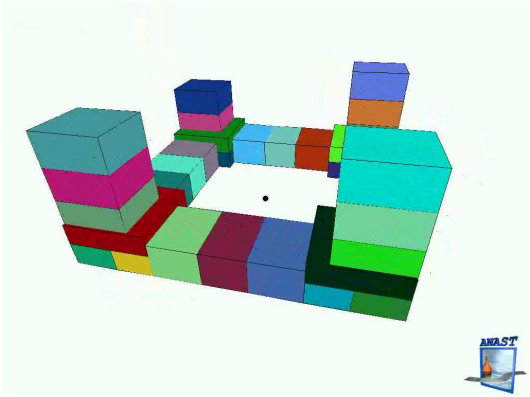
Block splitting opt.

- Strategic decisions for production
- Many constraints
- Need to minimize assembly costs

Presentation of the developments

The holistic ship design optimisation strategy



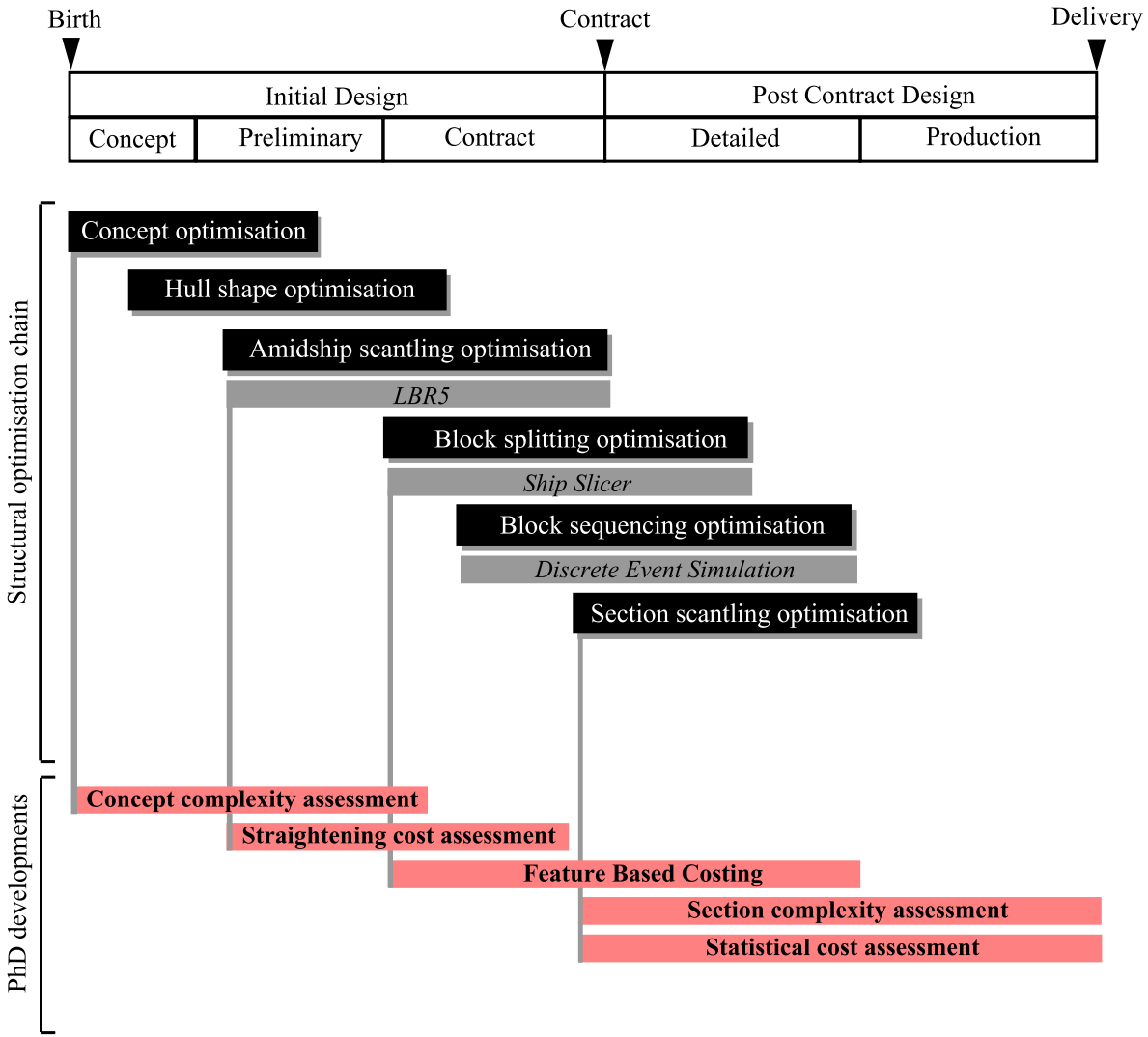


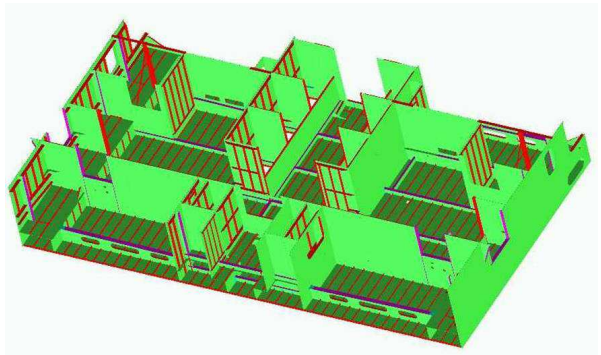
Block sequencing opt.

- Strong link with block splitting
- Beyond the scope of this work

Presentation of the developments

The holistic ship design optimisation strategy





Section scantling opt.

- Many different goals and constraints
- Many participants
- Need of design quality measurement

Presentation of the developments

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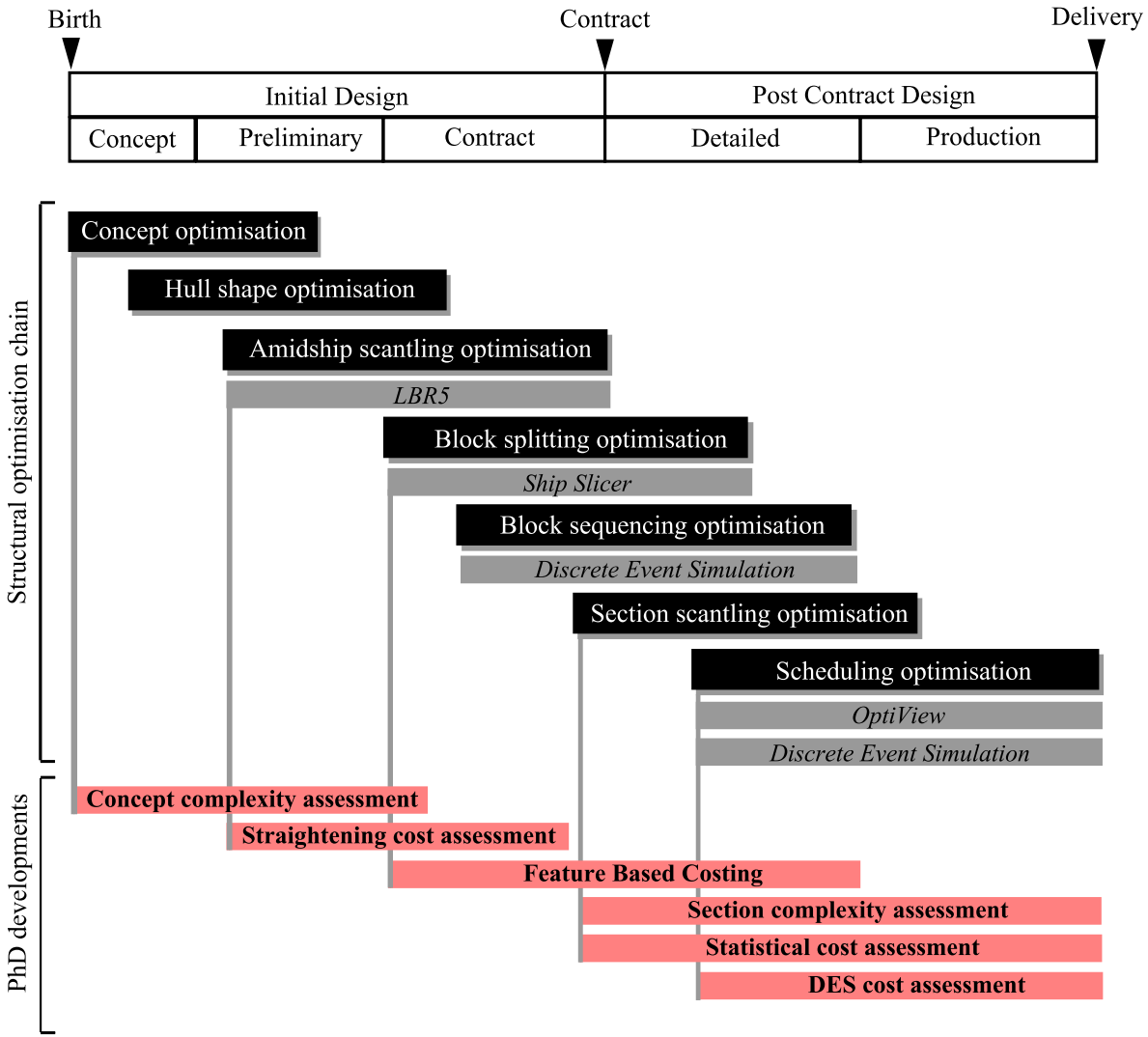
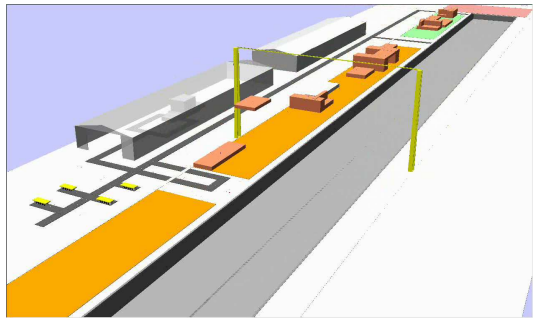


