Design Optimization of Floating Offshore Wind Turbine Substructures using Frequency Domain Dynamic Model and Genetic Algorithm

EERA DeepWind conference, 19th January 2023.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement N° 860879.

Floating Offshore Wind

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- High potential Worldwide, particularly in Europe

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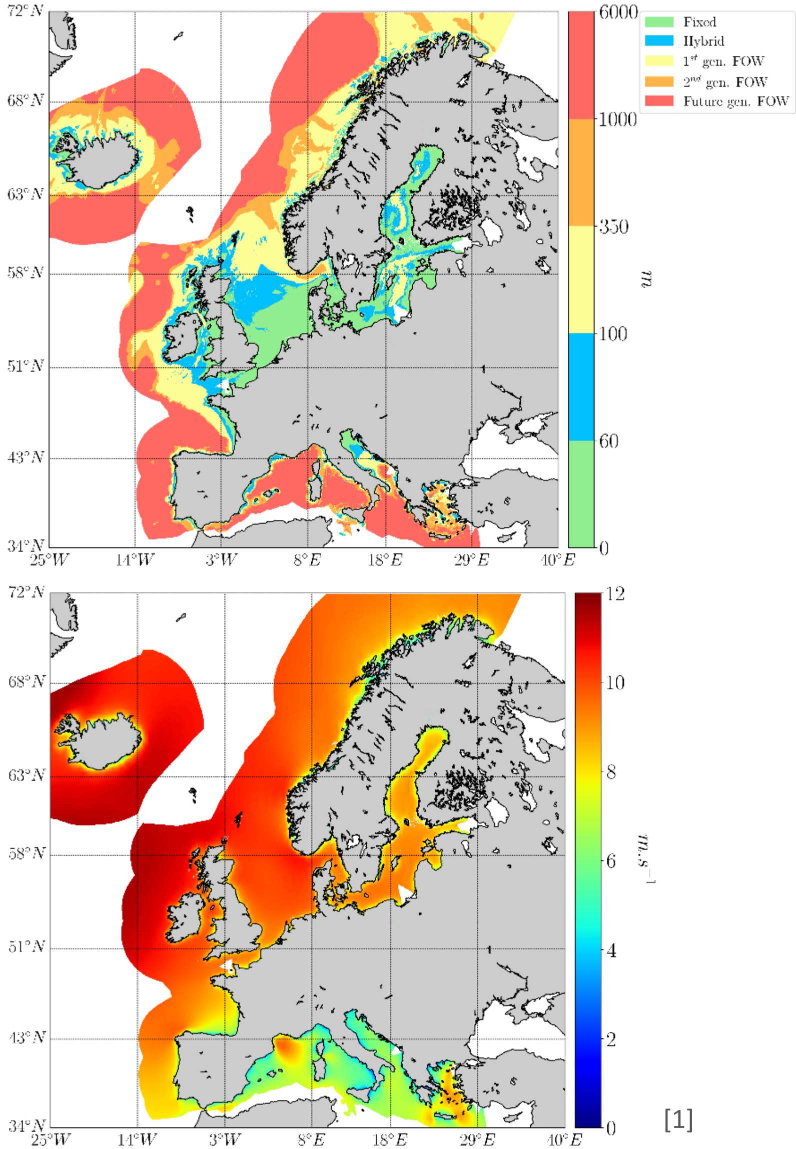
Floating Offshore Wind

- ❑High potential Worldwide, particularly in Europe
- ❑Higher wind loads and extreme sea state



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LEHRSTUHL WINDENERGIETECHNIK

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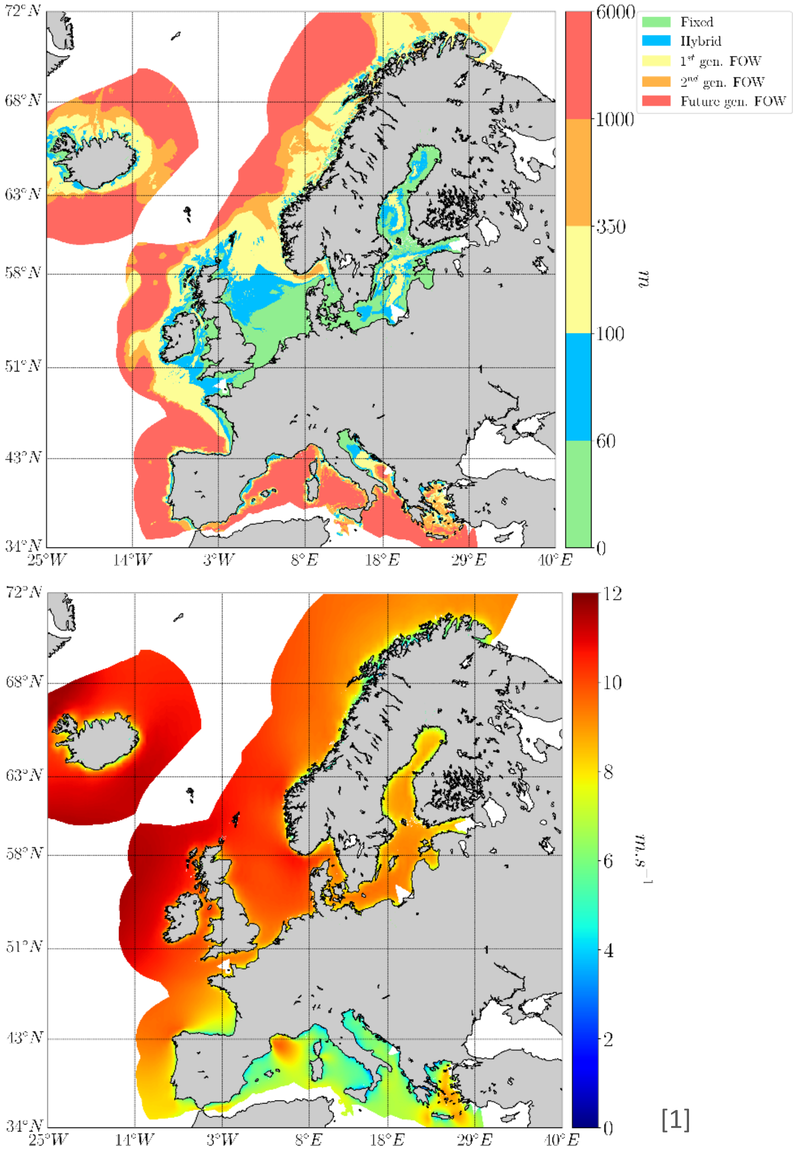
- ❑High potential Worldwide, particularly in Europe
- ❑Higher wind loads and extreme sea state
- ❑Different type of substructures



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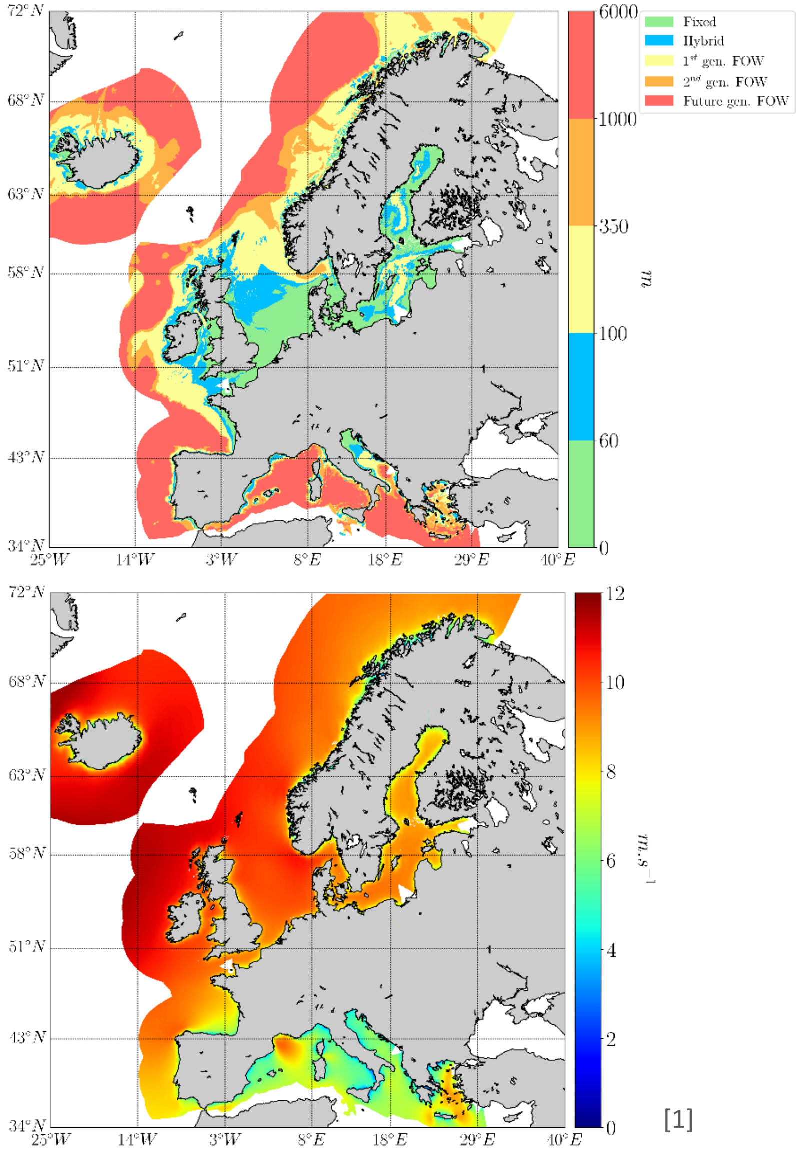
- Higher wind loads and extreme sea state
- Different type of substructures
- Complex manufacturing and low production rate



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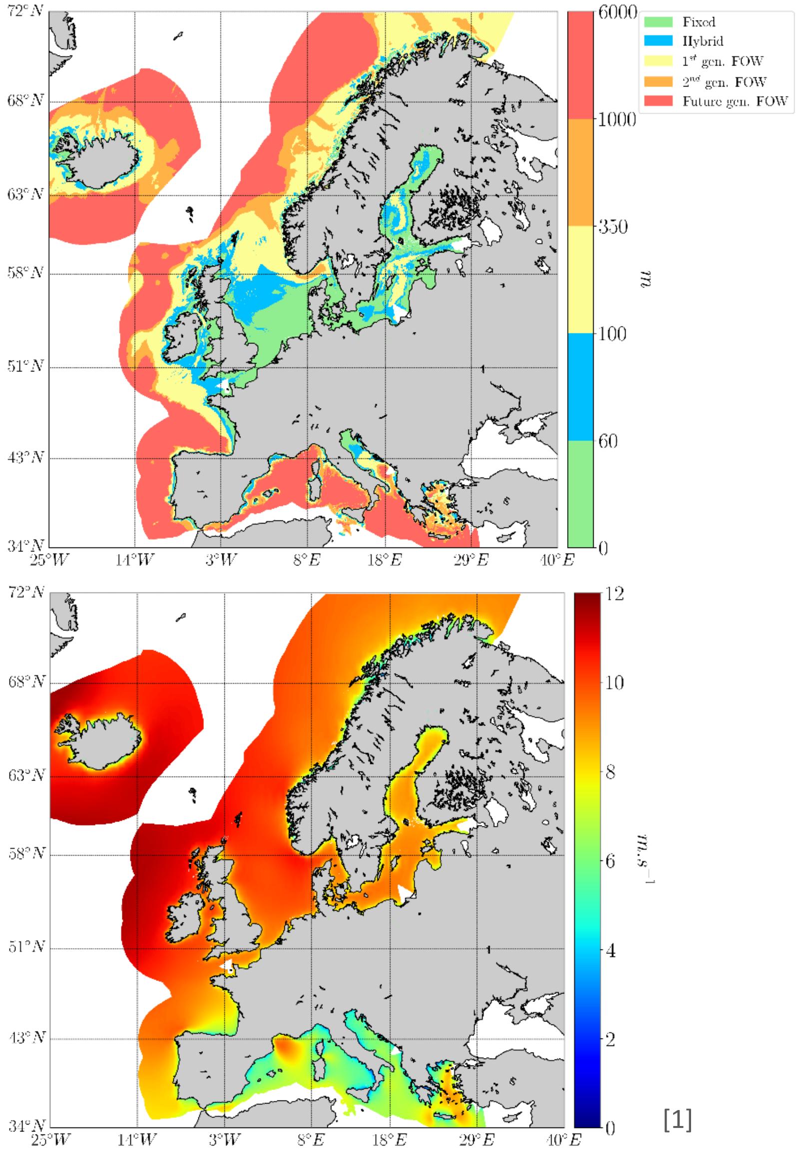
- ❑Higher wind loads and extreme sea state
- ❑Different type of substructures
- ❑Complex manufacturing and low production rate
- ❑High Levelized Cost of Energy



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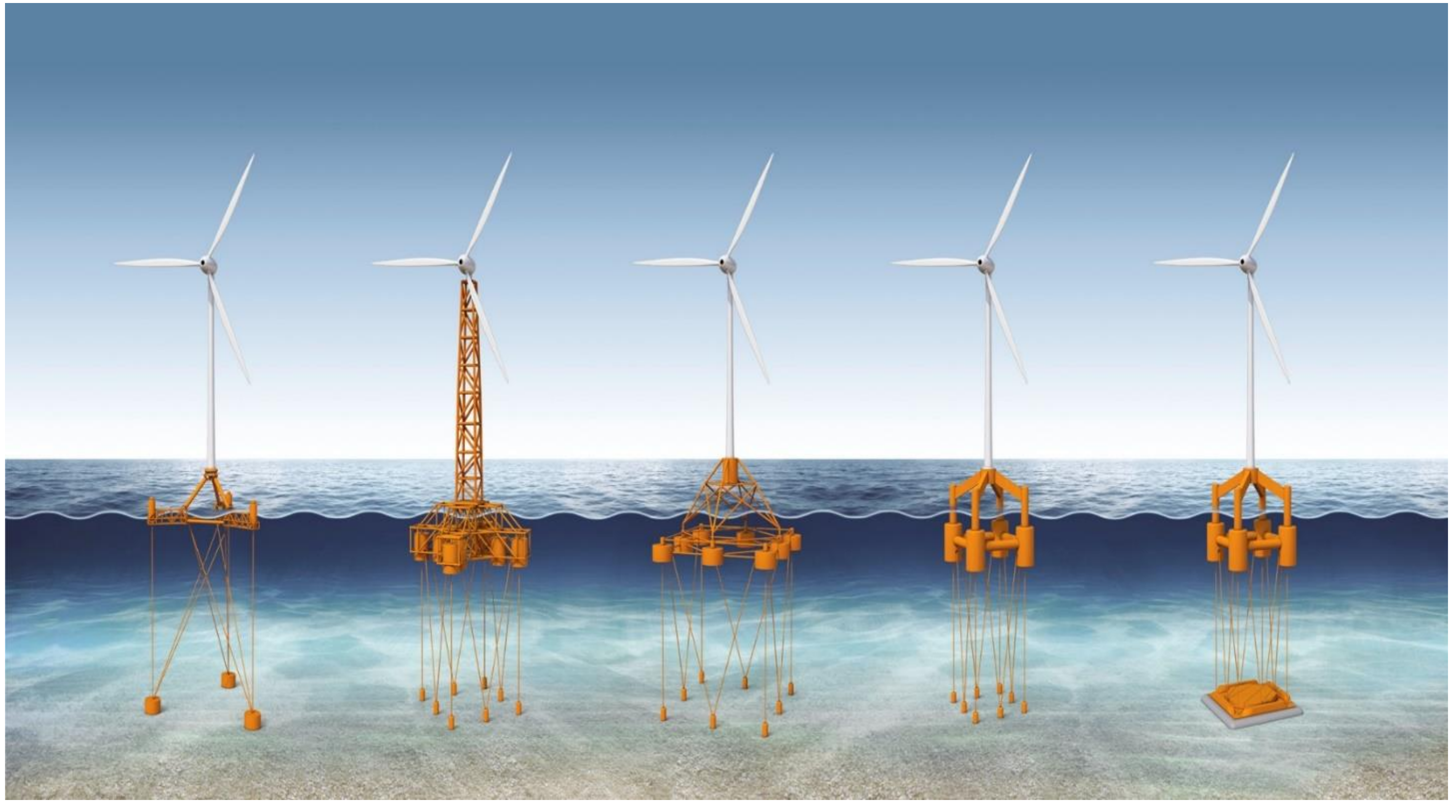

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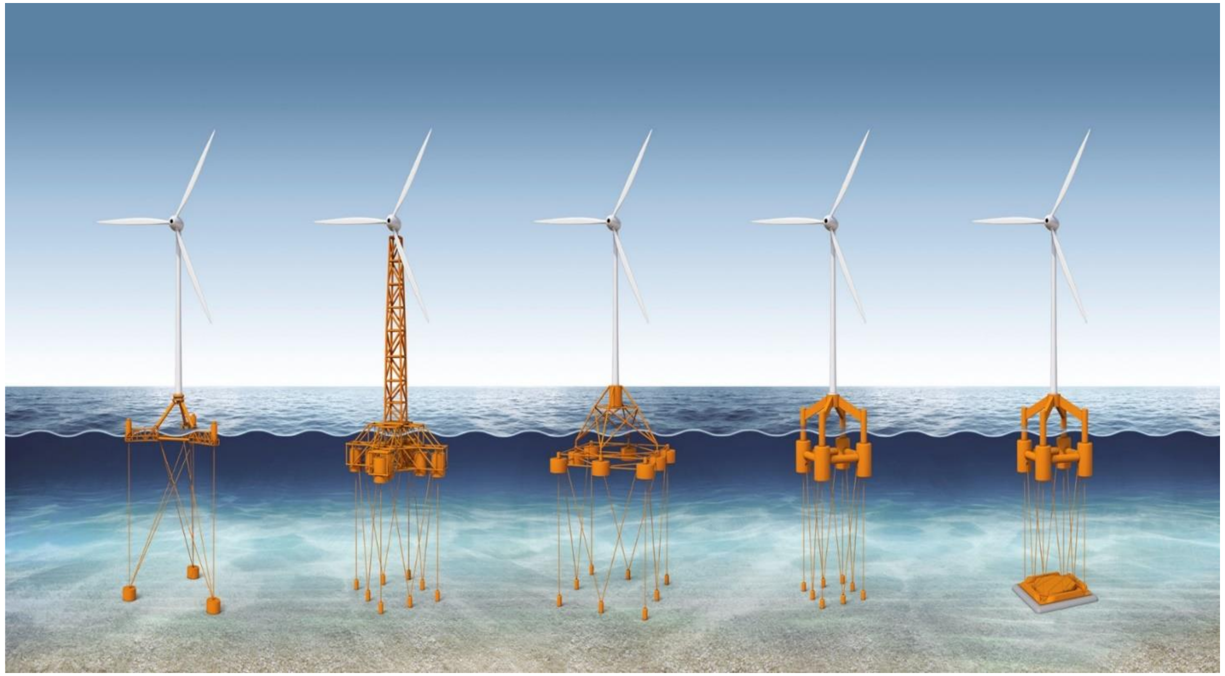
The GICON-TLP

- Steel and concrete Tension Leg Platform



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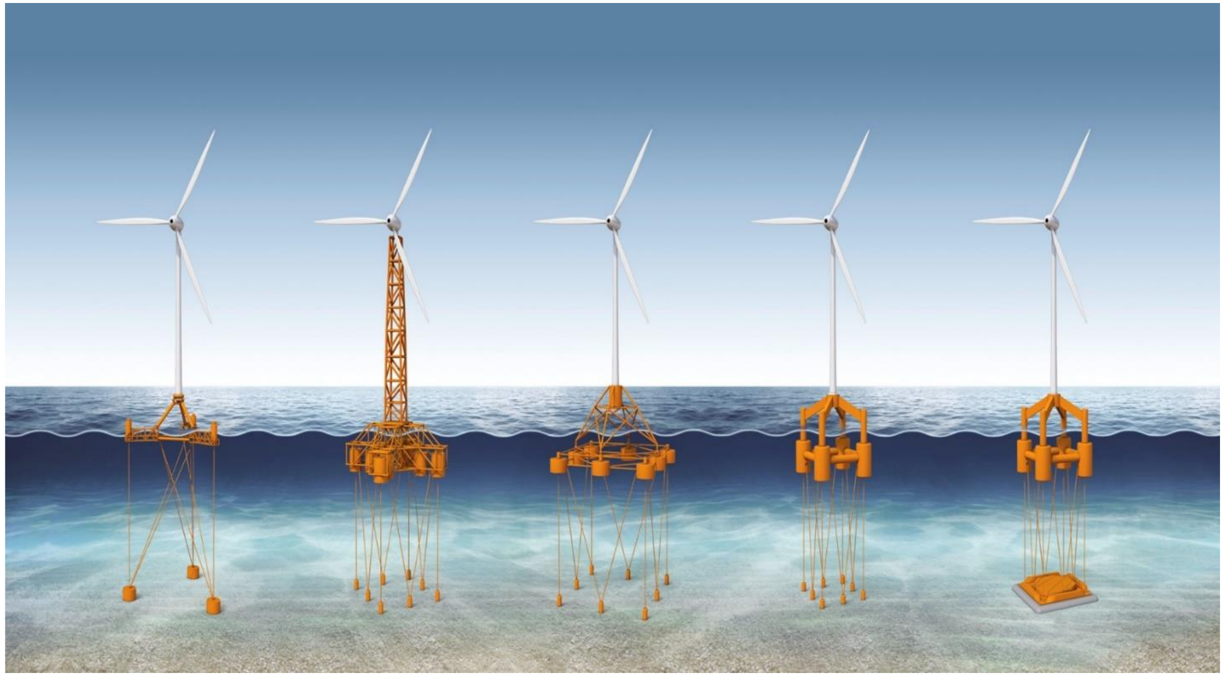
The GICON-TLP

- Steel and concrete Tension Leg Platform
- Simple manufacturing and installation process
  - 4 buoyancy bodies
  - diagonal, vertical and horizontal pipes



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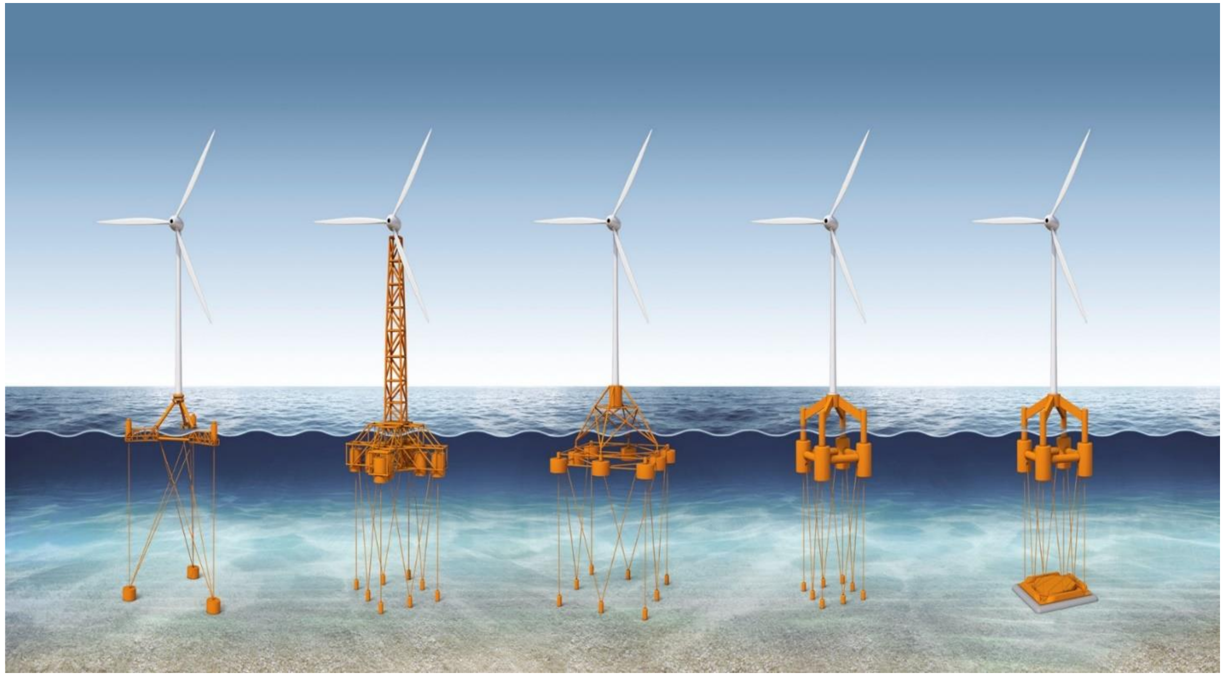

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The GICON-TLP

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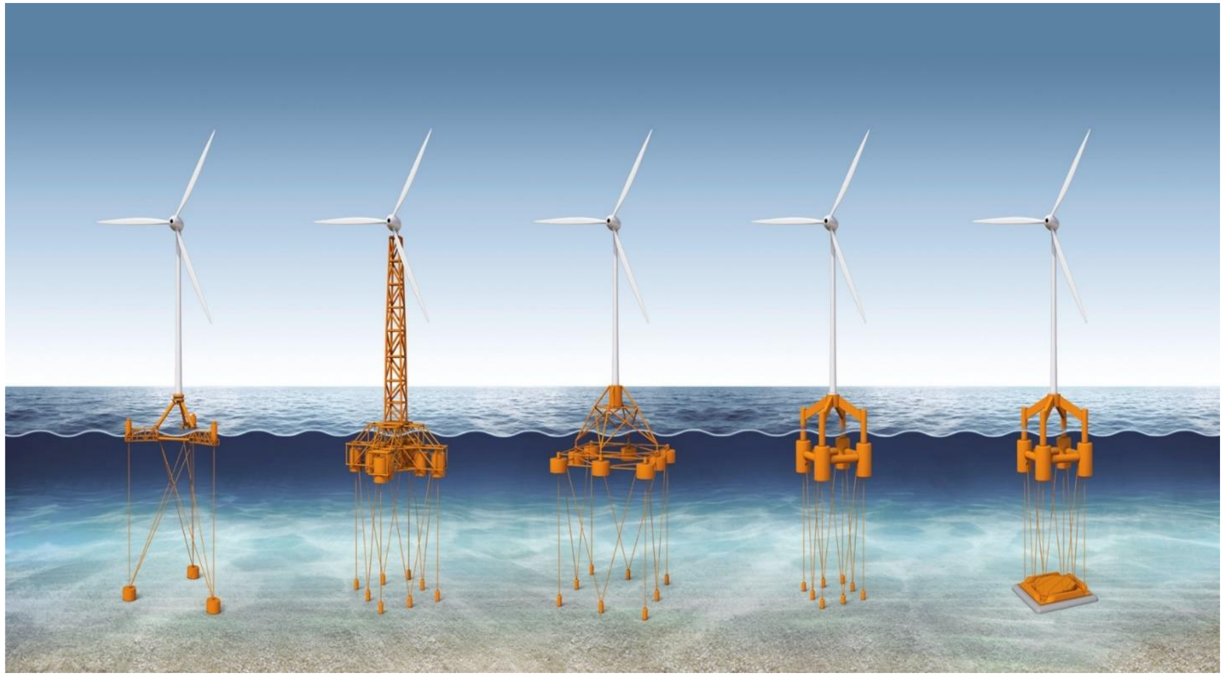
- Numerical and experimental analysis
- Optimization framework for the design of the Universal Buoyancy Body (UBB) [3]



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Design Optimization Framework

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- Numerical model: frequency domain dynamic model

Numerical model

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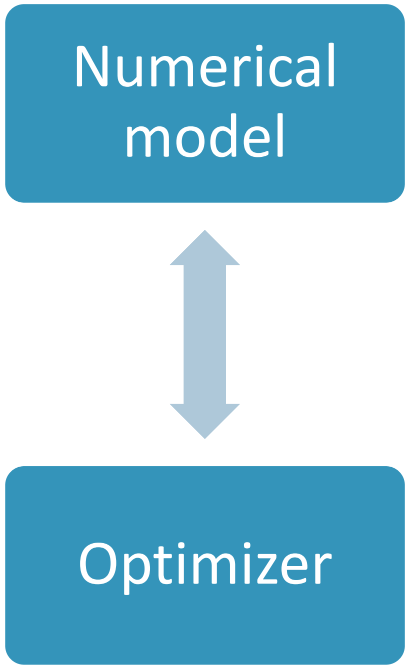

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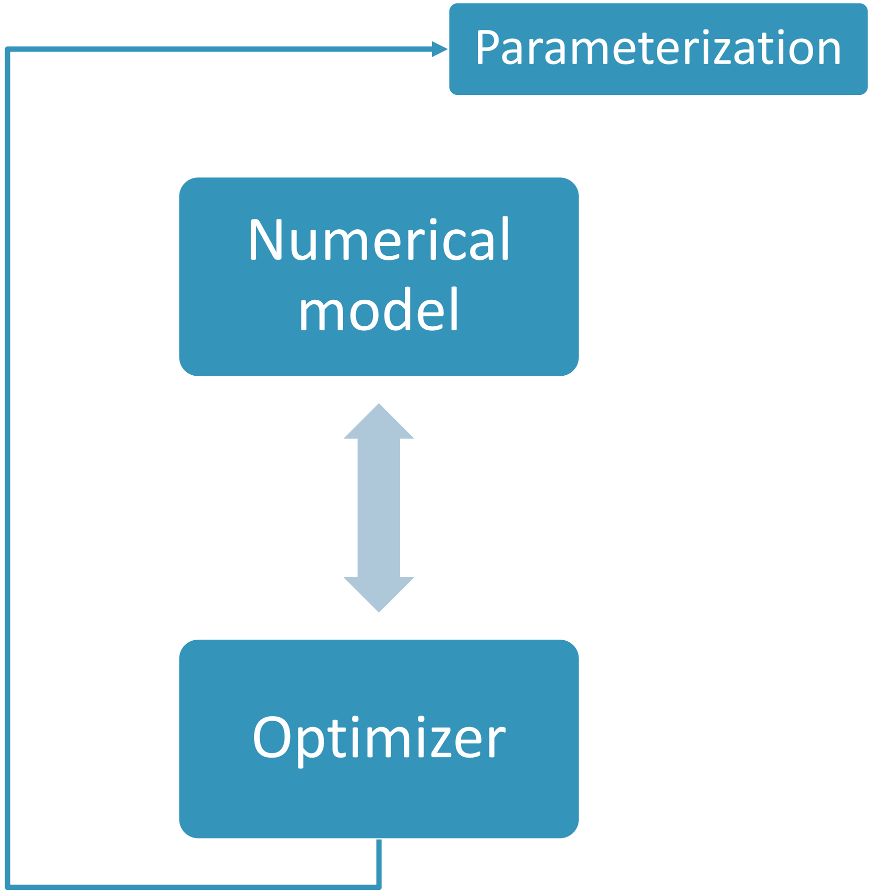
- ❑ Design parameterization: geometrical