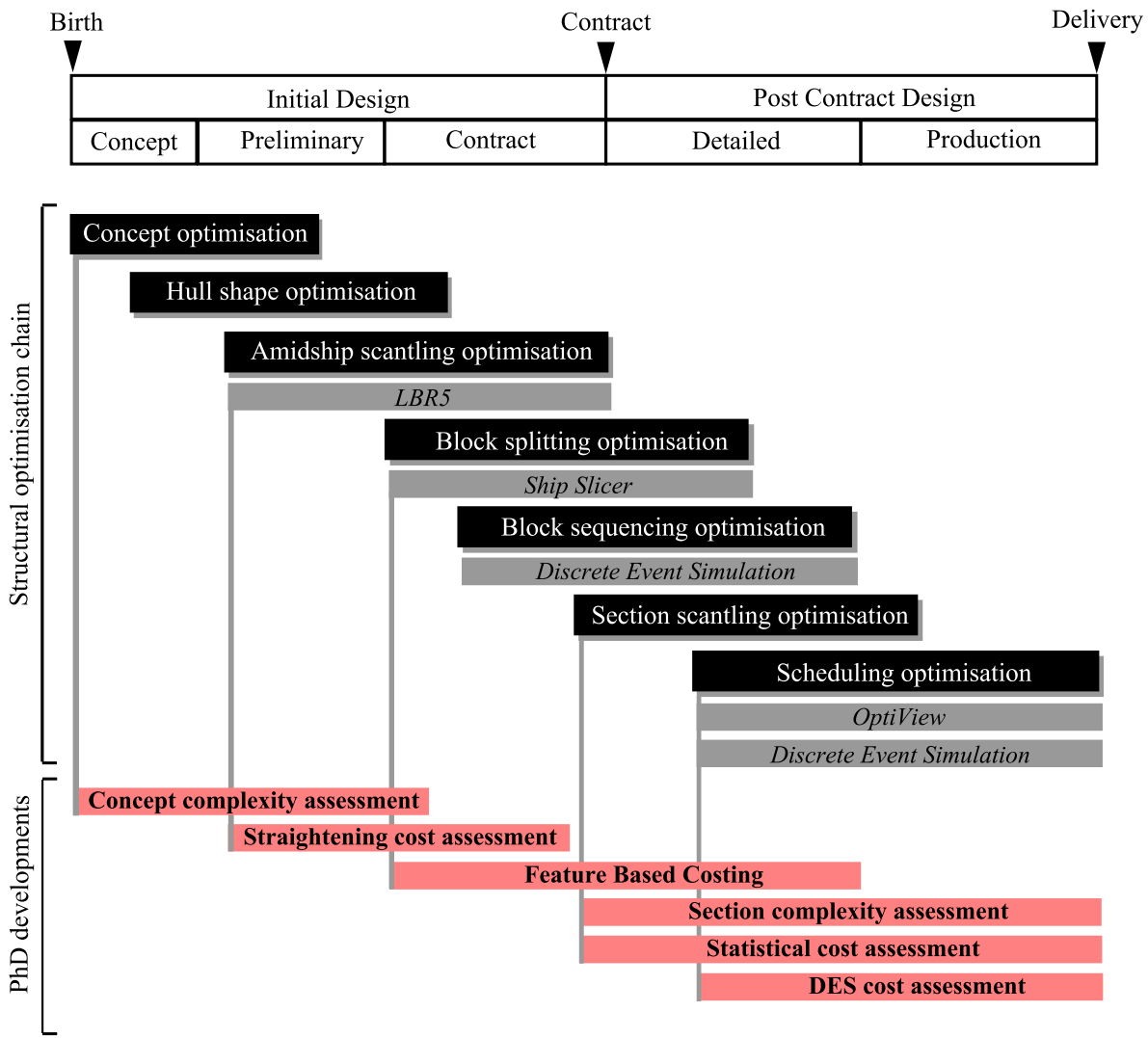


Scheduling optimisation

- Space allocation and production flow problems
- Needs of budget assessment modules

Presentation of the developments

The holistic ship design optimisation strategy



Developments

- Concept complexity assessment
- Straightening cost assessment
  - ANN
  - Fuzzy logic
- Feature Based Costing
- Section complexity assessment
- Statistical cost assessment
- DES cost assessment

Presentation of the developments

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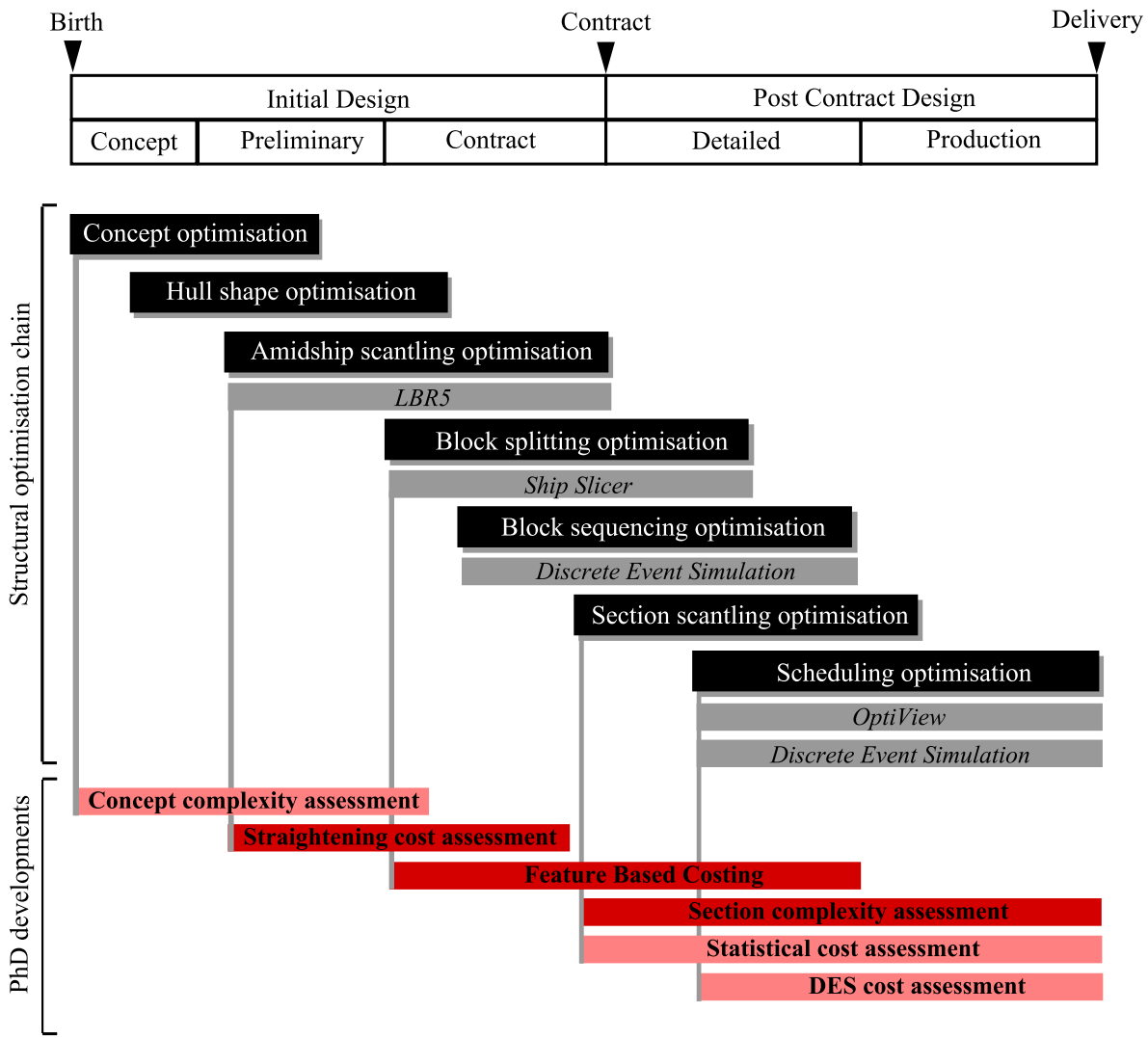

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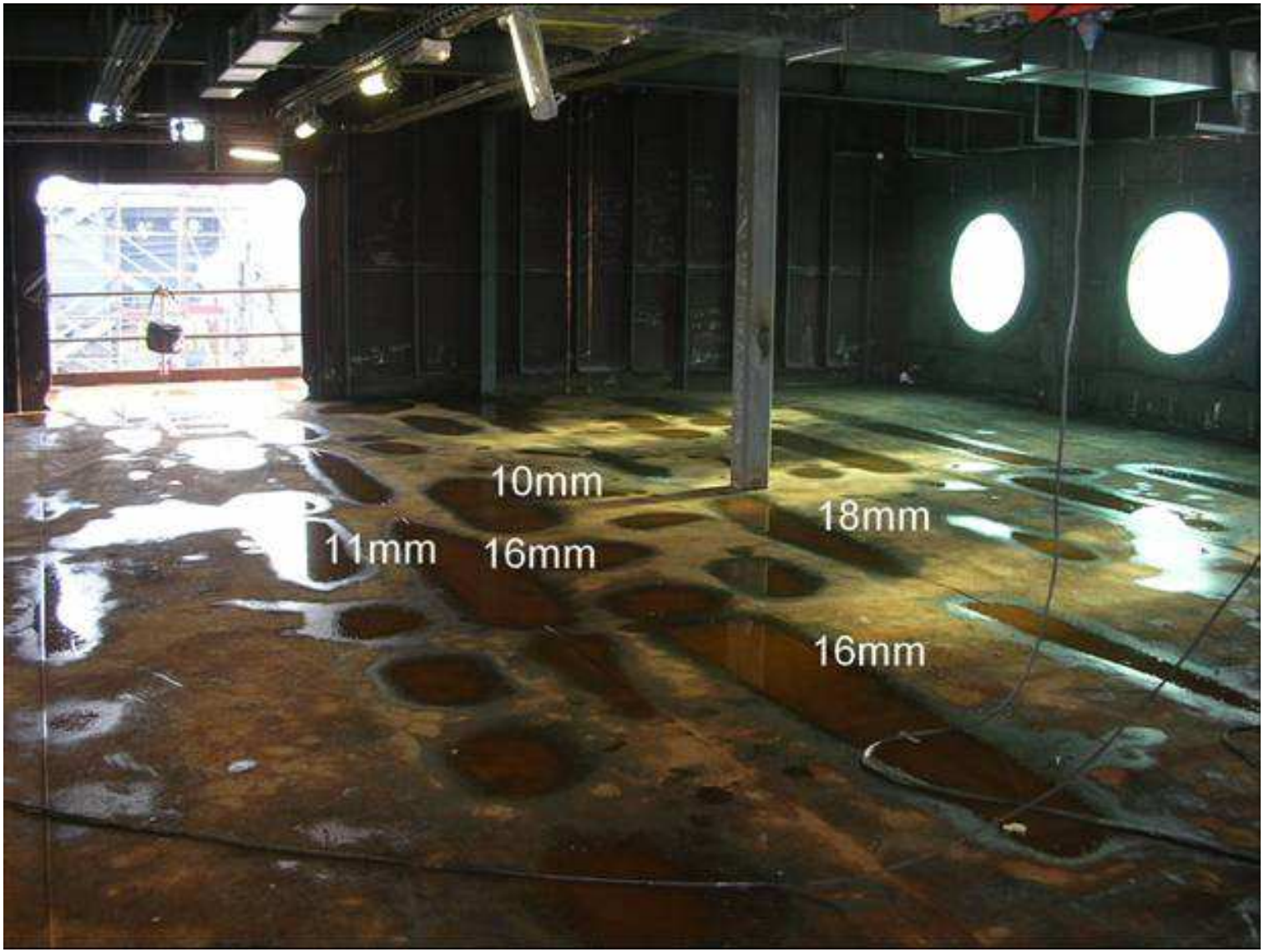
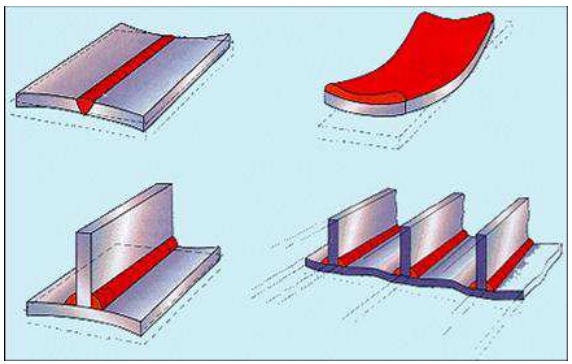
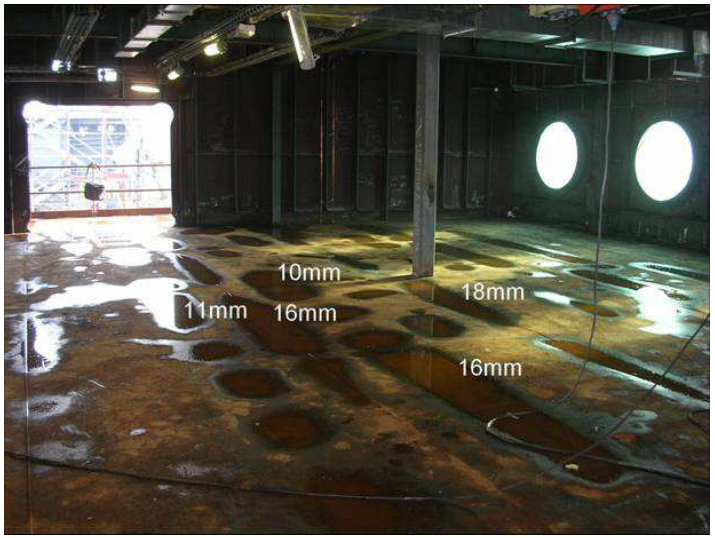


Straightening cost assessment prototype

Why straightening operation is required?