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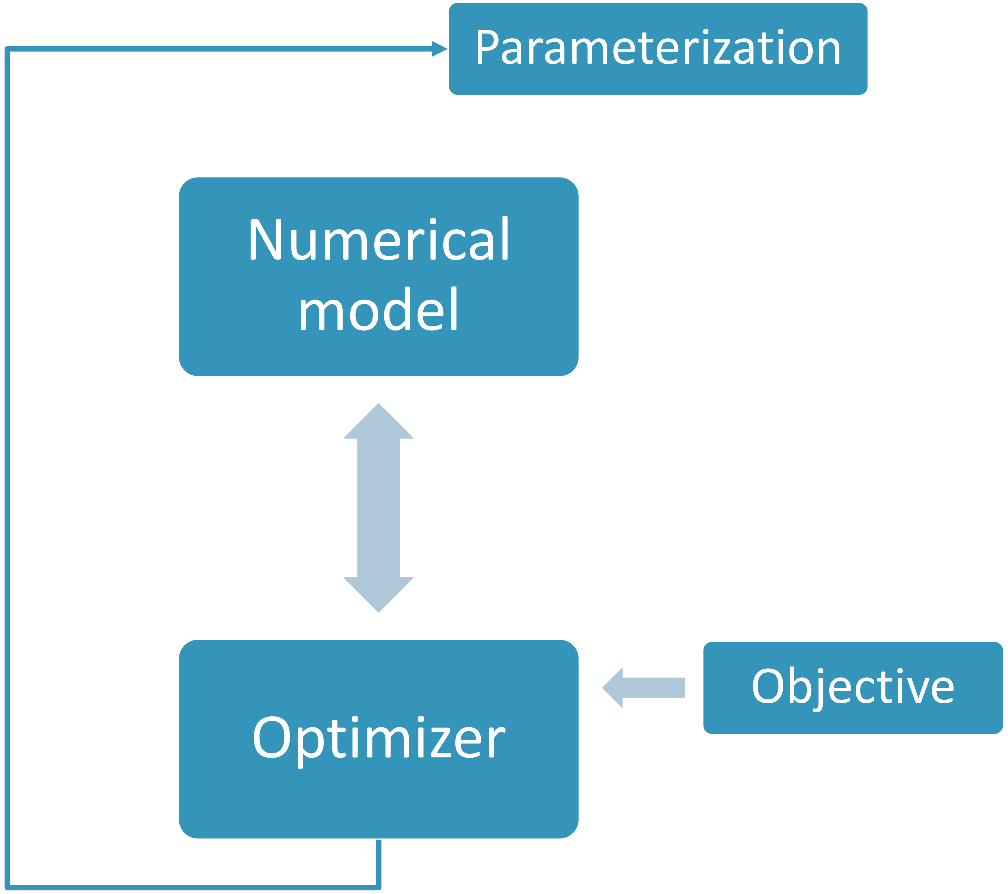
- ❑Objective: minimize the substructure's mass/cost



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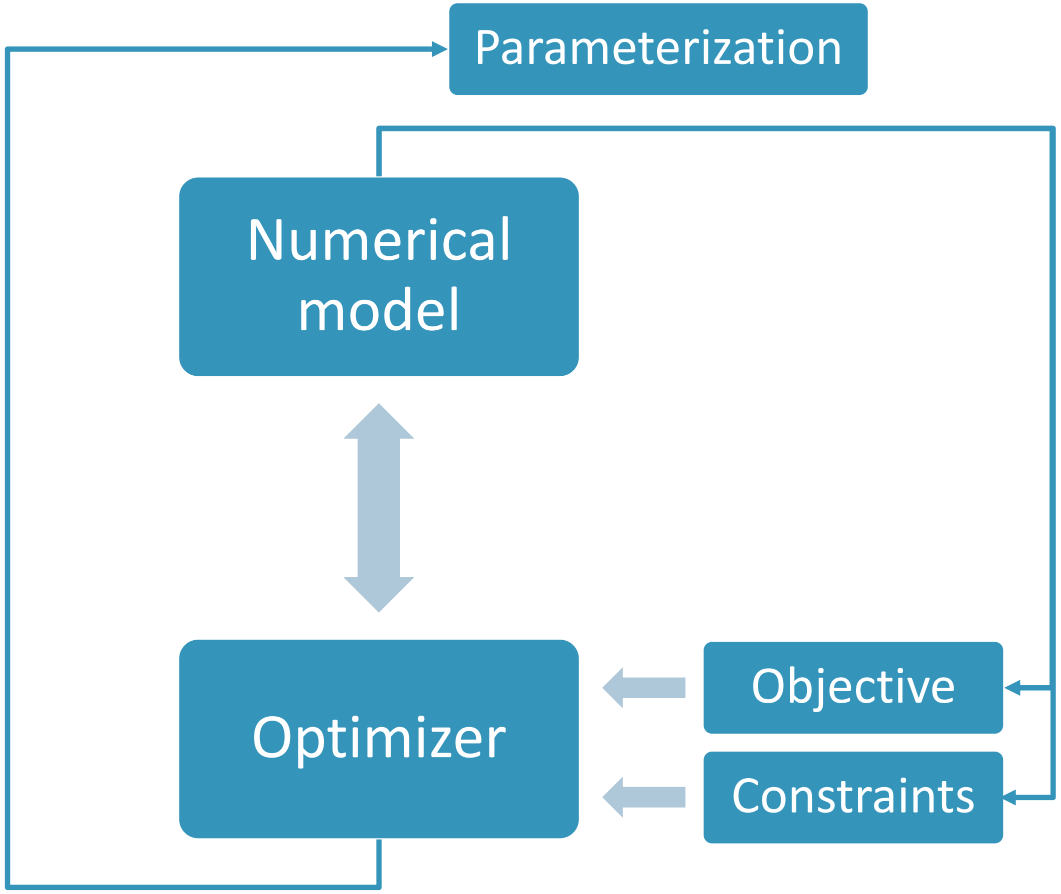
- Objective: minimize the substructure's mass/cost
- Constraints: system's dynamic response



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Numerical model

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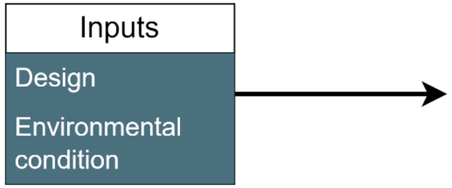
- ❑GICON-TLP with IEA 15-MW wind turbine



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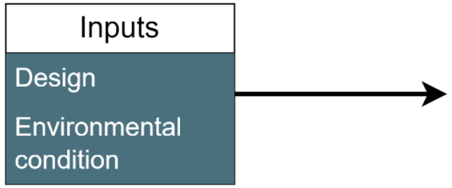

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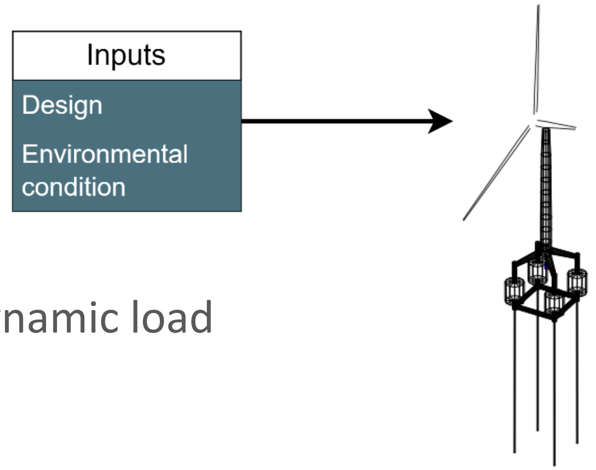

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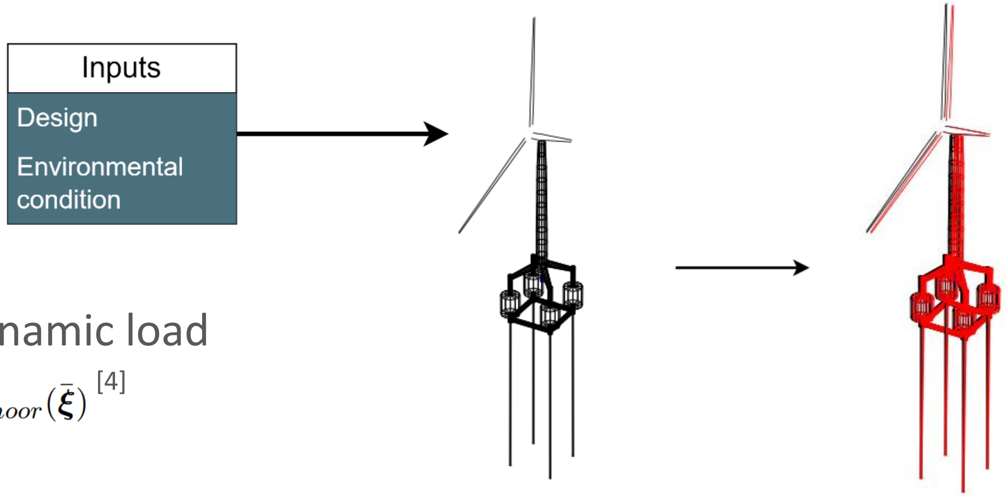

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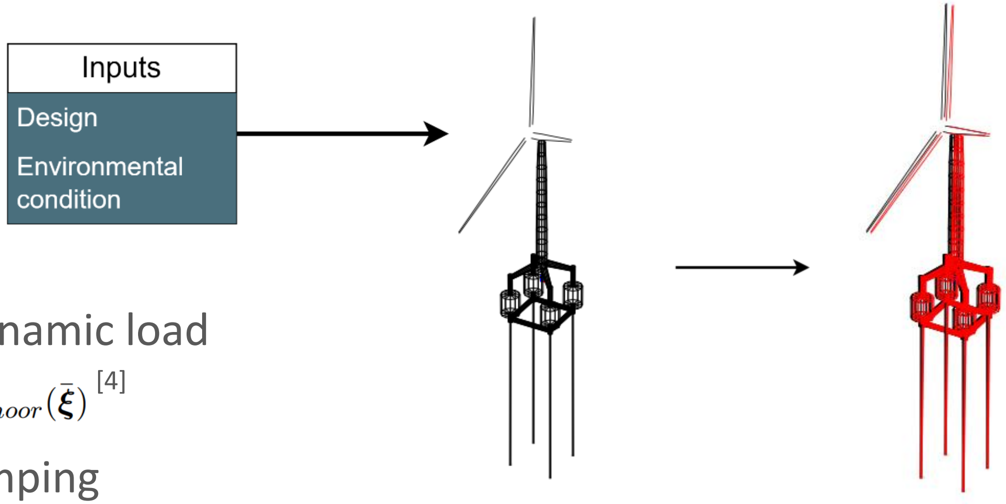

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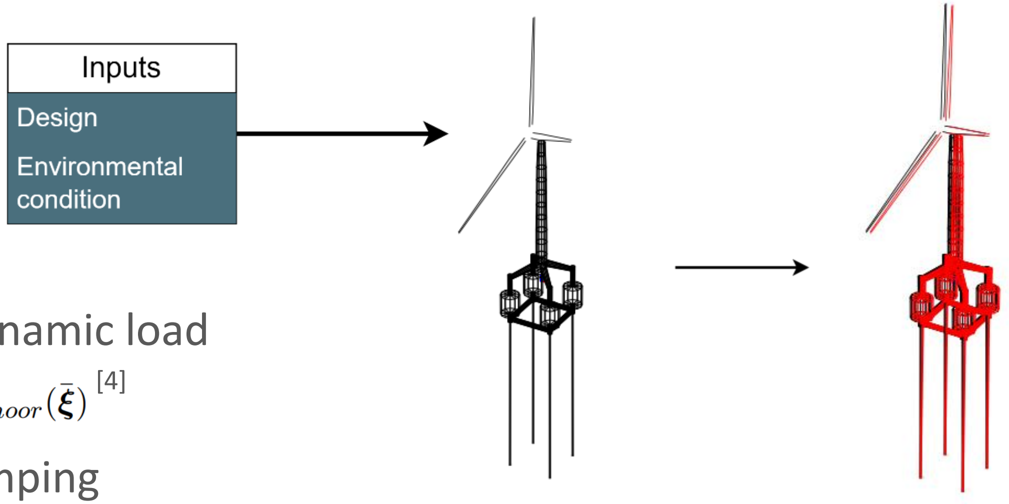

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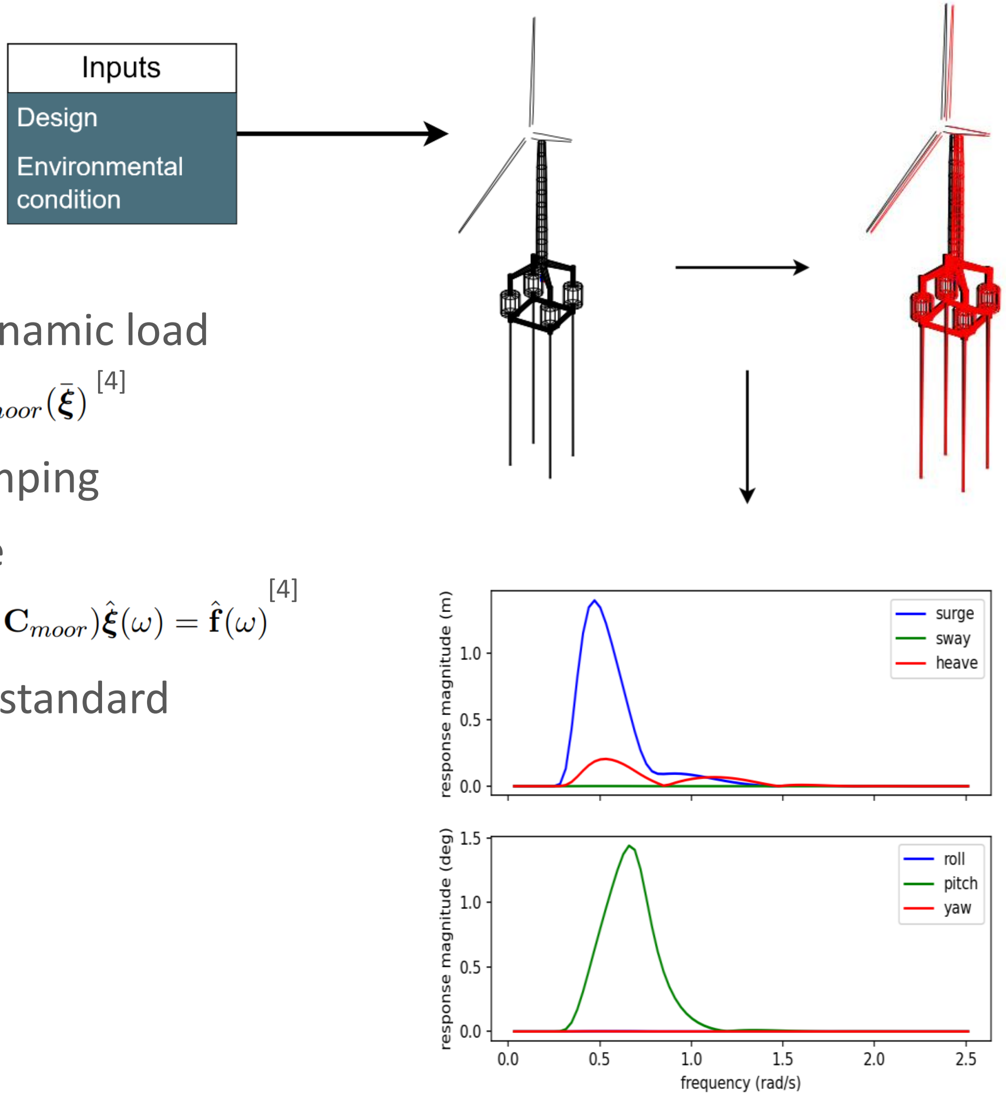
  - get system's mean offset and extreme values from standard deviations (RMS) of the response spectra.



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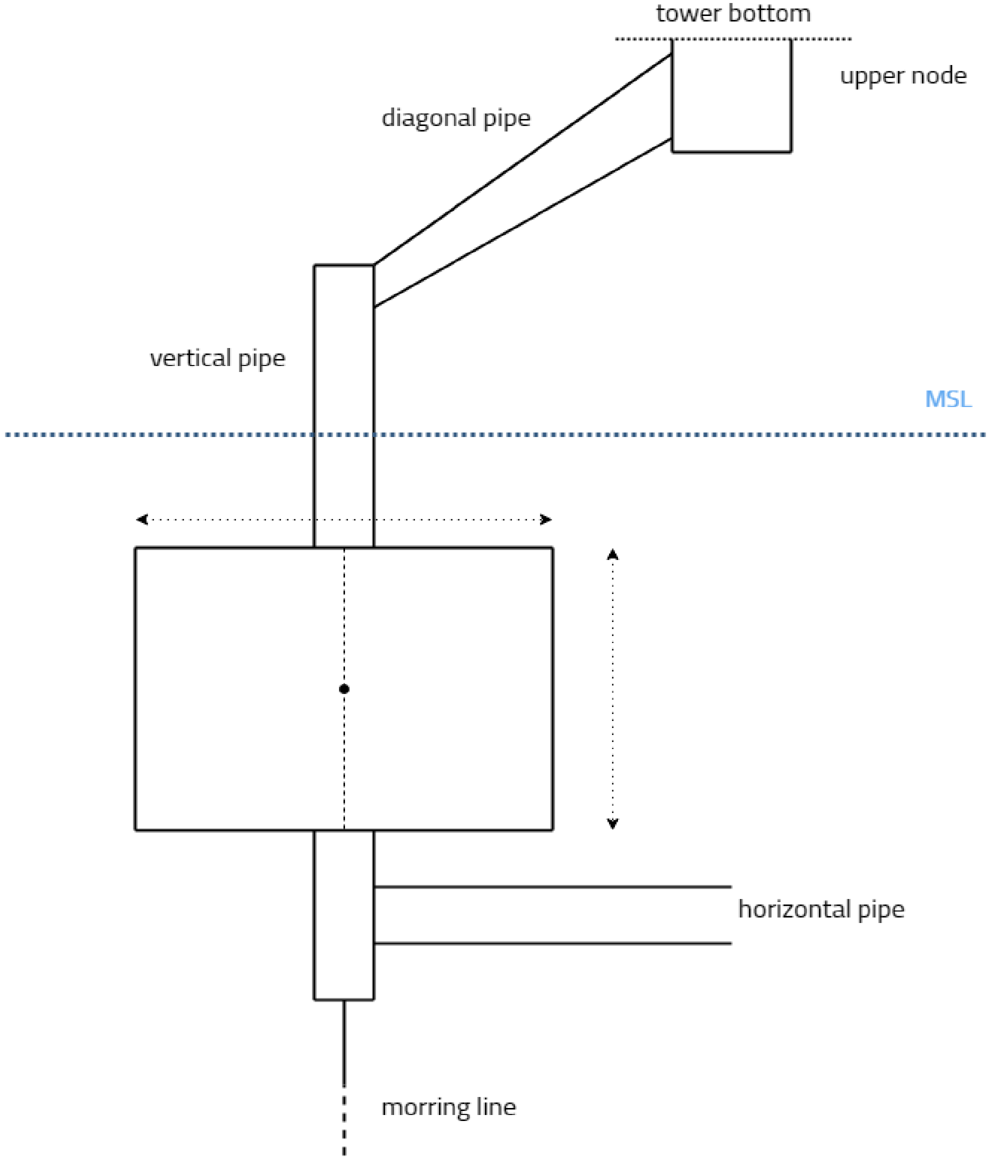

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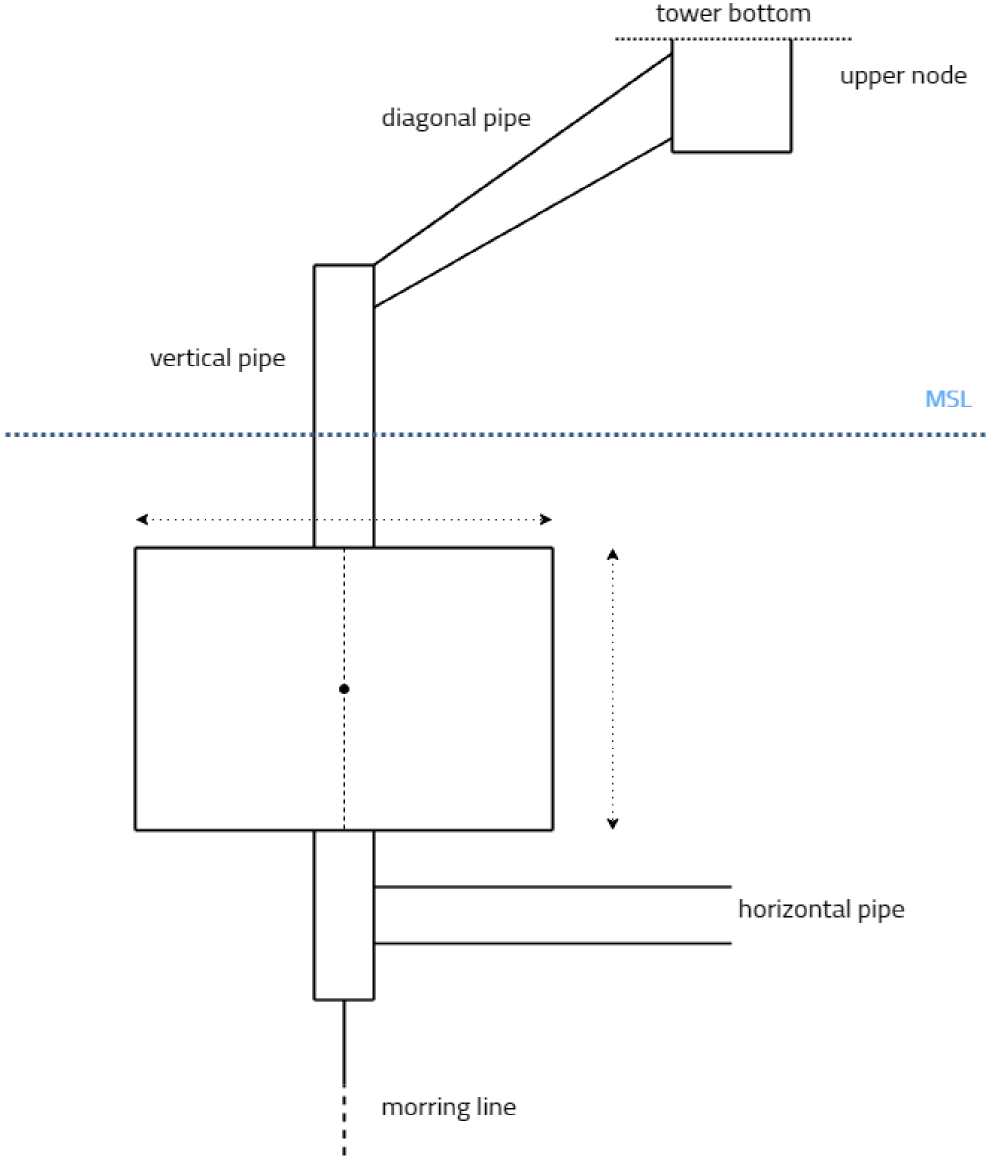
Design parameterization

- IEA 15MW wind turbine:[5]
  - $D_{rot} \sim 240\ m$, $RNA_{mass} \sim 1000$ t
  - $H_{hub} \sim 150$ m, $L_{tower} \sim 120$ m



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❑ Mooring lines:

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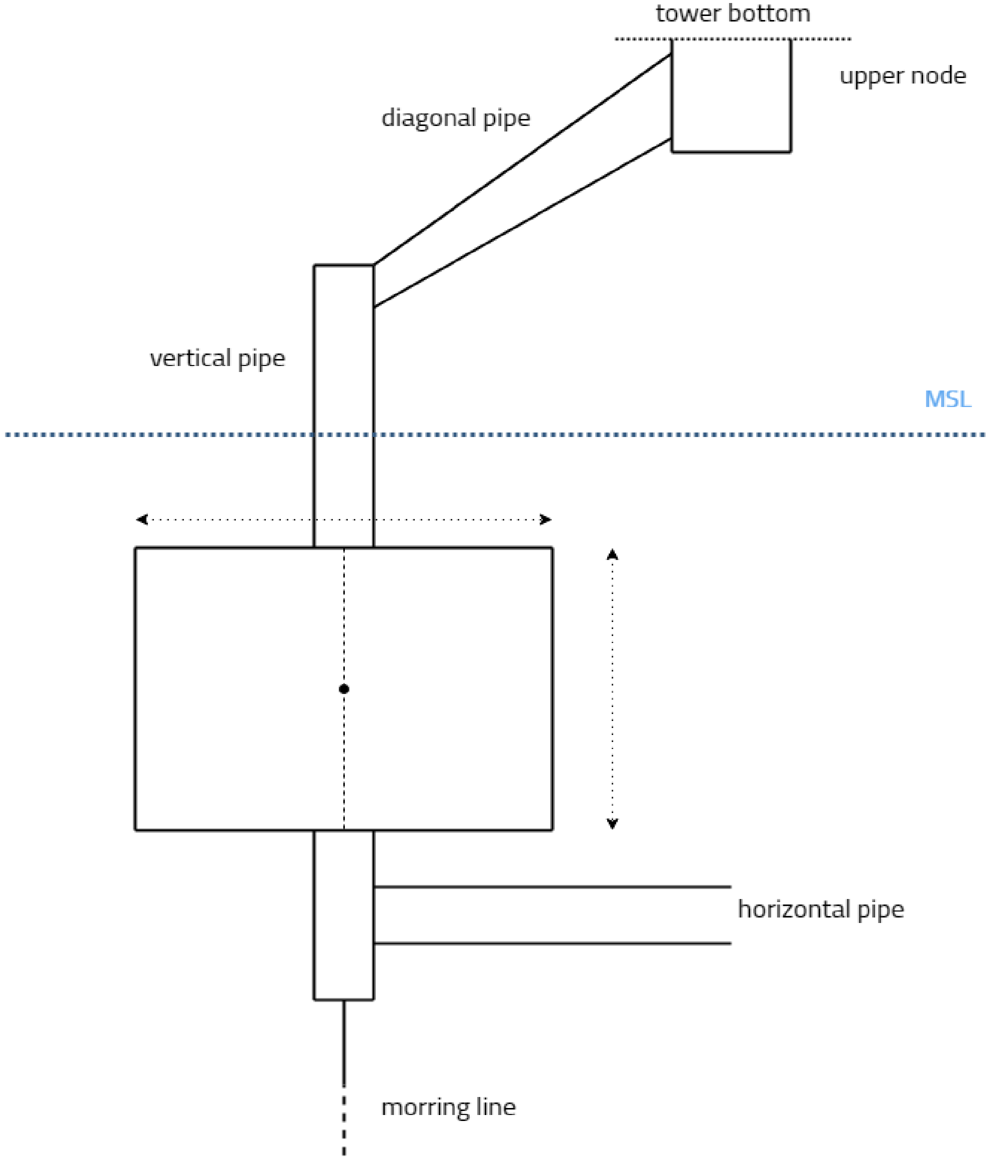
- $E_A \sim 2\ .\ 10^9$ N, $L \sim 150\ m$



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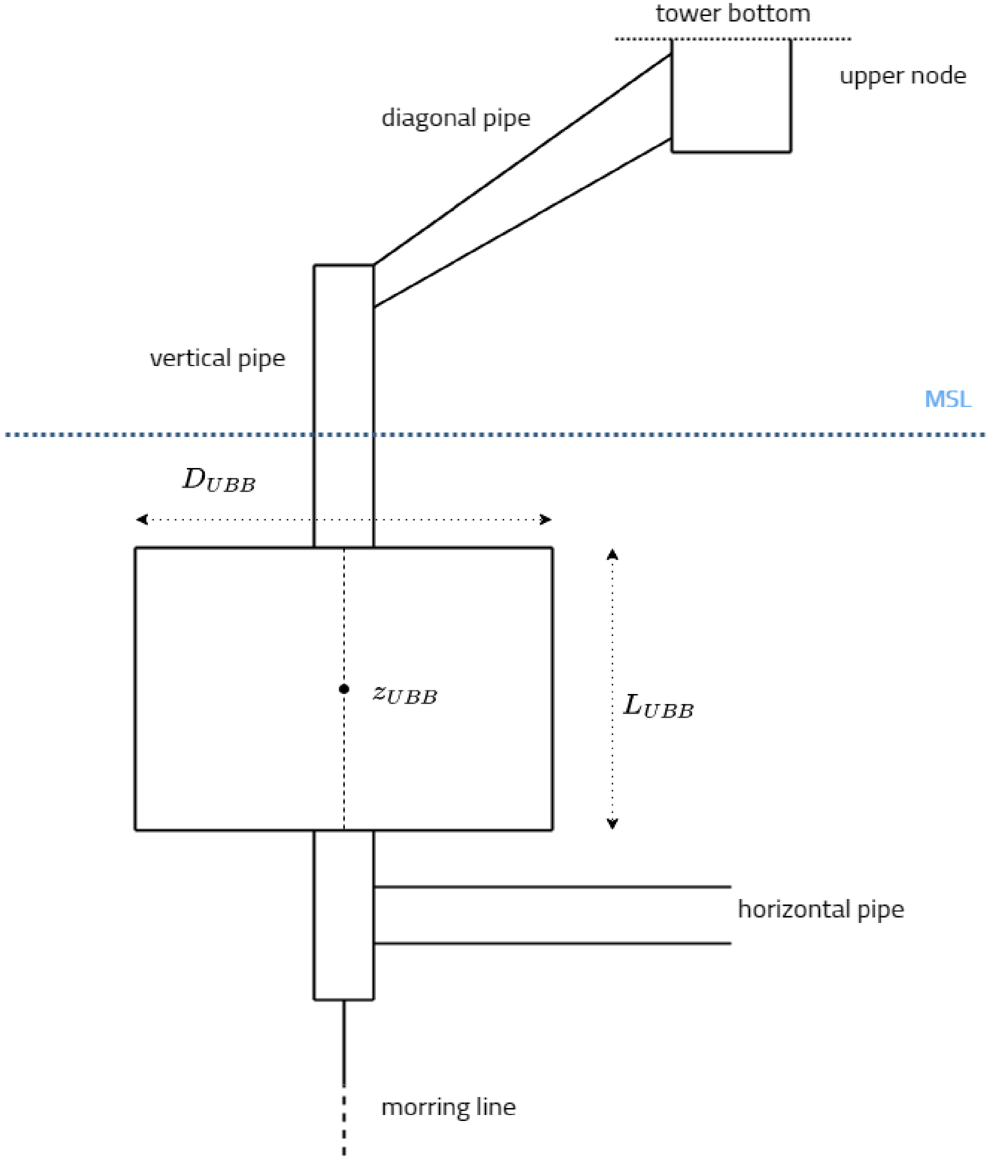
  - $E_A \sim 2\ .\ 10^9$ N, $L \sim 150\ m$
- Design variables:
  - length L_{UBB} and diameter D_{UBB}
  - center z_{UBB}



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Optimizer: Genetic Algorithm

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- Fitness: -1 * $M_{substructure}$

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- Constraint handling technic: efficient penalty function
- Fitness scaling and addition operation: [6]
  - global and Local optima
  - fewer fitness function evaluation