- Shipbuilding production
  - Uses of thin plates
    - Decrease the structural weight
    - Cruise vessels, fast ships
- Assembly of elements
  - Welding ⇒ Temperature gradient
  - Distortions into the steel structure





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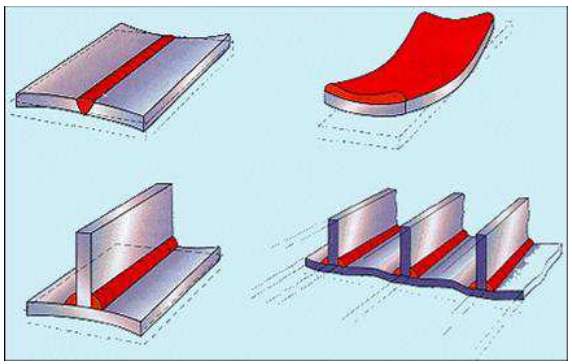

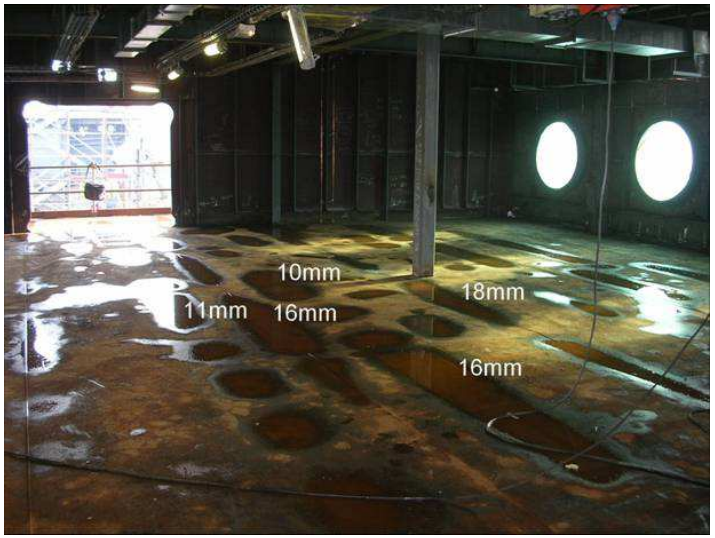

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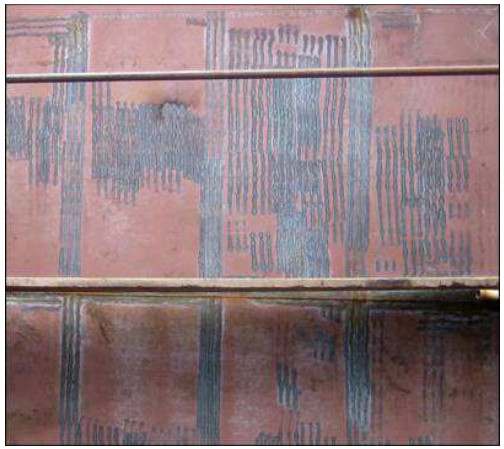
What is the straightening operation?

- Straightening operation
  - Remove distortions ⇒ Flatness
    - Esthetical reasons
    - Service reasons
  - Blowtorch or induction coil
    - Energy consumption
    - Take a lot of time
- Issue ⇒ mainly manual work
  - Non negligible workload (3-10%)
    - Workload impact on production cost
    - Impact on time schedule
    - Requires skilled workers
- Development of 2 different approaches
  - Artificial Neural Network
  - Fuzzy Metric



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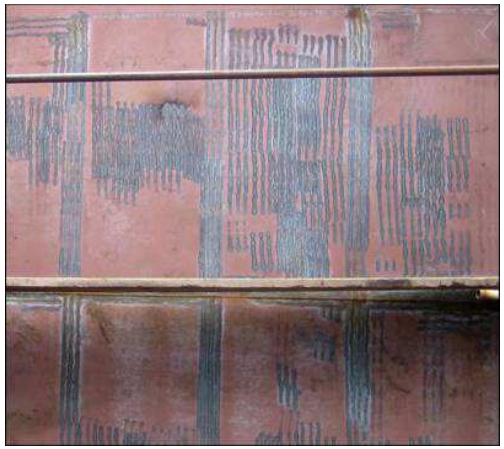

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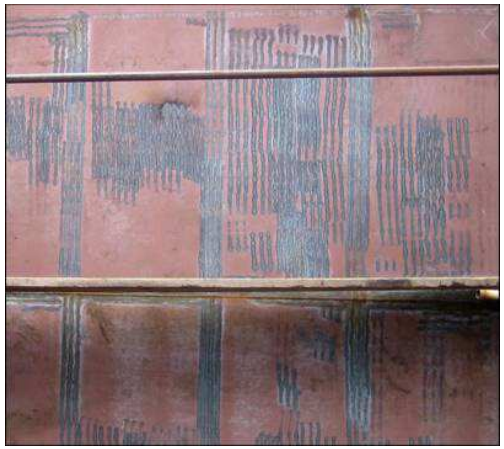

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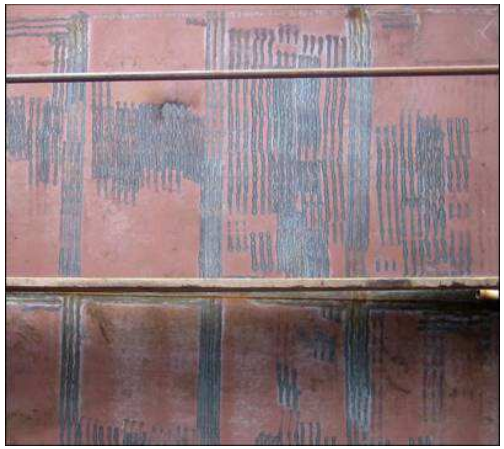

Straightening cost assessment prototype

Risk to use fuzzy logic

- Fuzzy rules based on human expertise and know-how
  - Different experts ⇒ Different opinions ⇒ Different rules
  - Expert know-how ≠ The real system behavior
  - Very difficult to model complex system
  - Very good interpretability ⇒ Never *black box*

Goals

- Development of a fuzzy metric to assess straightening cost
- Compare and optimize the fuzzy output with real data

Straightening cost assessment prototype

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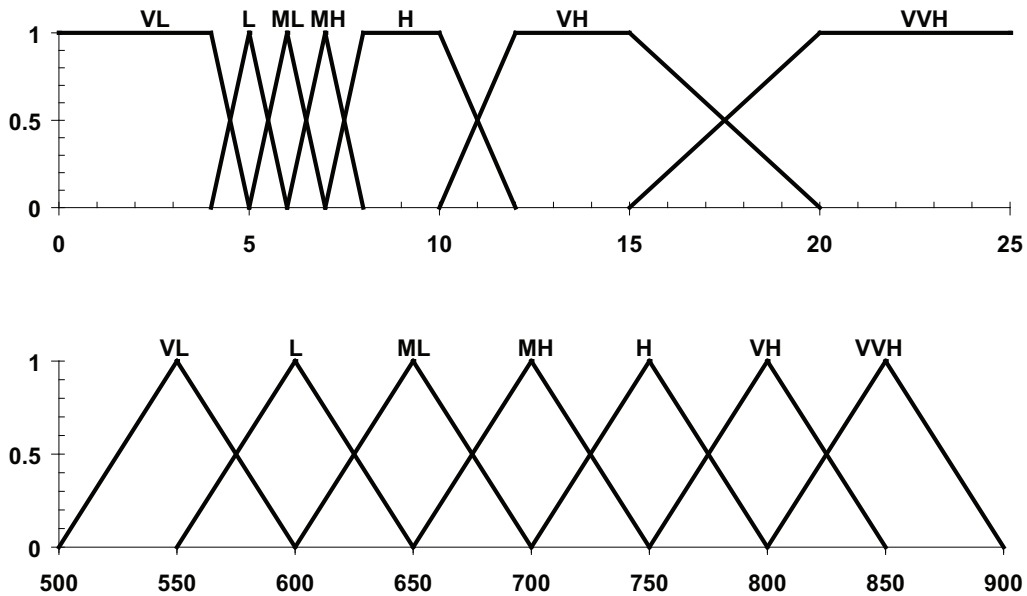
Straightening cost assessment prototype

Fuzzy sets and membership function

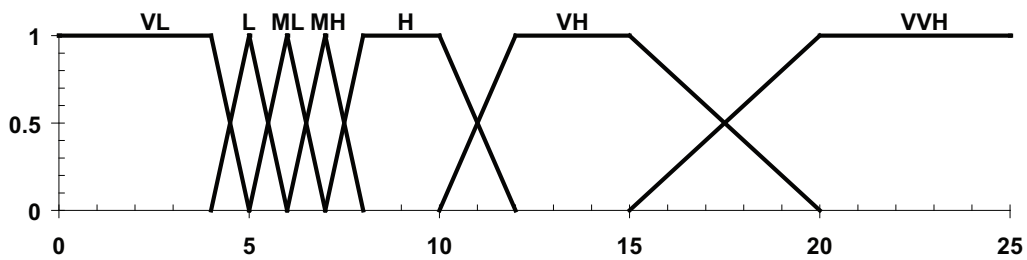
- Various expert's opinion from different EU shipyards
- 2 inputs
  - Plate thickness (5-25 mm)
  - Stiffener spacing (500-900 mm)
- 1 output
  - Straightening cost (0-1 h/m^2)

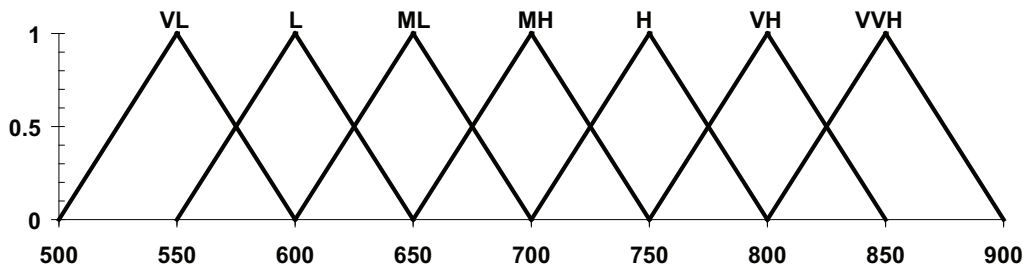


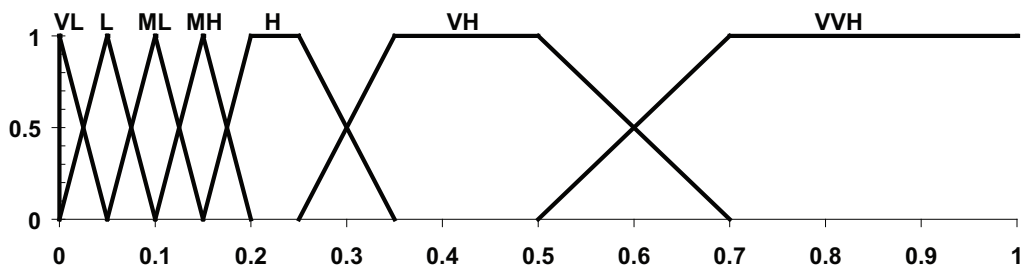
Straightening cost assessment prototype

Fuzzy sets and membership function

- Various expert's opinion from different EU shipyards
- 2 inputs
  - Plate thickness (5-25 mm)
  - Stiffener spacing (500-900 mm)
- 1 output
  - Straightening cost (0-1 h/m^2)







Straightening cost assessment prototype

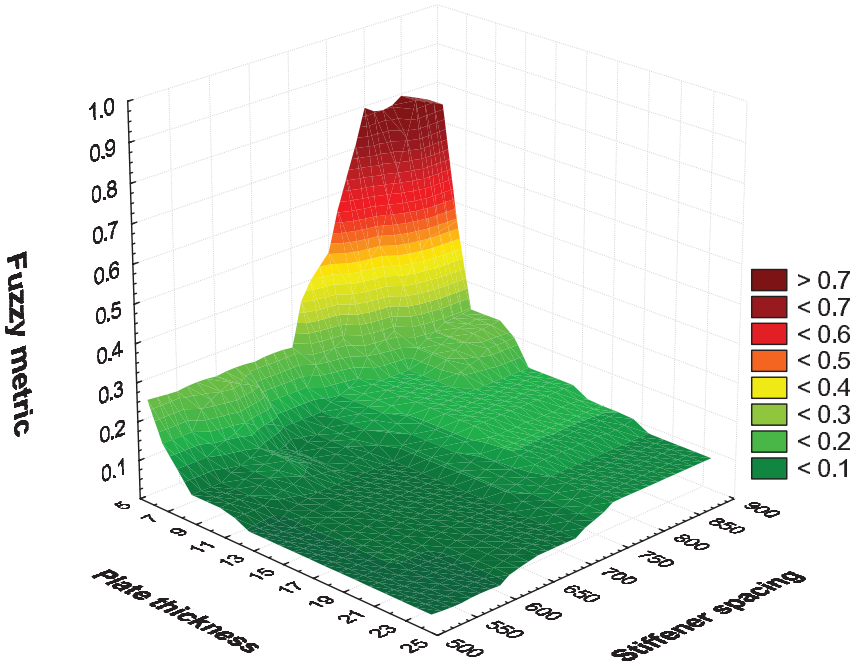
Fuzzy rule matrix and fuzzy output surface

- 49 rules with linguistic form
- Defined by various expert opinion of EU shipyards

IF Plate thickness = LOW
AND Stiffener spacing = HIGH

THEN Straightening cost = VERY HIGH

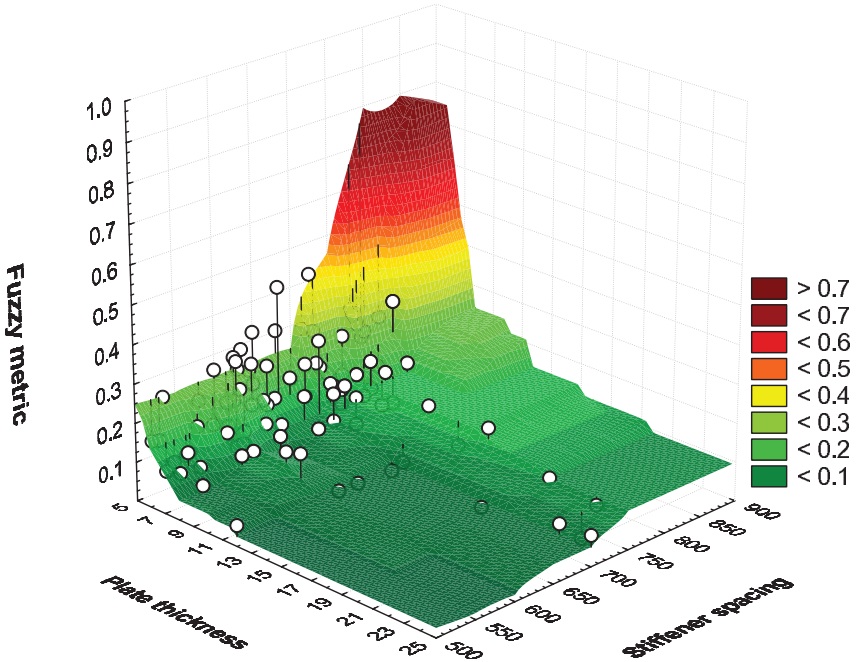
		Stiffener spacing						
		VL	**L**	**ML**	**MH**	**H**	**VH**	**VVH**
Plate Thickness	**VL**	VH	VH	VH	VH	VVH	VVH	VVH
	L	H	H	H	H	VH	VVH	VVH
	ML	MH	H	MH	MH	H	VH	VVH
	MH	ML	MH	ML	ML	MH	H	VH
	H	L	ML	L	ML	MH	MH	H
	VH	VL	L	L	L	MH	MH	MH
	VVH	VL	VL	L	L	ML	ML	ML



Straightening cost assessment prototype

Comparison with real data

- Human expertise and know-how
  - Define membership functions
  - Define fuzzy linguistic rules
- **Output does not fit completely with reality**
- Comparison with real data
  - $\simeq$1000 measures
  - 15 passenger ships
  - $\simeq$150 combinations between stiffener spacing and plate thickness
- Definition of an error function



$$error = \sqrt{\sum_{i=1}^{n} \left(S_{fuzzy} - S_{real}\right)^2}$$

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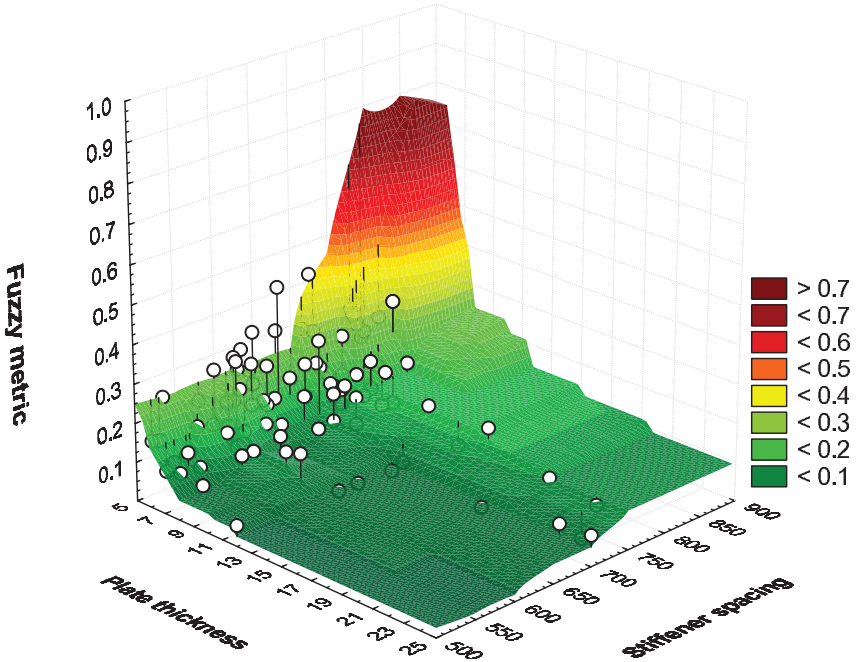

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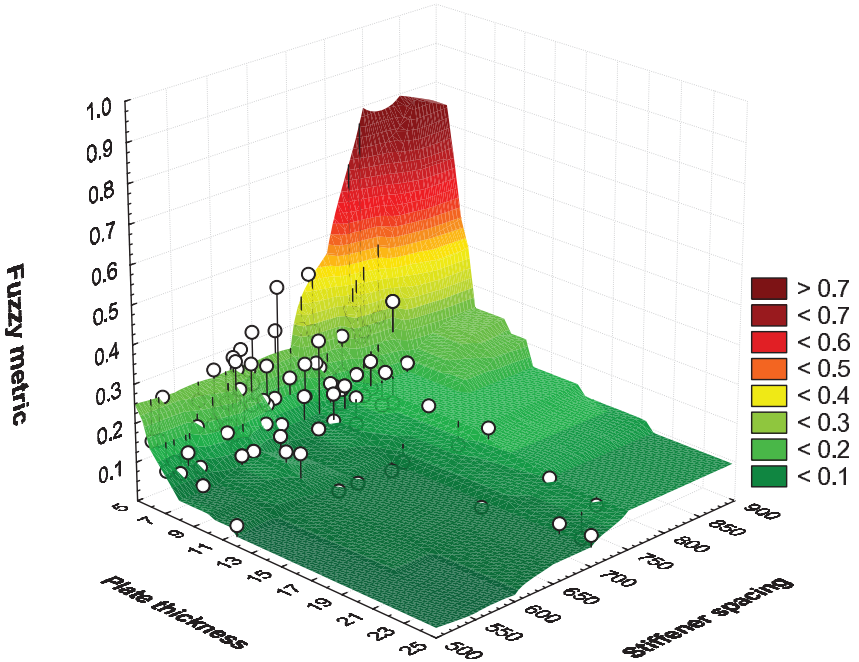

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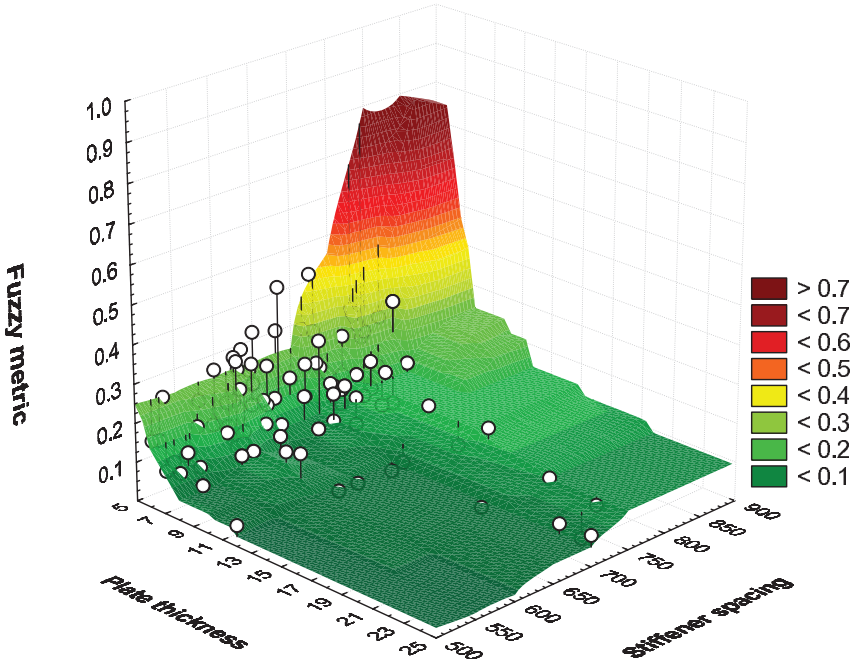

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Straightening cost assessment prototype

Optimization of the fuzzy outputs

- Objective function $\Rightarrow$ Minimize the error function
- Optimization algorithm $\Rightarrow$ Jump (better than gradient descent)
- Design variable $\Rightarrow$ Weighting factor [0,1]

IF Plate thickness = LOW
AND Stiffener spacing = HIGH
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WITH 0.456