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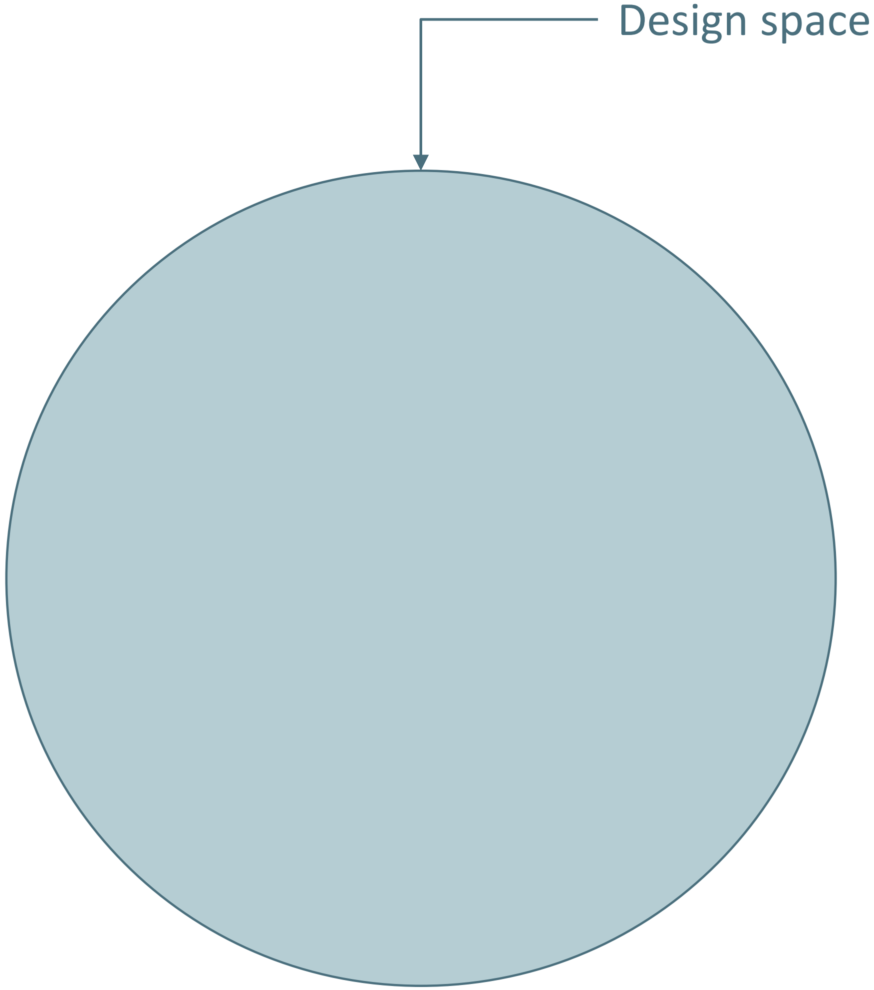

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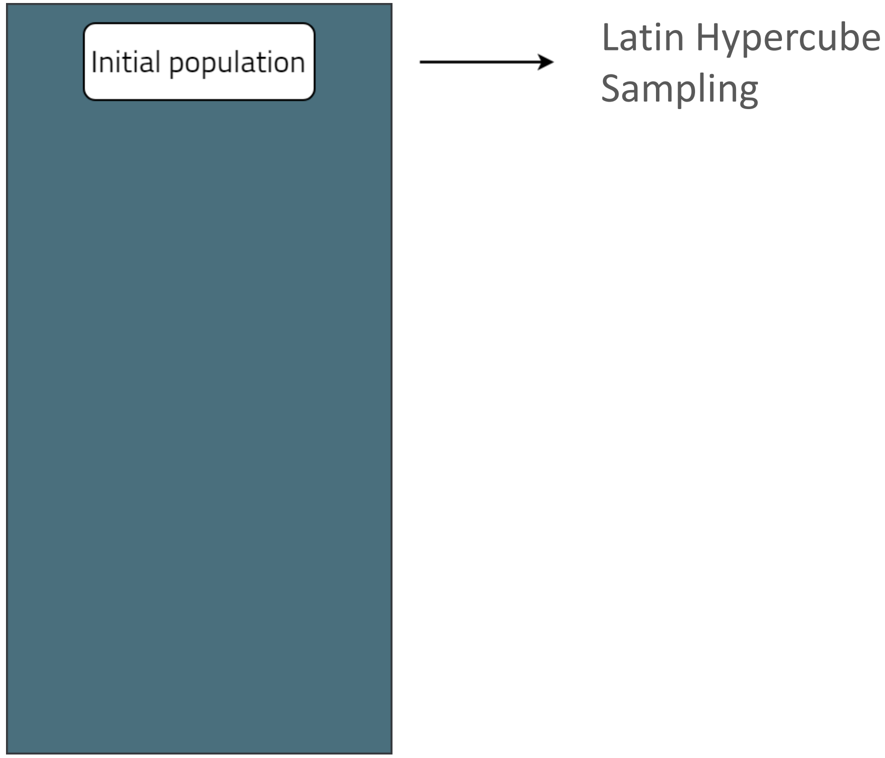

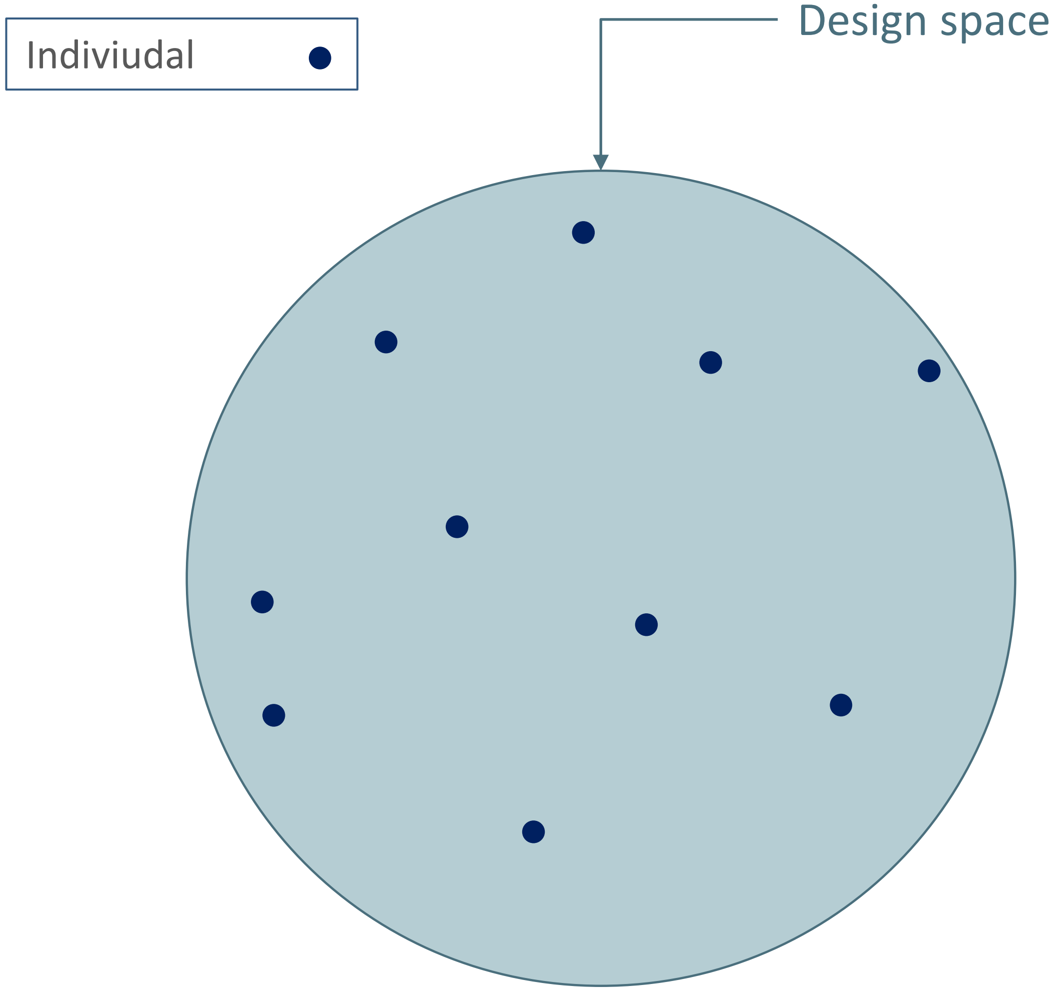

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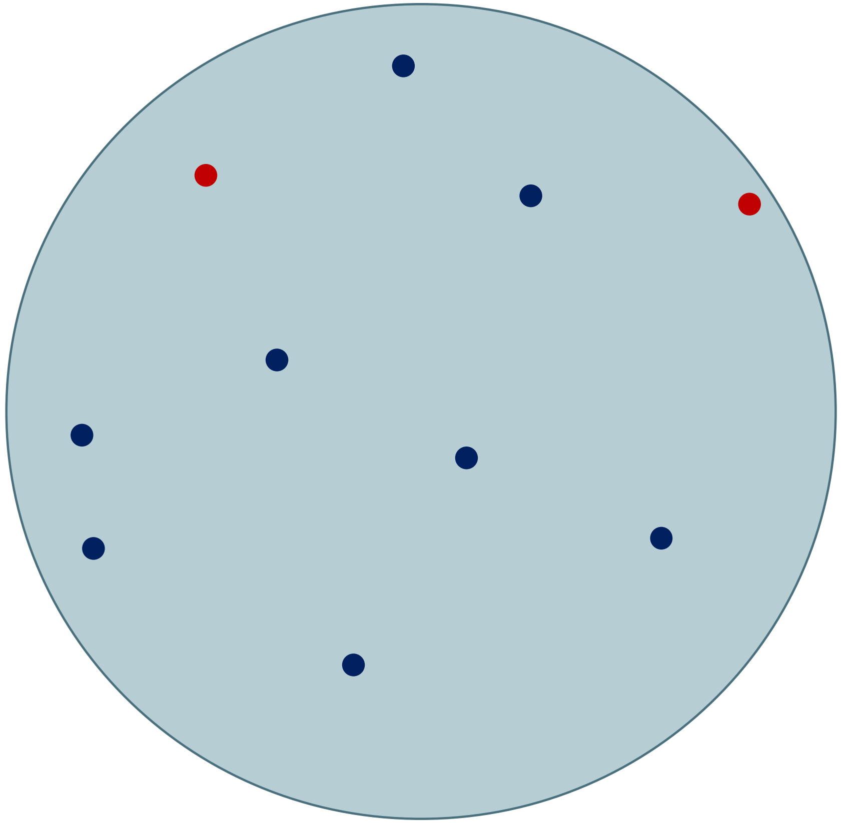
Indiviudal ●
Optima ●

→ Latin Hypercube Sampling

→ scale fitness to population optima



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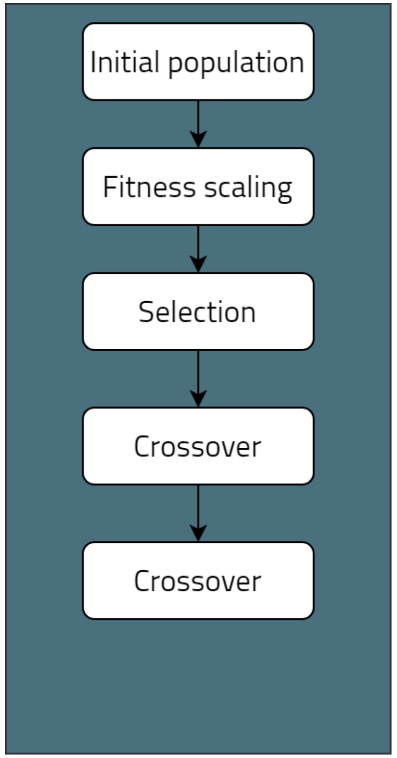

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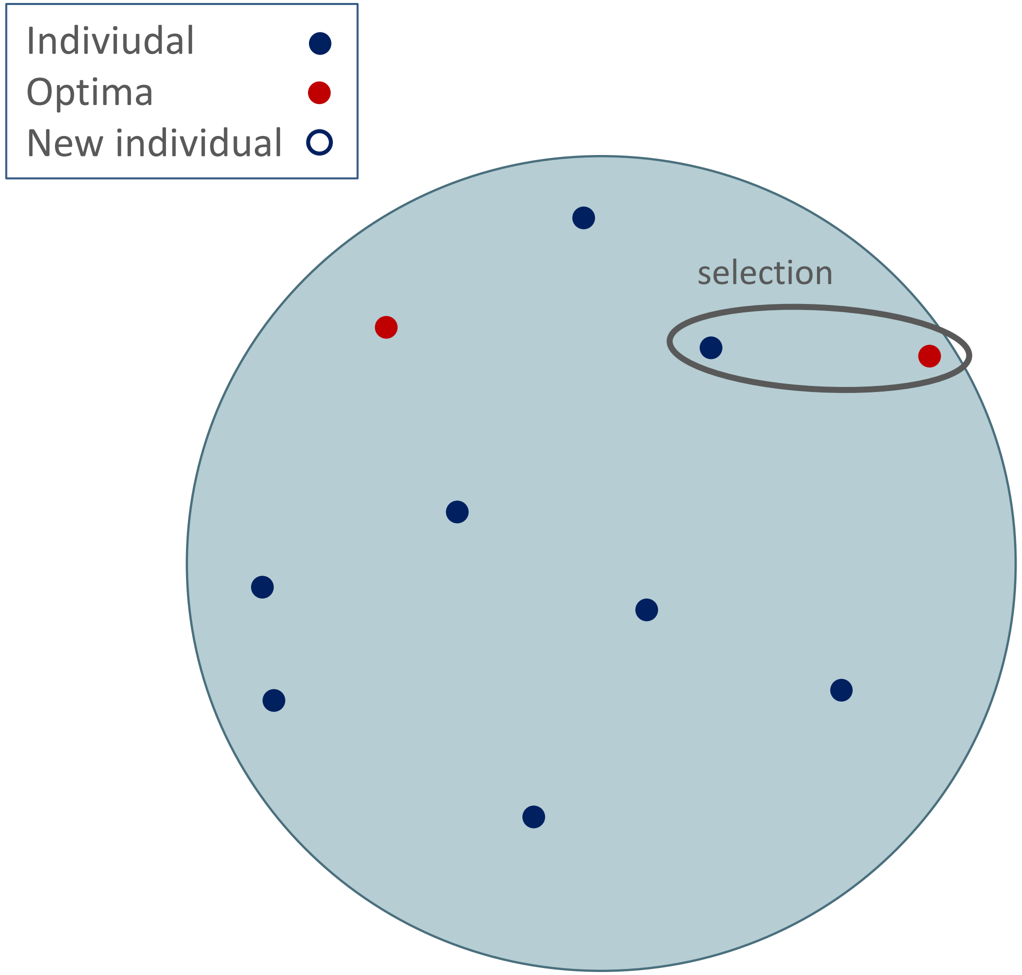

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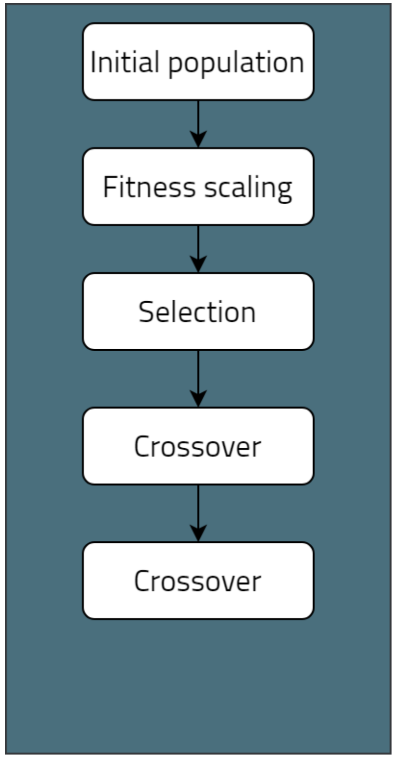