- Reduction of 26%
- Output surface fits better with the measurements

Straightening cost assessment prototype

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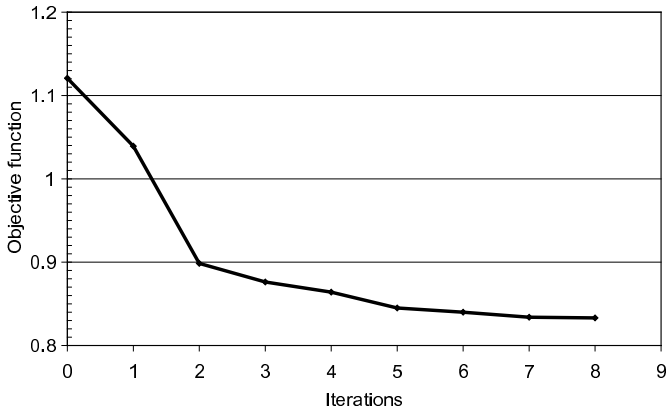

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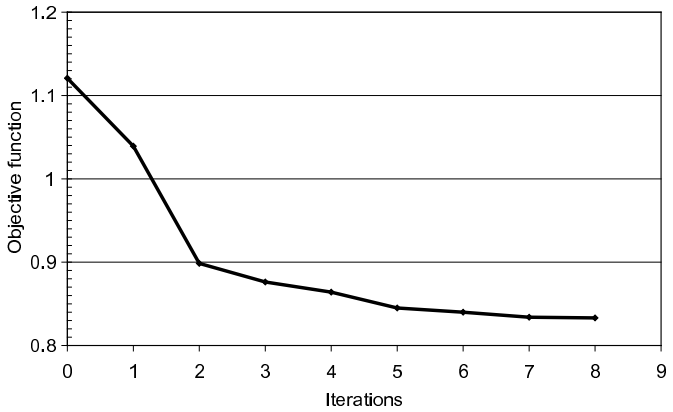

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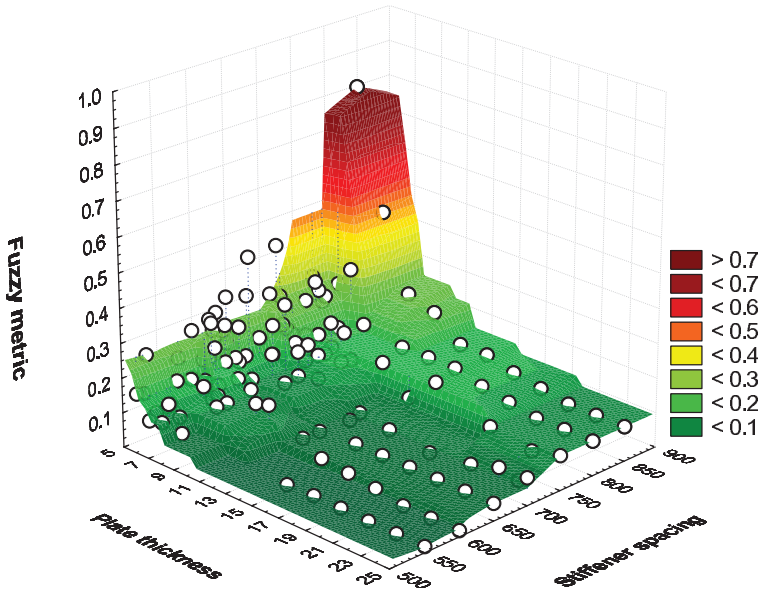

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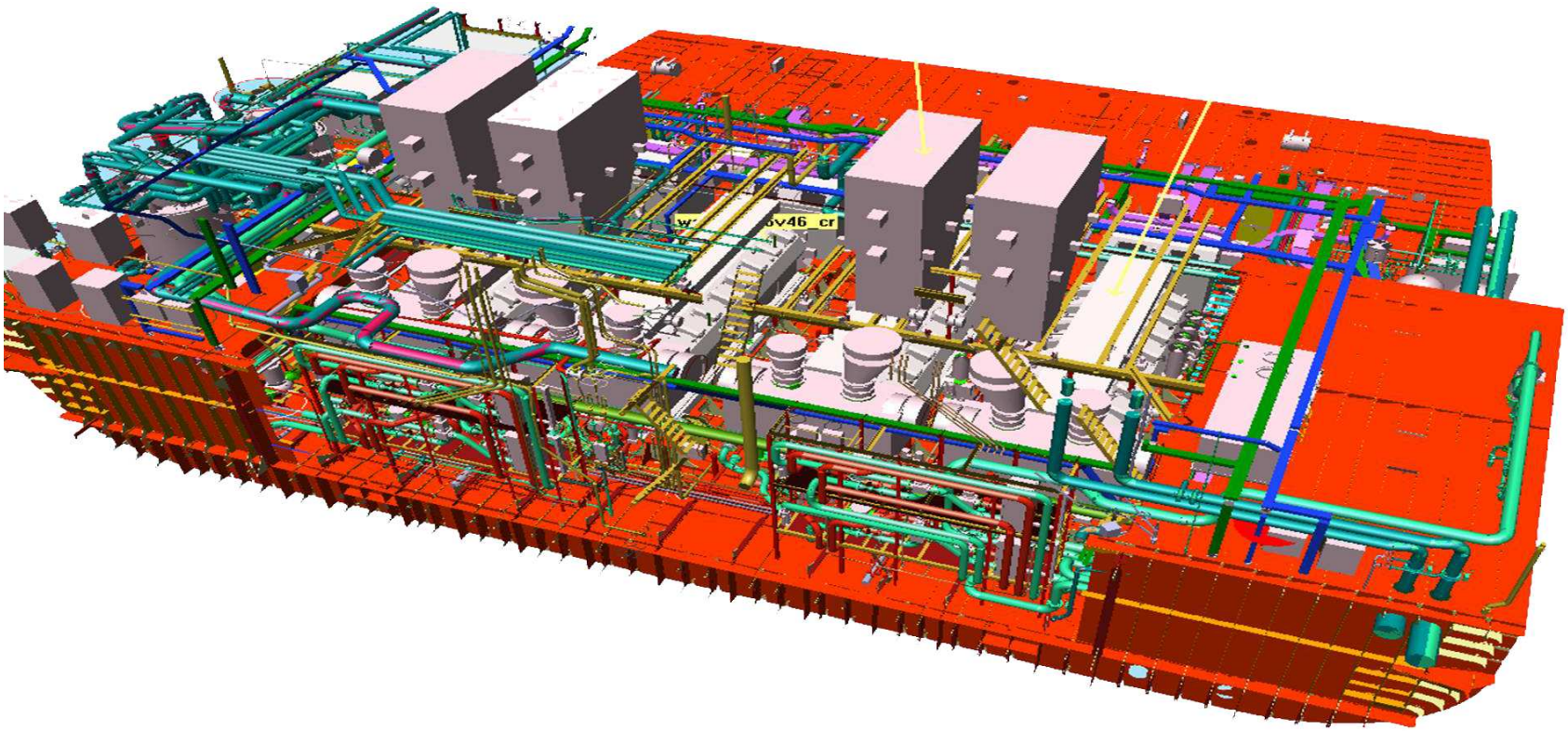
Feature Based Costing prototype



Feature Based Costing prototype

Introduction

- Many approaches to cost assessment are
  - Mysterious and not formally validates
  - Complicated
  - Difficult to use
  - Too simplistic
- Thus, typical cost estimation techniques become
  - Increasingly inefficient and ineffective
  - Taking days to generate cost estimates
  - Instantly out-of-date every time design change
- FBC prototype provides
  - Assesses production cost for ship steel structure
  - Assesses cost by product and/or process
  - Offers electronic imports, aggregates, and stores return cost data
  - Reduces the time and increases the accuracy
  - Identifies cost drivers
  - Provide information for production process improvement

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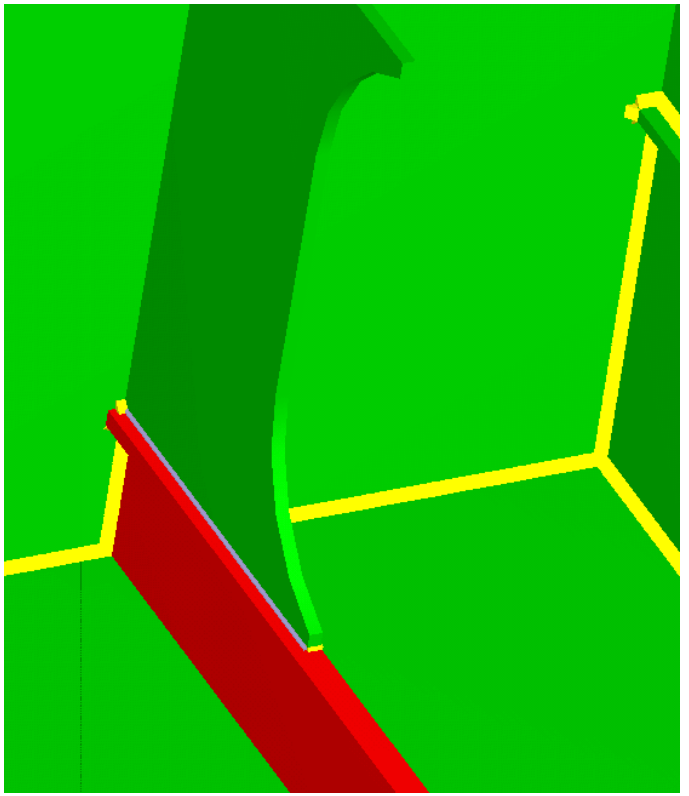
Feature Based Costing prototype

Cost Evaluation Relationships (CERs)

$$CO = CQ \times CU \times CK \times CA \times CW$$

- CO - **Labour cost (man-hours)**
- CQ - Quantity (welding length, number of brackets, etc.)
- CU - Unitary costs (cost-per-unit)
- CK - Corrective coefficient used to calibrate the unitary costs
- CA - Accessibility/Complexity coefficient
- CW - Workshop coefficient



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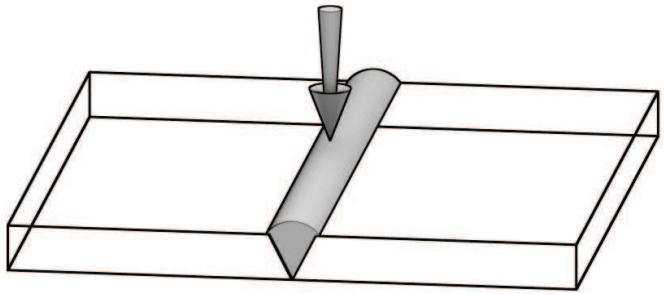

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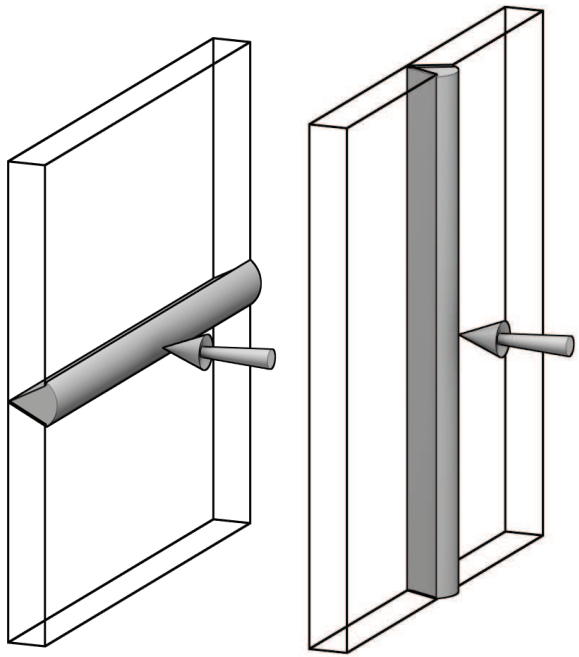

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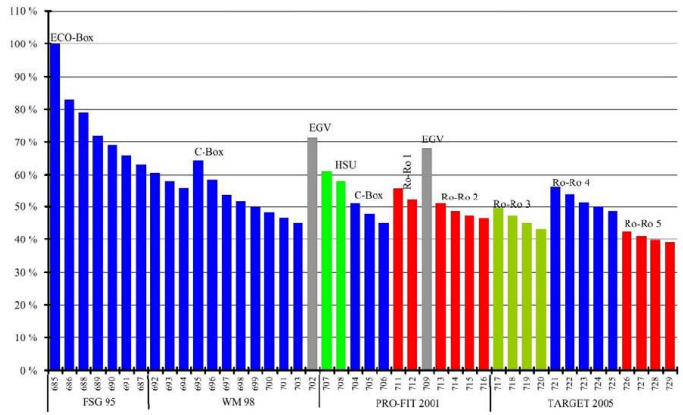

Learning curve

Inflation

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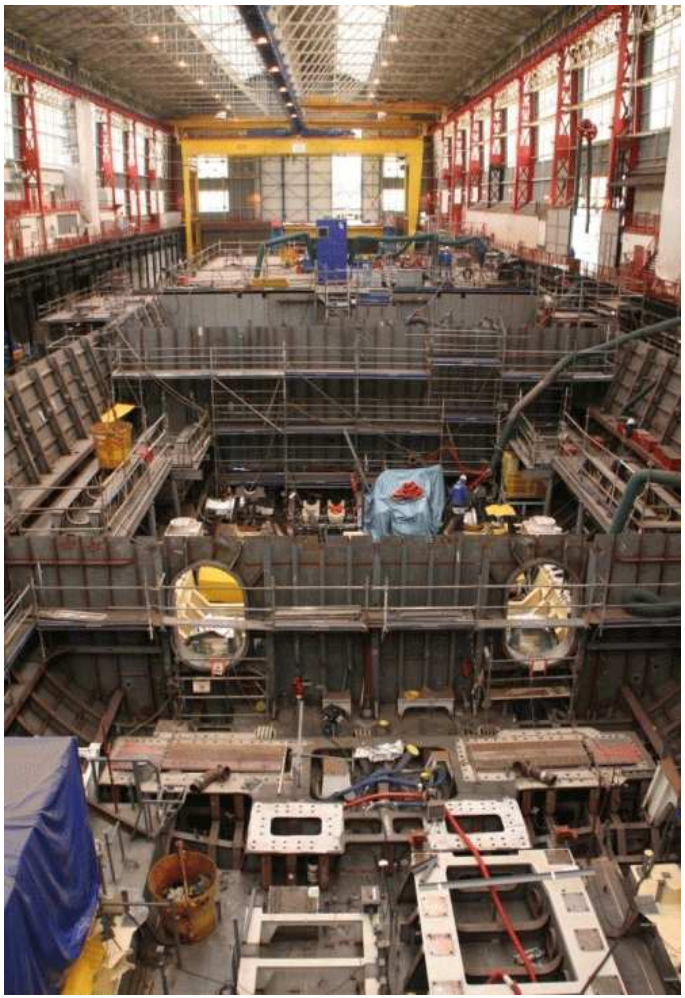

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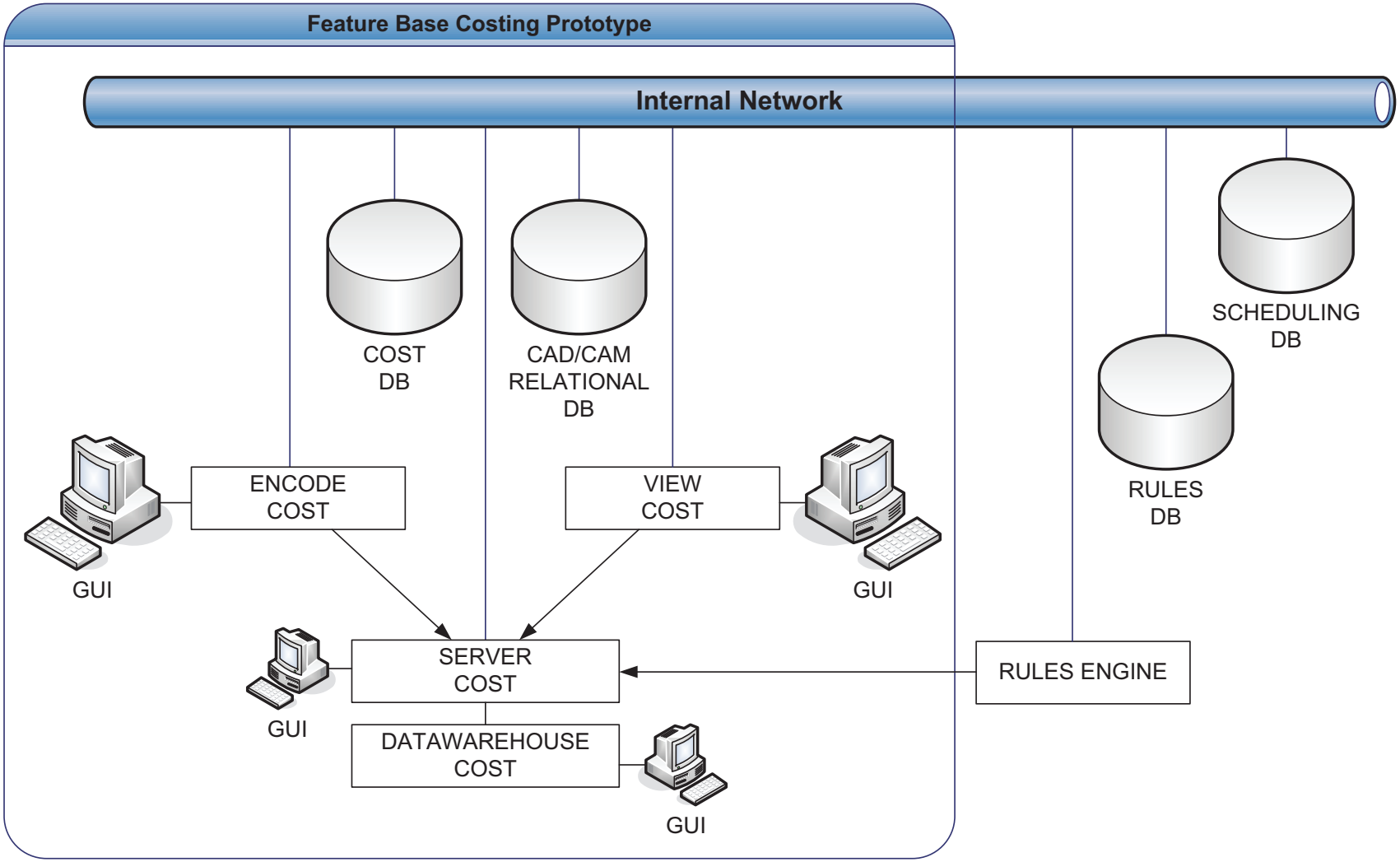
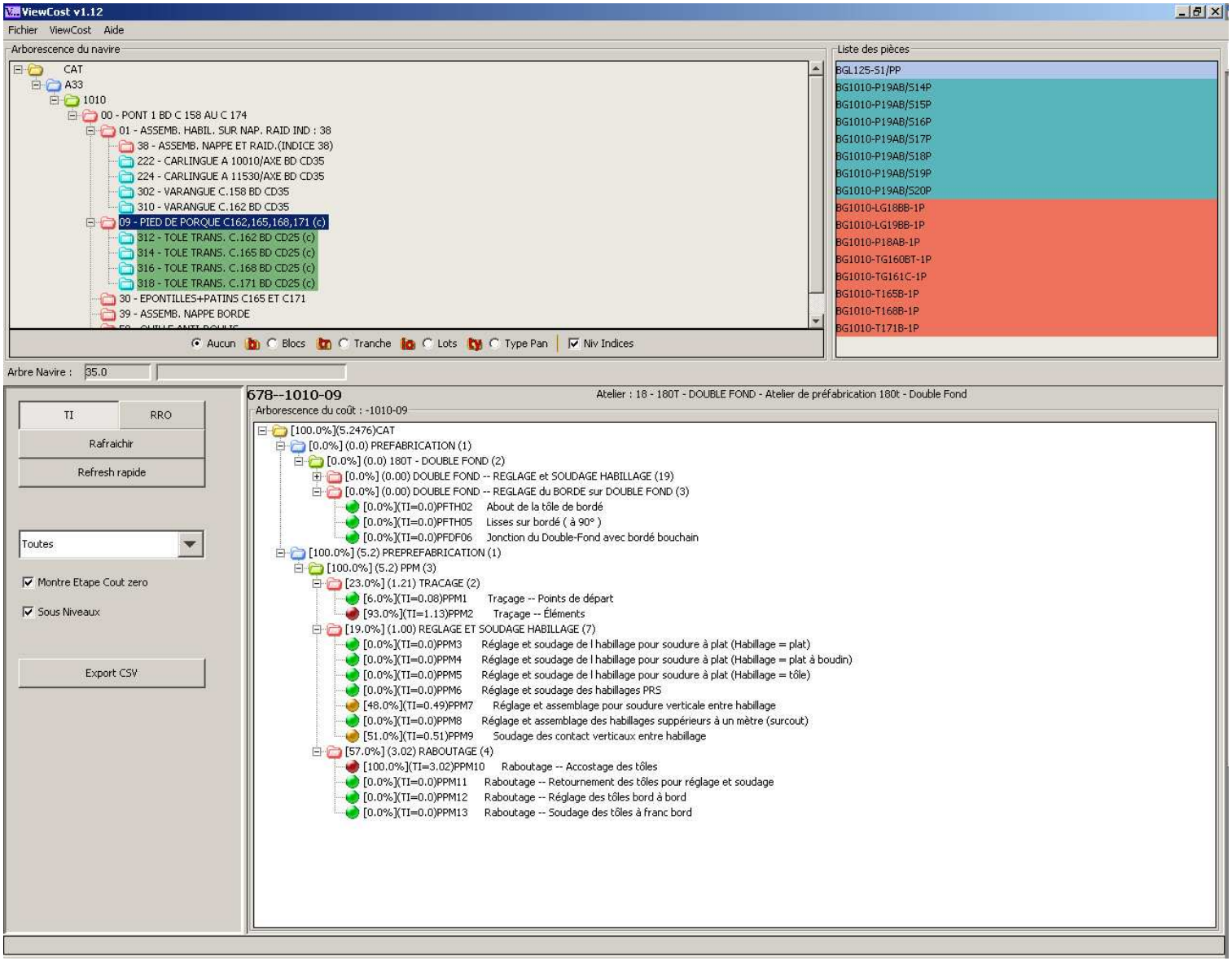
Feature Based Costing prototype

Workflow architecture



Feature Based Costing prototype

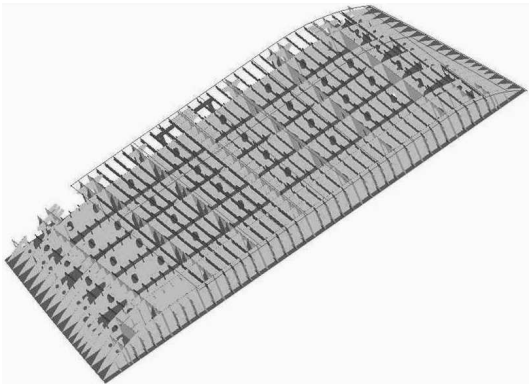
Main frame of the ViewCost module



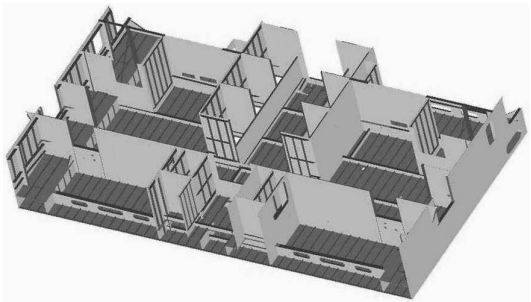
Feature Based Costing prototype

Analysis and results

	Number of	**Average error**	
	Section	*Before data correction*	*After data correction*
Complex	16	-22.3%	-1.6%
Medium	8	-9.2%	-0.8%
Simple	13	1.7%	1.7%