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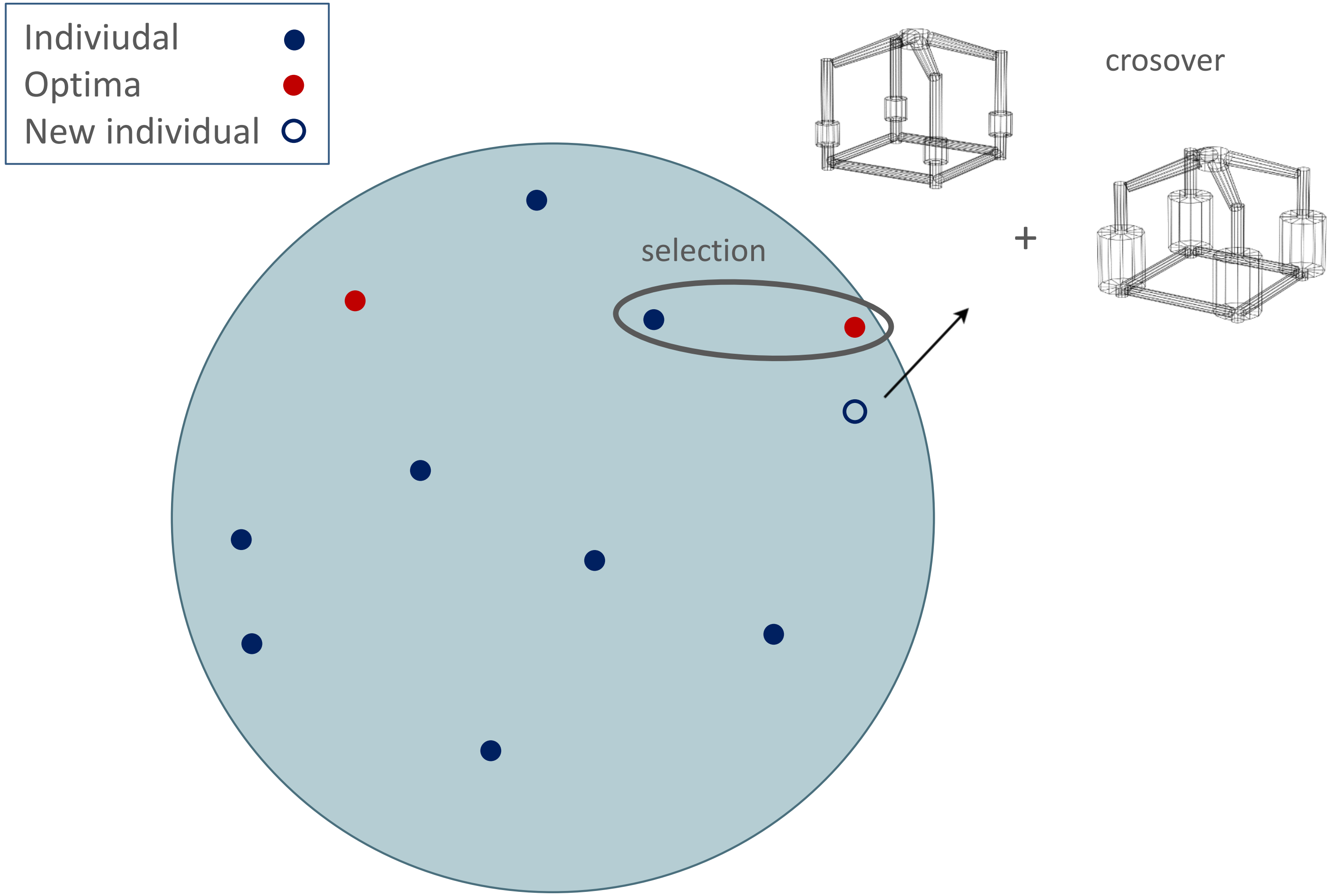

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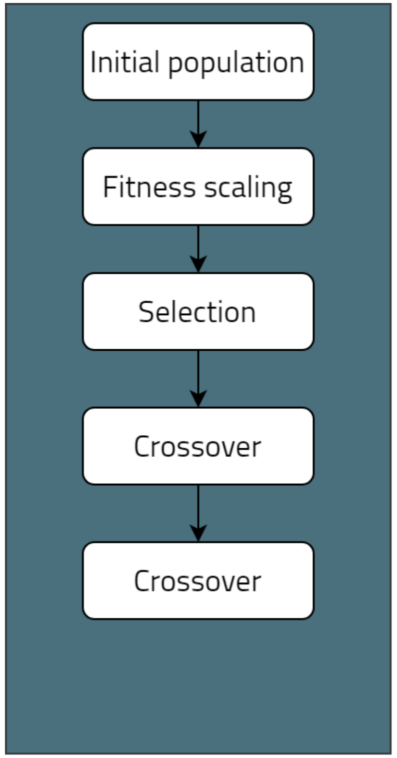

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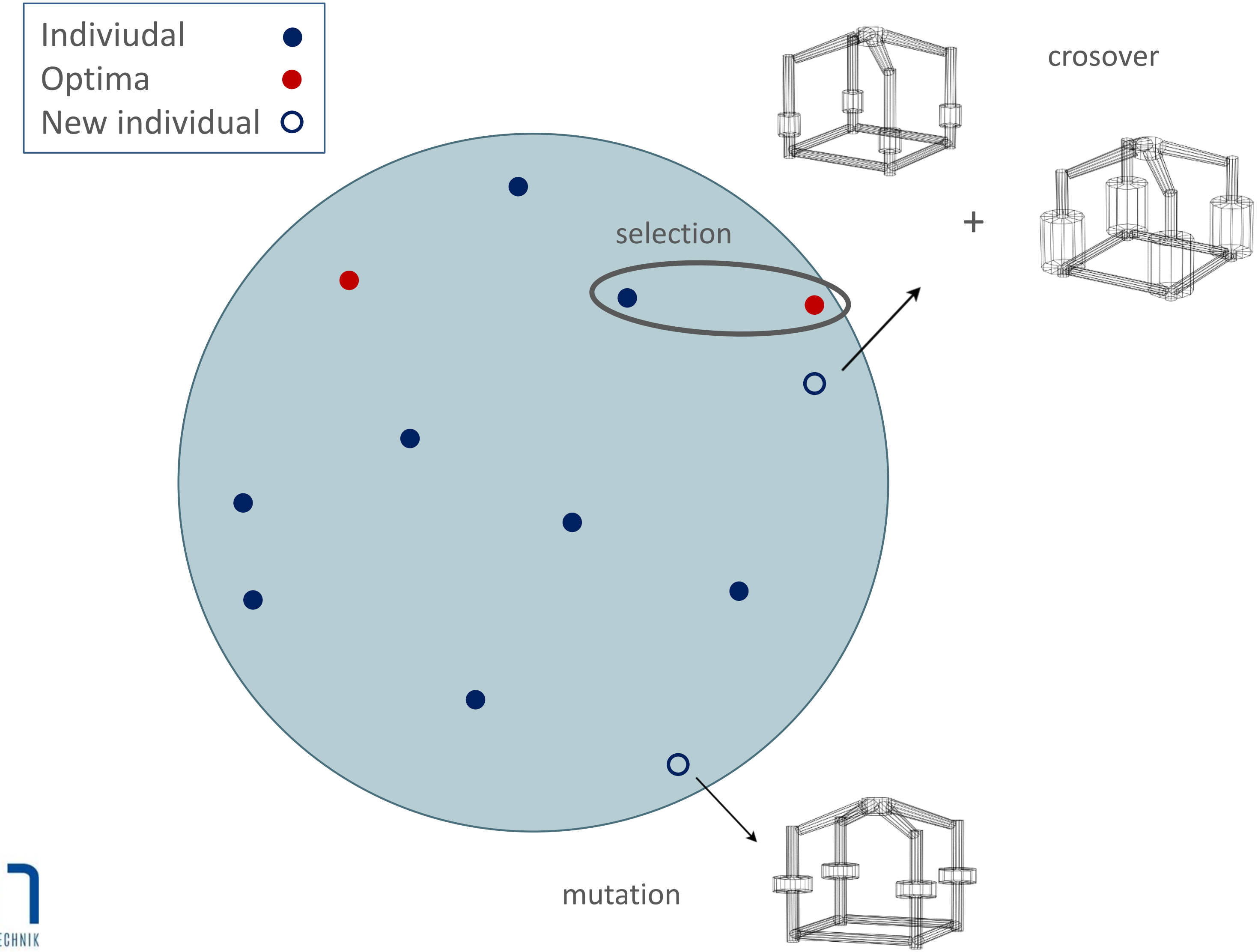

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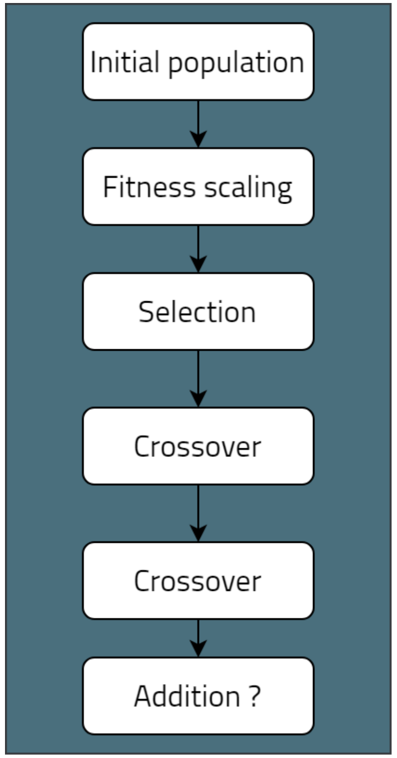
Optimizer: Genetic Algorithm



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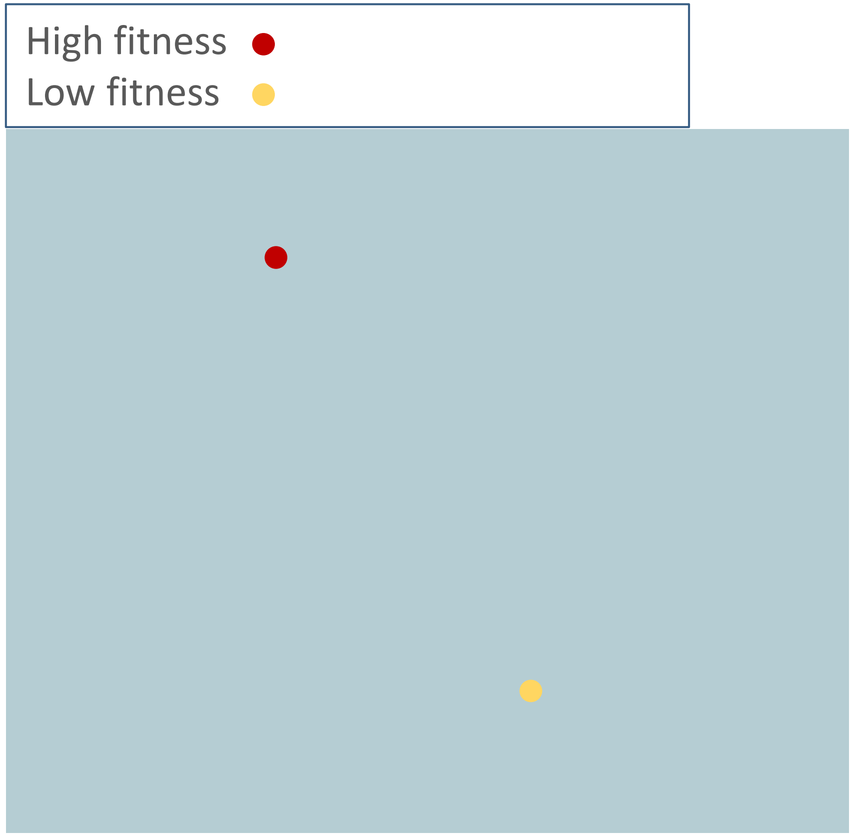
→ normal genetic operations

→ add new individuals?



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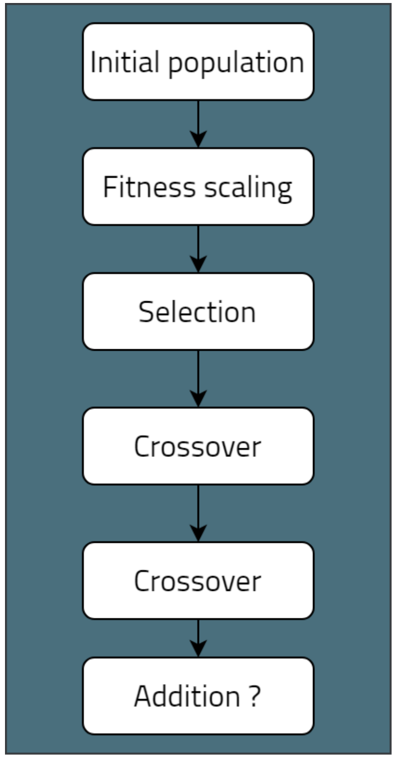

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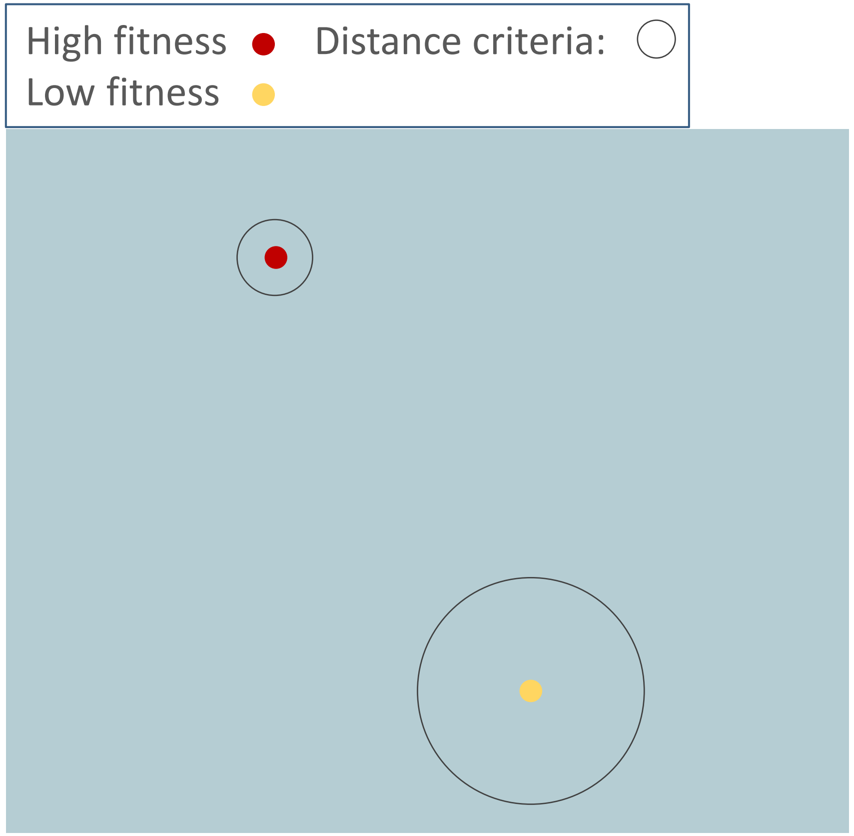

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LEHRSTUHL WINDENERGIETECHNIK