Complex



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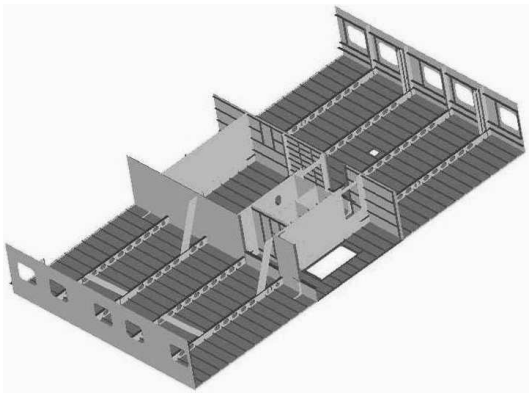

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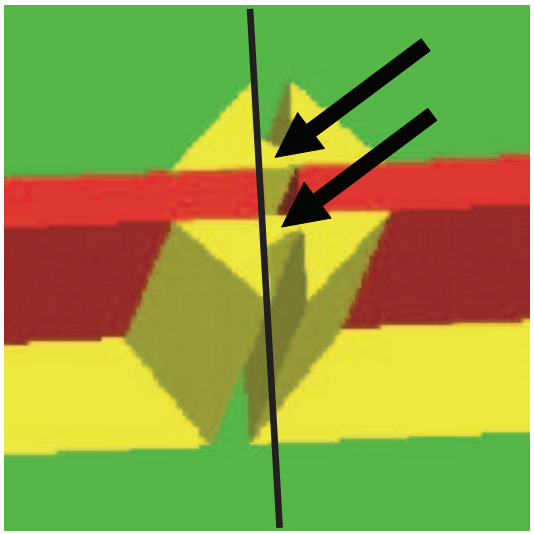
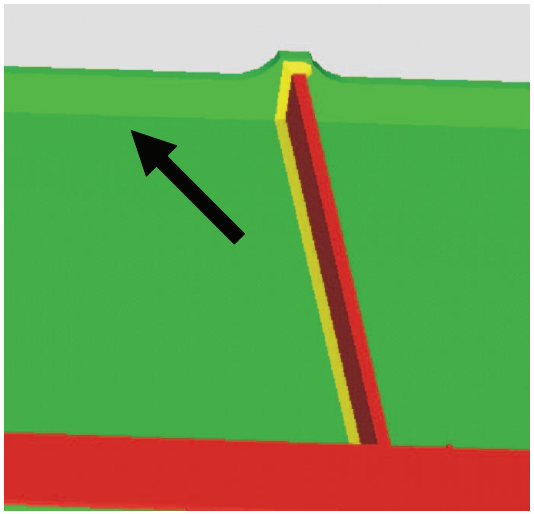


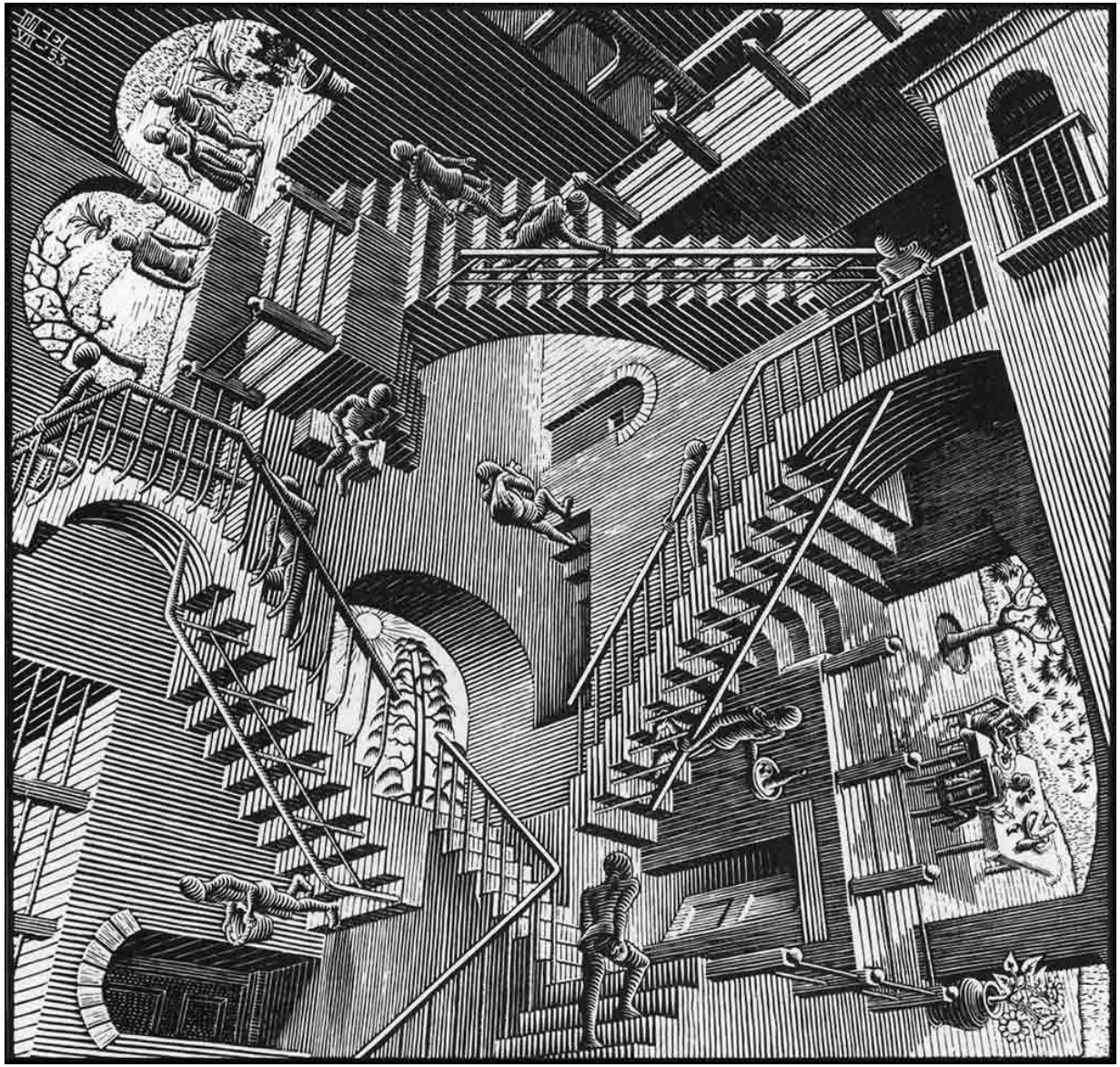
Double welds

Missing weld



Missing weld

Complexity evaluation



Complexity evaluation

How to measure the ship complexity?

- Very hard to find a formal definition of a *complex system*
- Complexity often implies
  - Many parts with a lot of redundancy
  - Many relationships/interactions among the parts
  - Combination effects that are not easily predicted
  - A form of a hierarchy
- If ship complexity $\nearrow \Rightarrow$ LCC $\nearrow$

Goals

- To find an alternative to the cost evaluation methods
- To define a quantitative and objective complexity metric
  - Macroscopic complexity
  - Microscopic complexity

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Complexity evaluation

Definition of the micro complexity

- Micro complexity = combination of
  - **Shape complexity** (*Csh*)
    Ability to perform the manufacturing of individual parts of the products
  - **Assembly complexity** (*Cas*)
    Ability to easily assemble the components of a product
  - **Material complexity** (*Cmt*)
    Ability to use different types of material in a product

- Based on *sphericity* of the product components - ψ

$$C_{sh} = 1 - \psi$$

$$\psi = \frac{A_s}{A} = \frac{\pi^{1/3}(6V)^{2/3}}{A}$$

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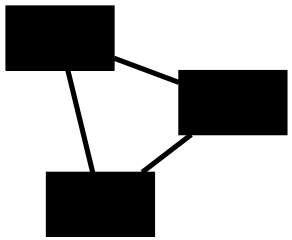

- Based on a recursive formulation similar to the *Shanon entropy*

$$C_{as} = \sum_{i=1}^{n} C(T_i) + N_T \log_2(2^{k_T} - 1)$$

Complexity evaluation

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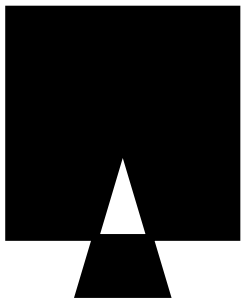

- Based on the number of different material and scantling used in the product

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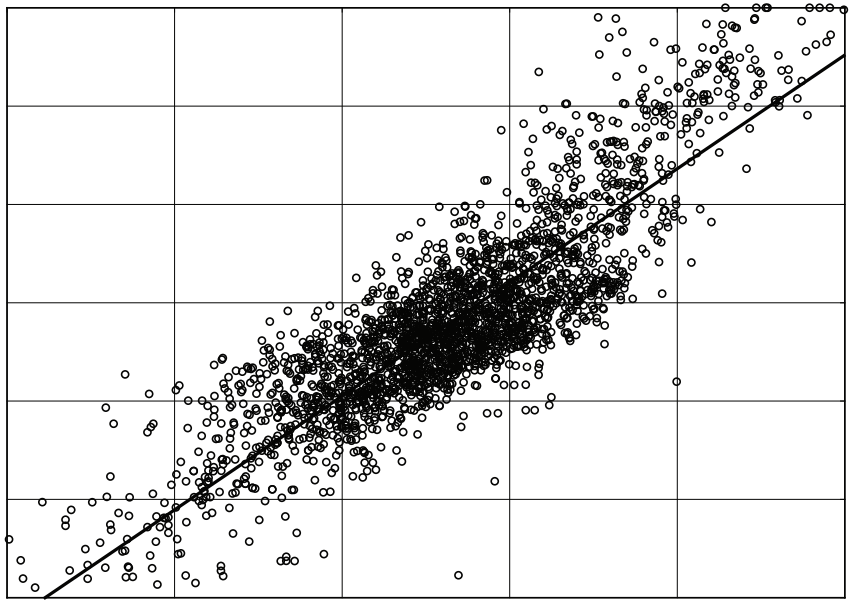
$$C_T = \frac{w_1 C_{sh} + w_2 C_{as} + w_3 C_{mt}}{w_1 + w_2 + w_3}$$

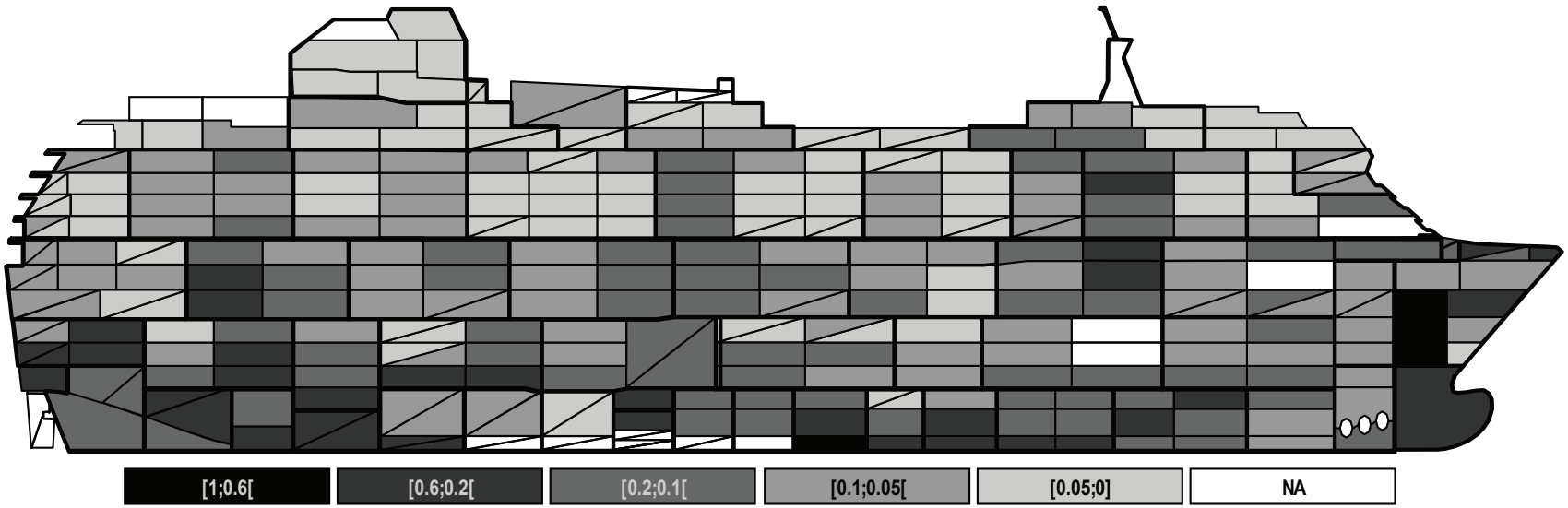
Production time vs **Complexity**



Complexity evaluation

Results on a passenger ship

Global complexity



Conclusion and recommendations

Summary

Conclusion and recommendations

Main contributions

- Various cost and complexity assessment methods has been presented and tested
- This methodology provides:
  - An aid for designers ⇒ compare different design alternative based on cost and complexity
  - An environment which supports strategic decisions AEAP
  - A monitoring of the sources of complexity and cost which helps to determine the consequences of decision making
  - A spotting of the sources of complexity and cost which helps to reduce design effort
  - An objective, quantifiable, unambiguous metrics of cost and complexity

Results

- Reduction of lead time and Life Cycle Cost
- Increase the competitiveness of shipyards

Conclusion and recommendations

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  - A monitoring of the sources of complexity and cost which helps to determine the consequences of decision making
  - A spotting of the sources of complexity and cost which helps to reduce design effort
  - An objective, quantifiable, unambiguous metrics of cost and complexity

Results

- Reduction of lead time and Life Cycle Cost
- Increase the competitiveness of shipyards

Conclusion and recommendations

Main contributions

- Various cost and complexity assessment methods has been presented and tested
- This methodology provides:
  - An aid for designers $\Rightarrow$ compare different design alternative based on cost and complexity
  - An environment which supports strategic decisions AEAP
  - A monitoring of the sources of complexity and cost which helps to determine the consequences of decision making
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SWOT analysis

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Strength, Weaknesses, Opportunities and Threats analysis – SWOT

Strengths

- Provides innovative solution enhancing the *Design for X* concept
- Places the developments in a holistic optimization strategy
- Real-time complexity assessment $\Rightarrow$ requires less time than cost evaluation
- PhD has highlighted limitation of ANN and production simulation to handle innovative design

Weaknesses

- Life Cycle Cost cannot modelling all design criteria (i.e. safety)
- Research is confined on ship structure (not outfitting)
- Applications are mainly focused on labour cost
- Majority of developments are applied on large passenger ships

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Opportunities

- Maintenance part of the Life Cycle Cost should be investigated more deeply
- PhD can lead to the implementation of the cost and complexity assessment in a commercial CAD/CAM tool
- PhD may be used as an education and training guide for industry

Threats

- The availability of historical data for small shipyards is often compromised
- If the maintenance cost rises rapidly in the near future compared to the initial cost, current development becomes minor

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Thank you for your attention

Ship with low complexity and very efficient cost

Questions ?

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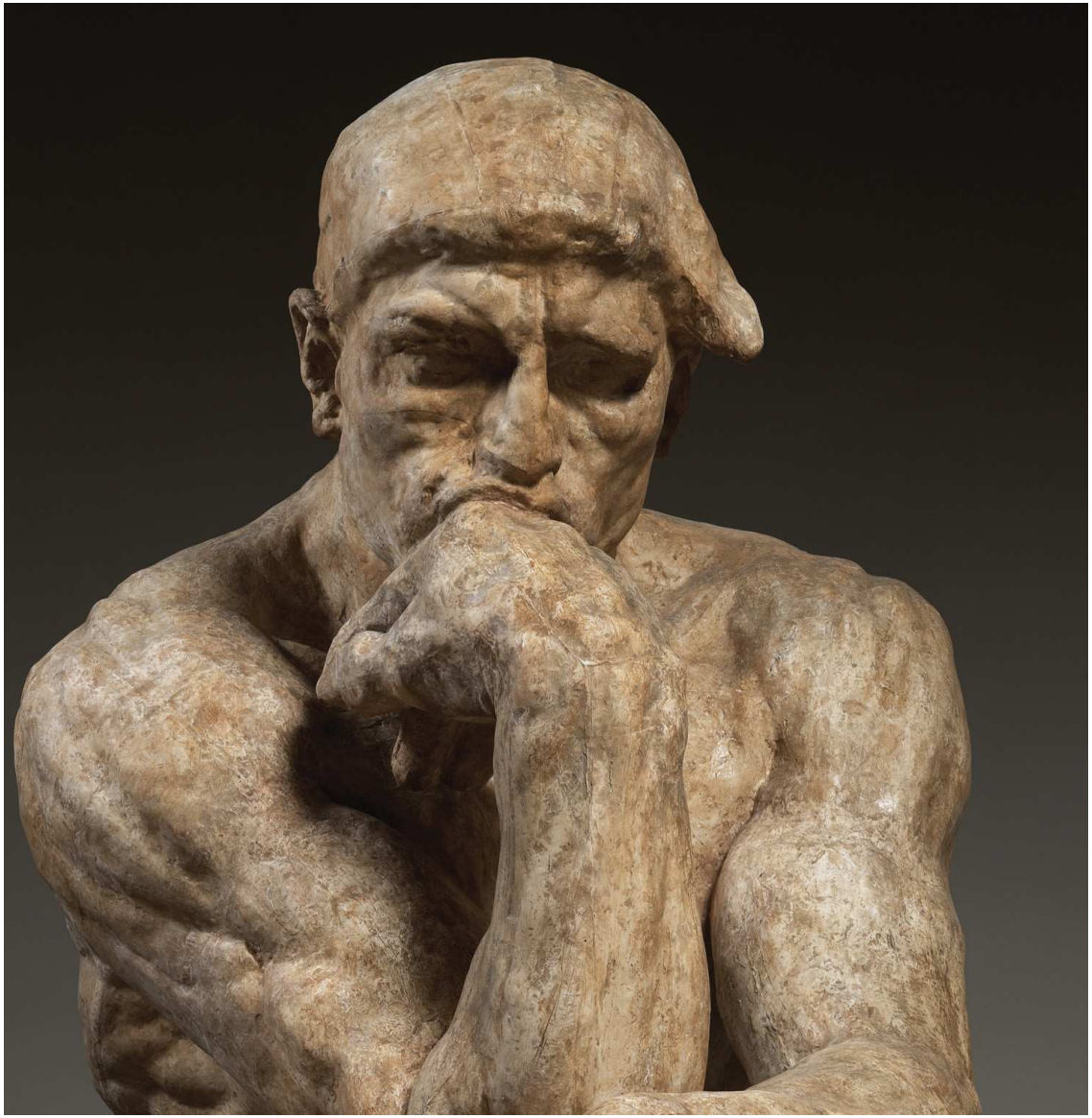

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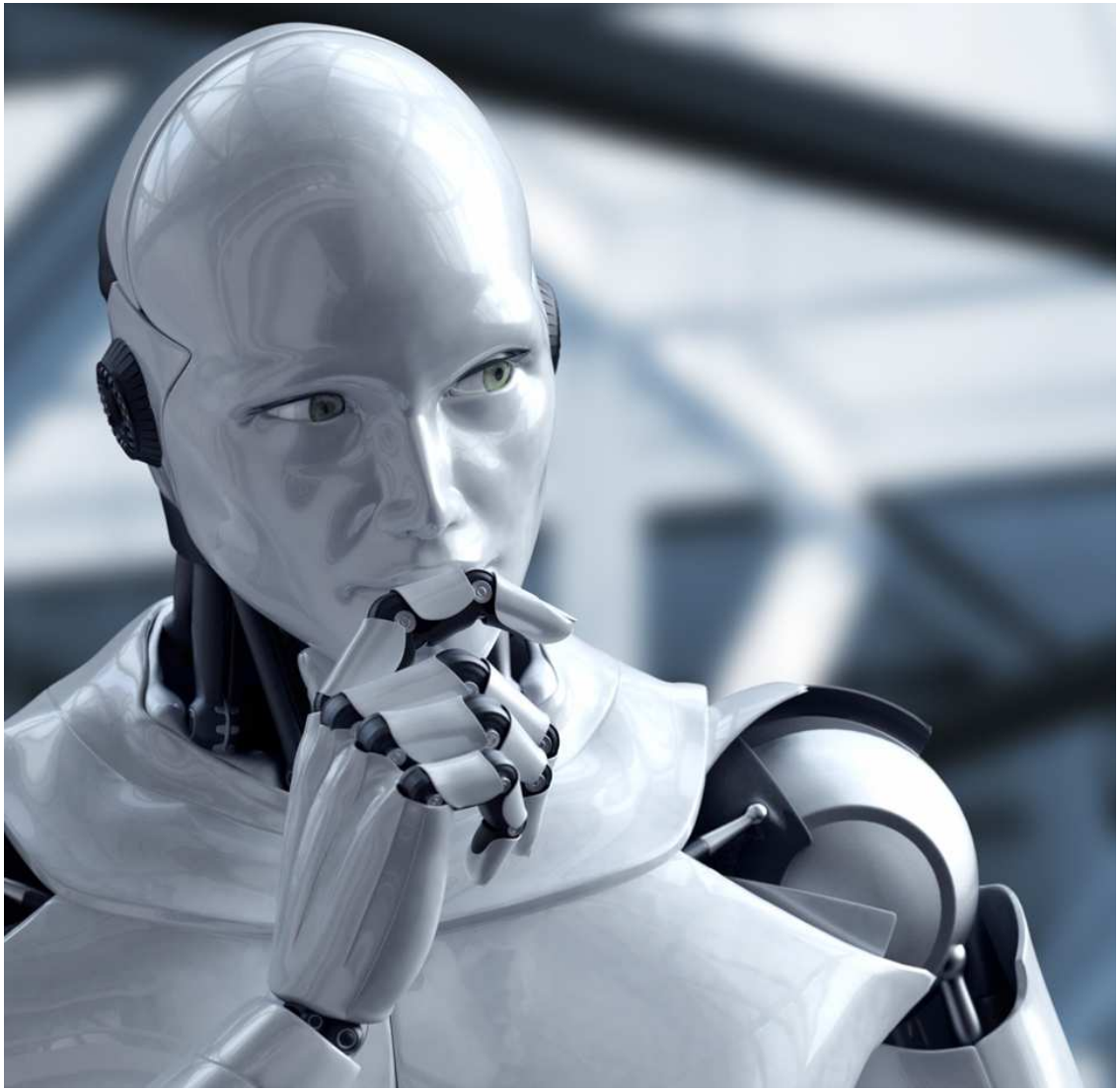

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Procrastination

Hard work often pays off after time,

but laziness always pays off now.