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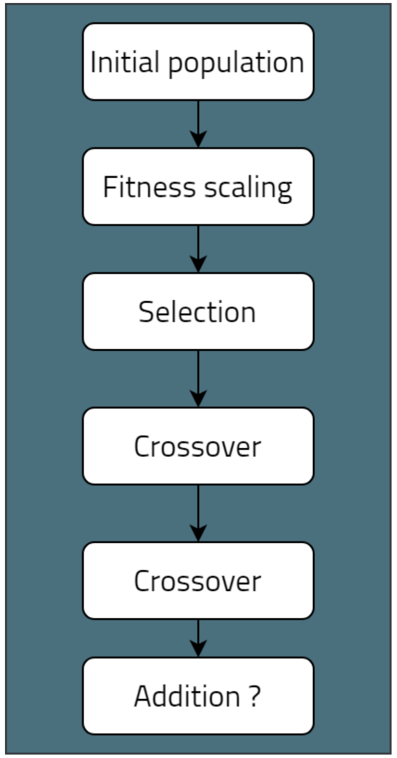

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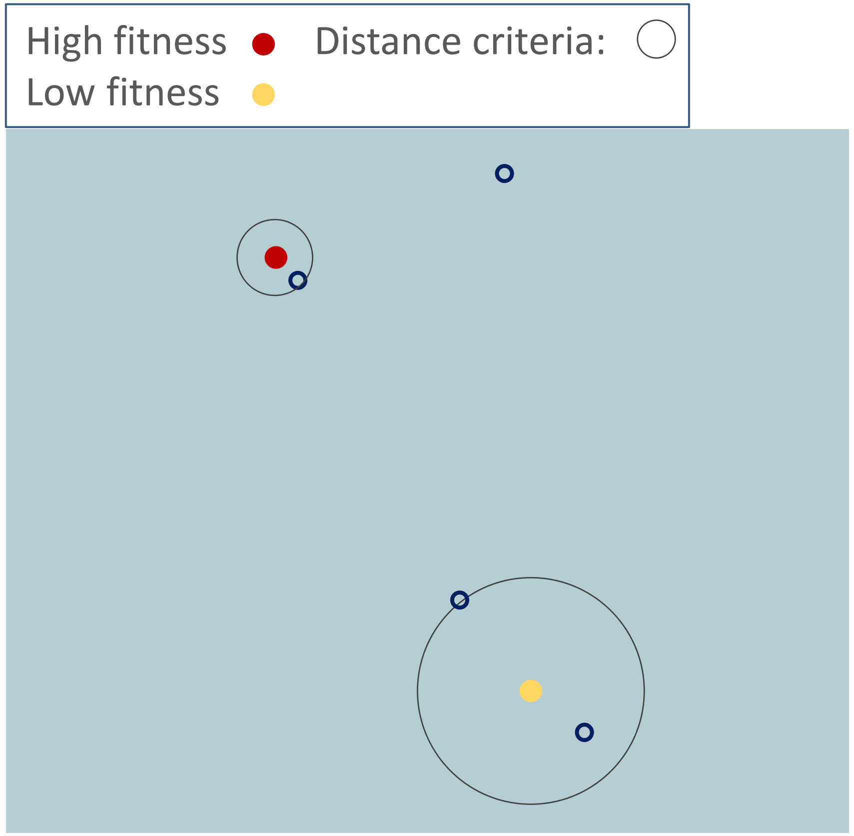

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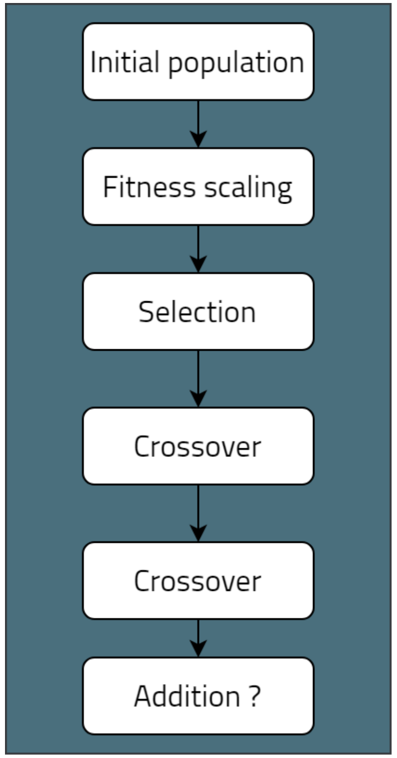

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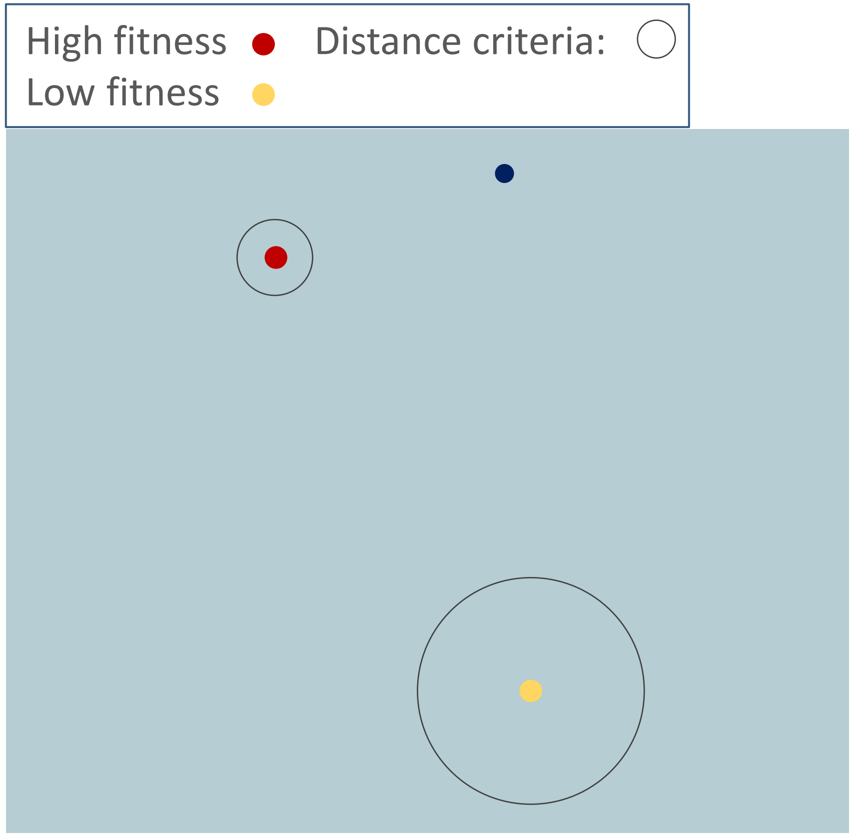

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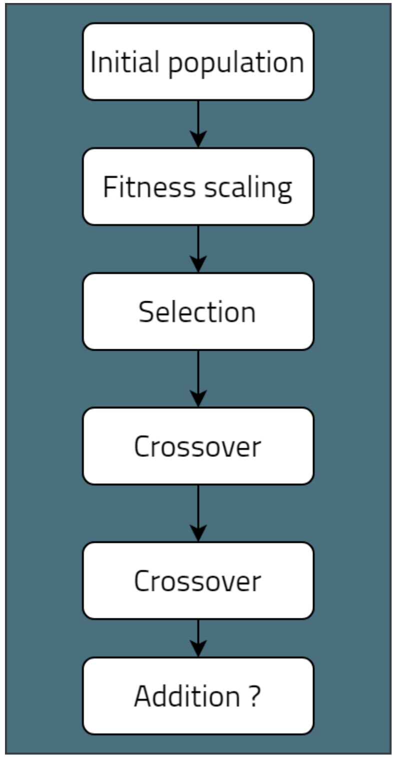

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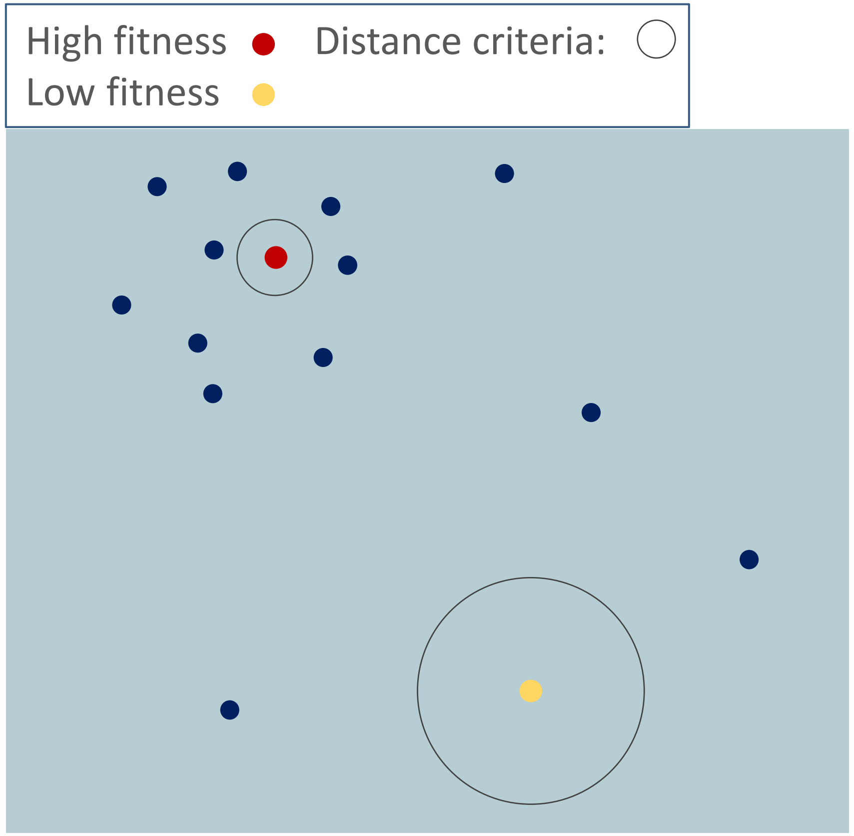

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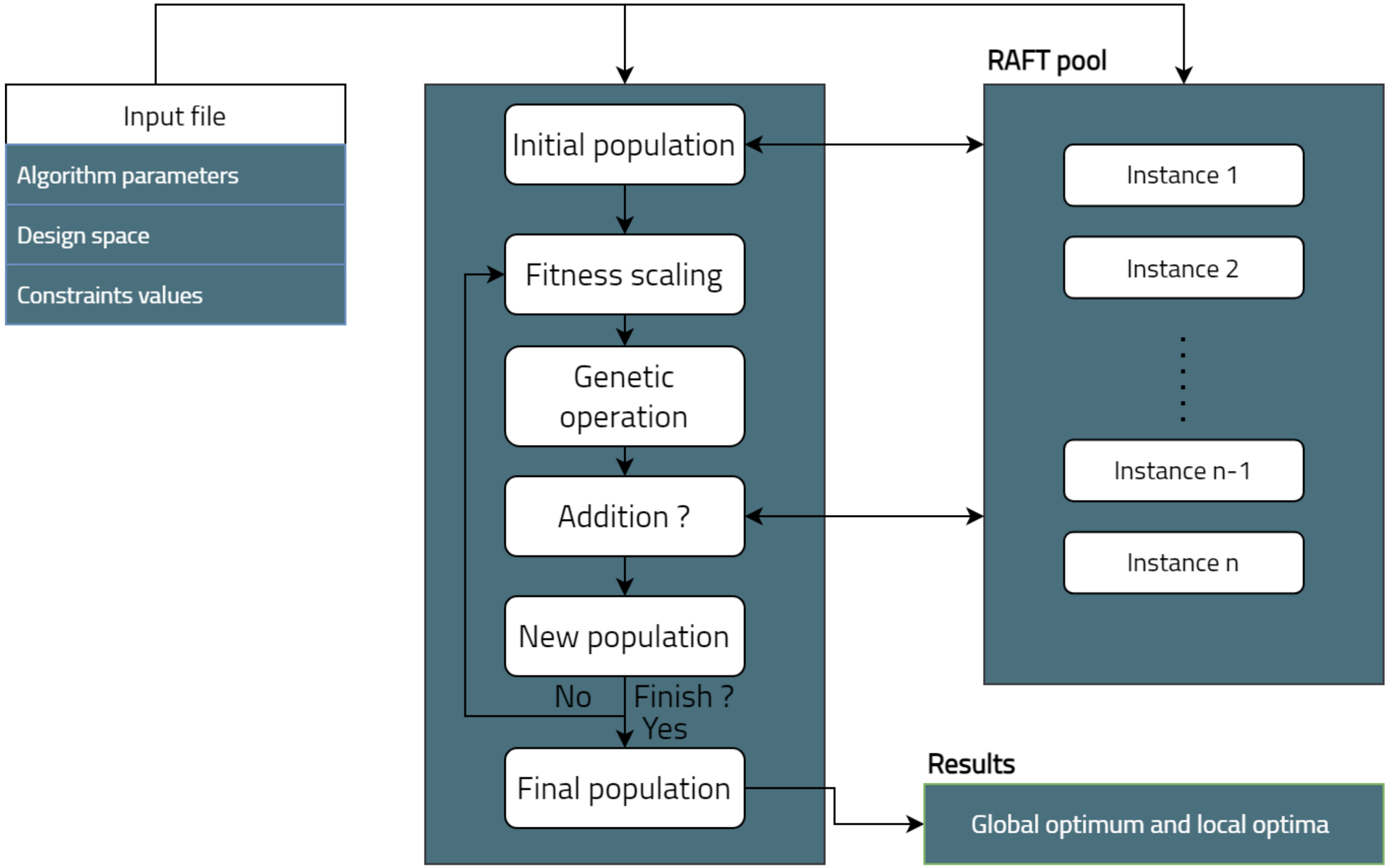
Optimization Framework



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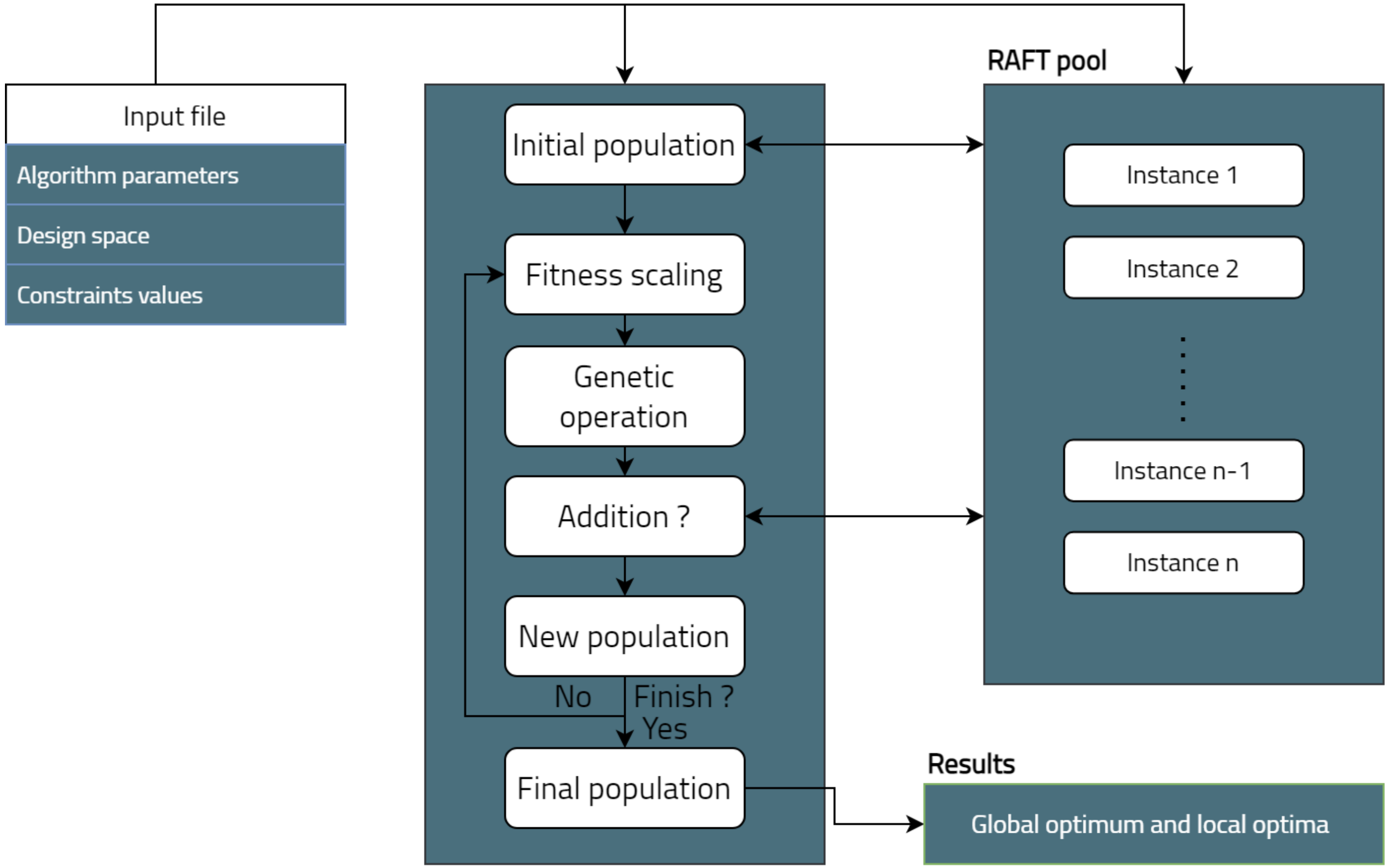
Optimization Framework

- Object Oriented (python)



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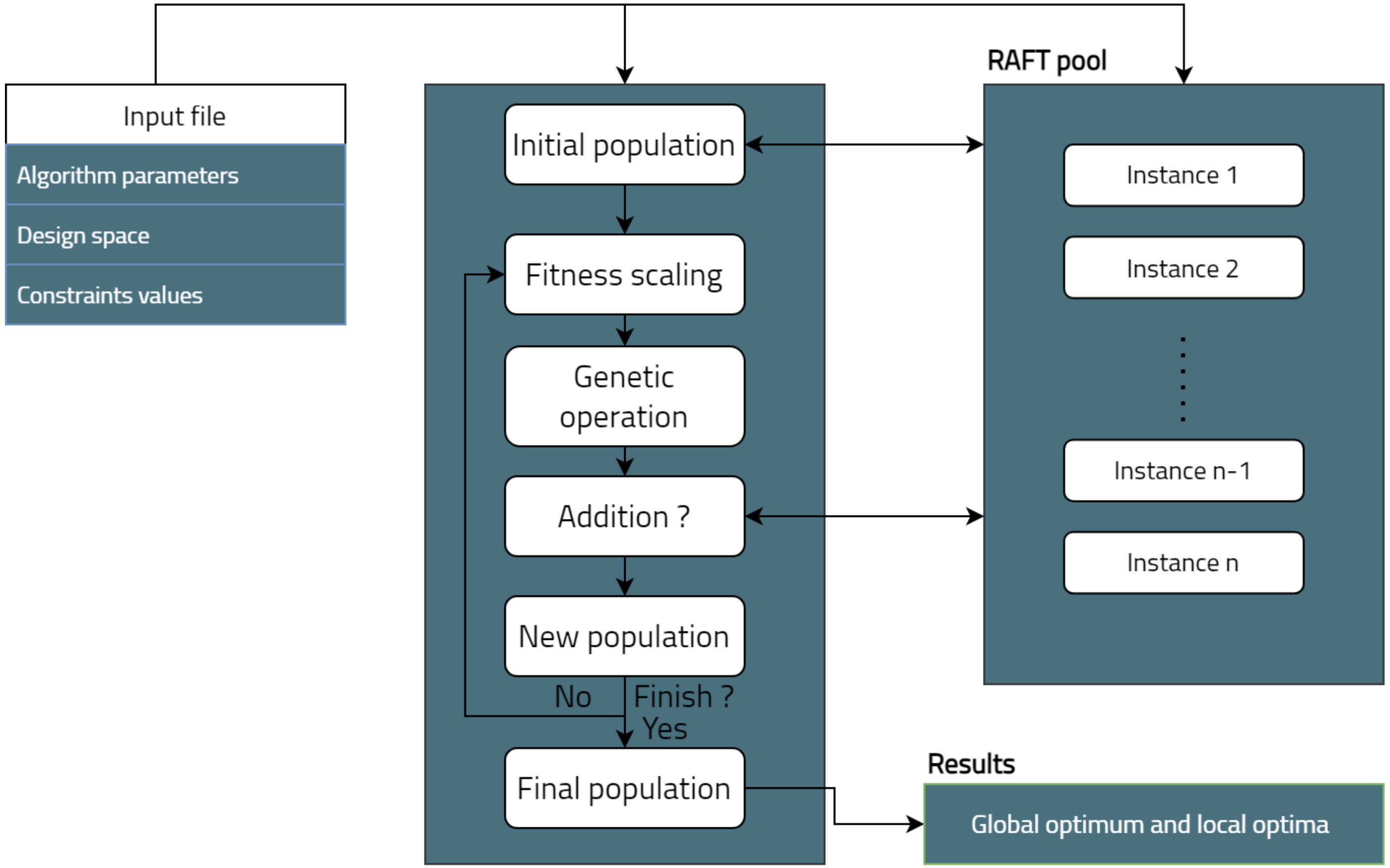
Optimization Framework

- Object Oriented (python)
- Modular approach



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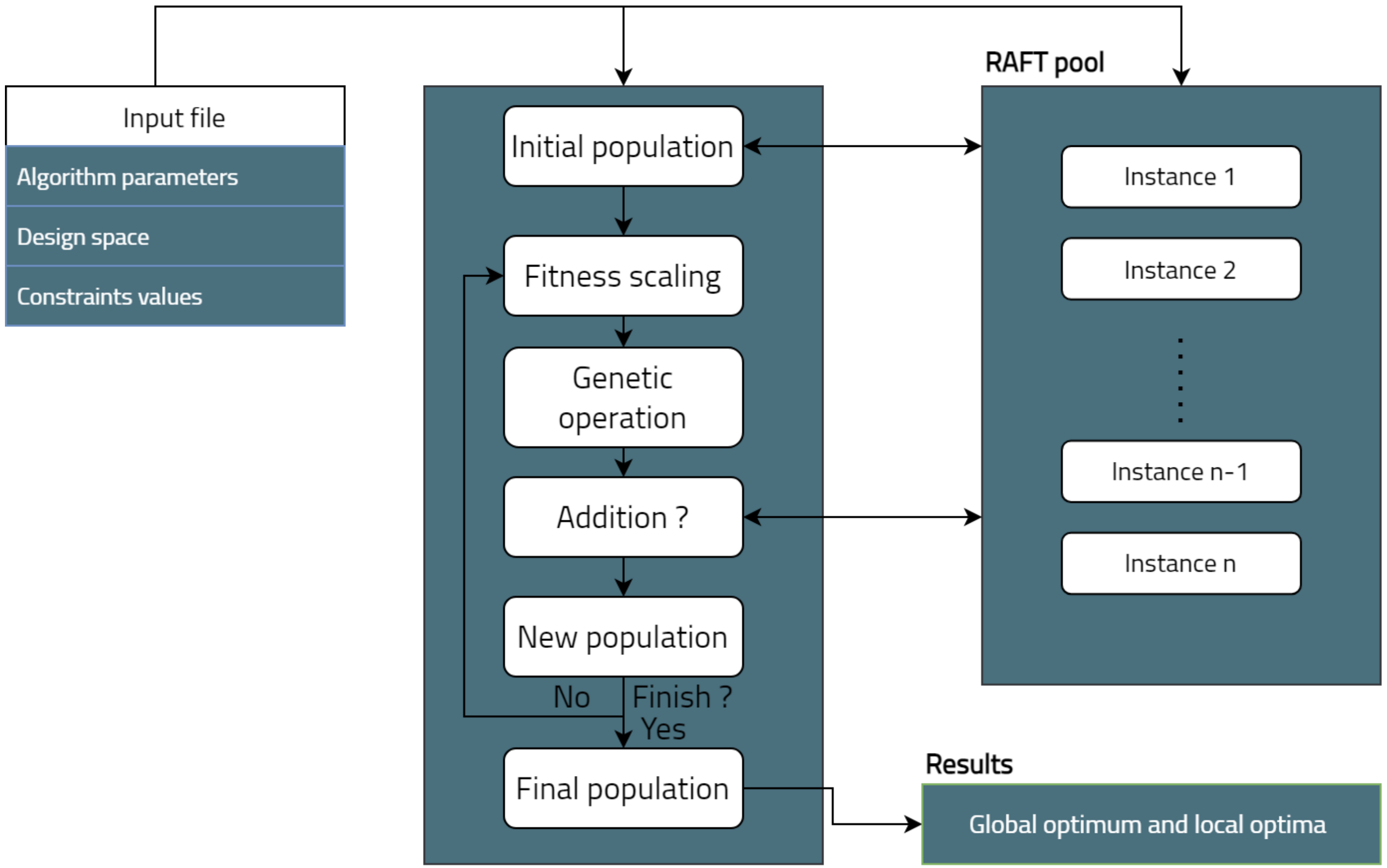
Optimization Framework

- ❑Object Oriented (python)
- ❑Modular approach
- ❑Multiprocessing



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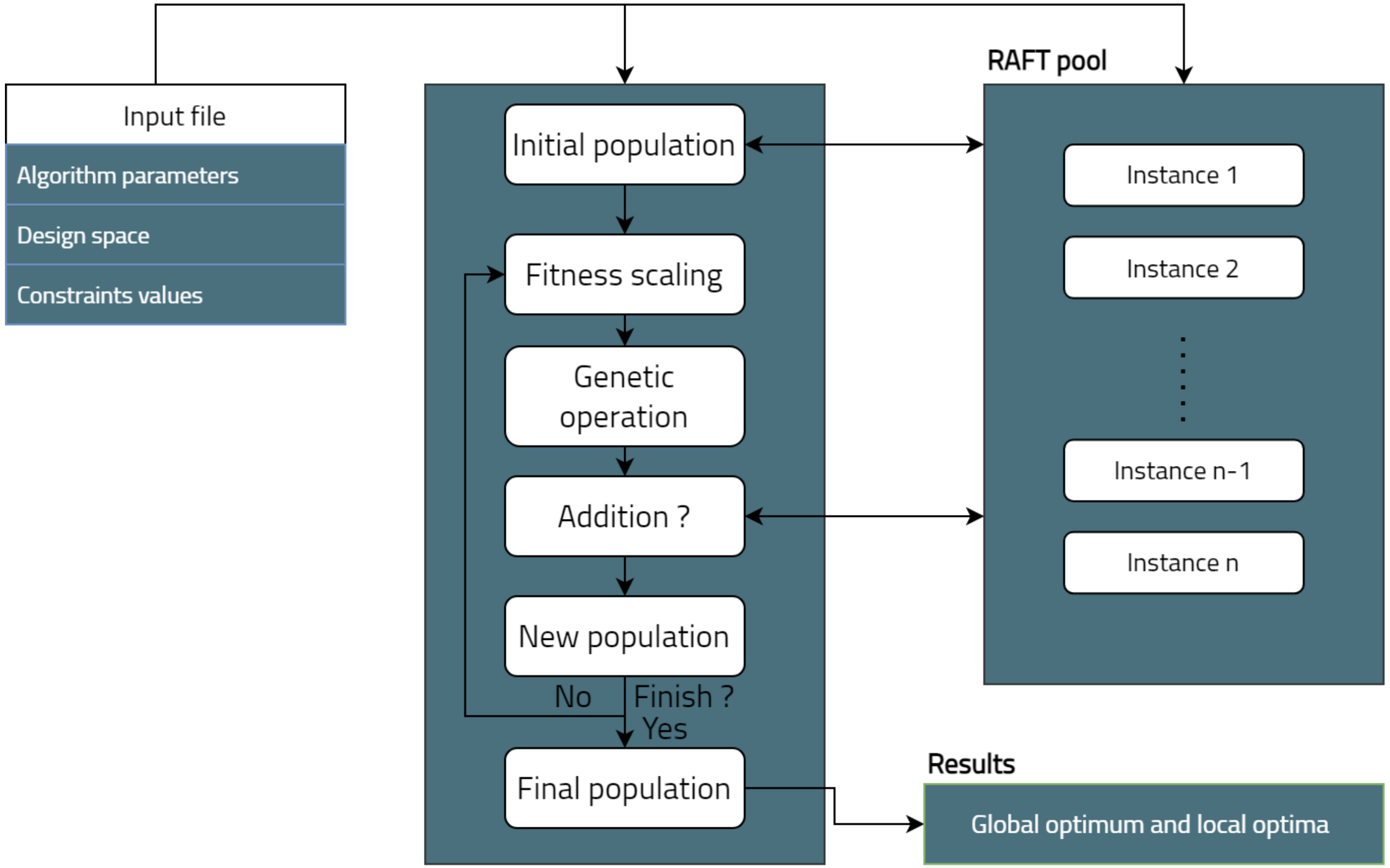
Optimization Framework

- ❑Object Oriented (python)
- ❑Modular approach
- ❑Multiprocessing
- ❑Easy to use (GUI)



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Results

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- Study case:
  - GICON-TLP with IEA15 MW

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Results

- Study case:
  - GICON-TLP with IEA15 MW
  - Environmental condition:
    - $U_w = 12$ m.s^{-1} , $H_s = 4$ m , $T_p = 12$ s

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Results

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  - GICON-TLP with IEA15 MW
  - Environmental condition:
    - U_w = 12 m.s^{-1} , H_s= 4 m , T_p = 12 s
  - Design variables:
    - L_{UBB} = [5 ; 35] m
    - D_{UBB}= [5 ; 20] m
    - Z_{UBB} = [-10 ; -30] m

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  - TwrBenMom < 6.10^8 Nm
  - H_{offset}< 5 m
  - V_{offset} < 2 m
  - Pitch < 3°

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  - GA Parameters:
    - Initial population size: 10
    - Max population size: 1000
    - max generation number: 300

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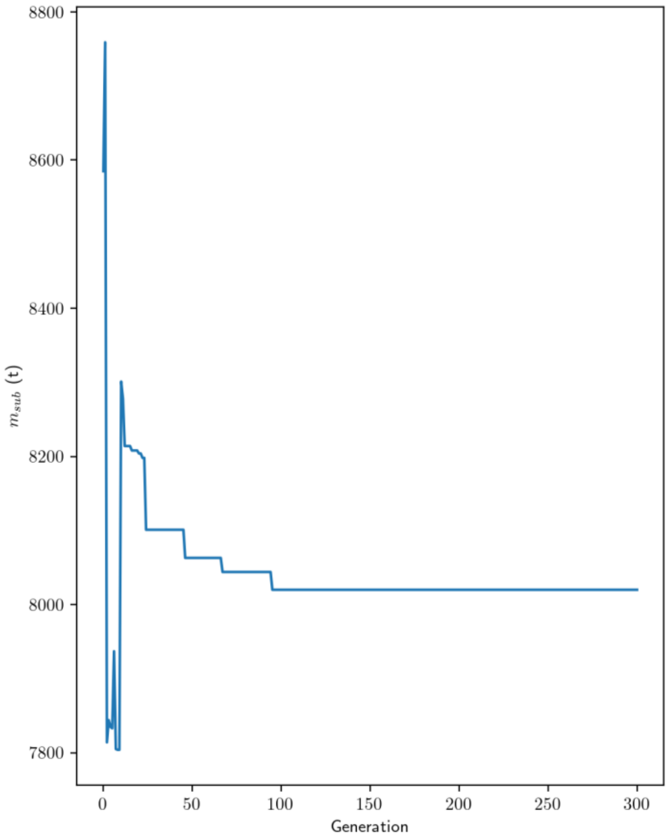
Results



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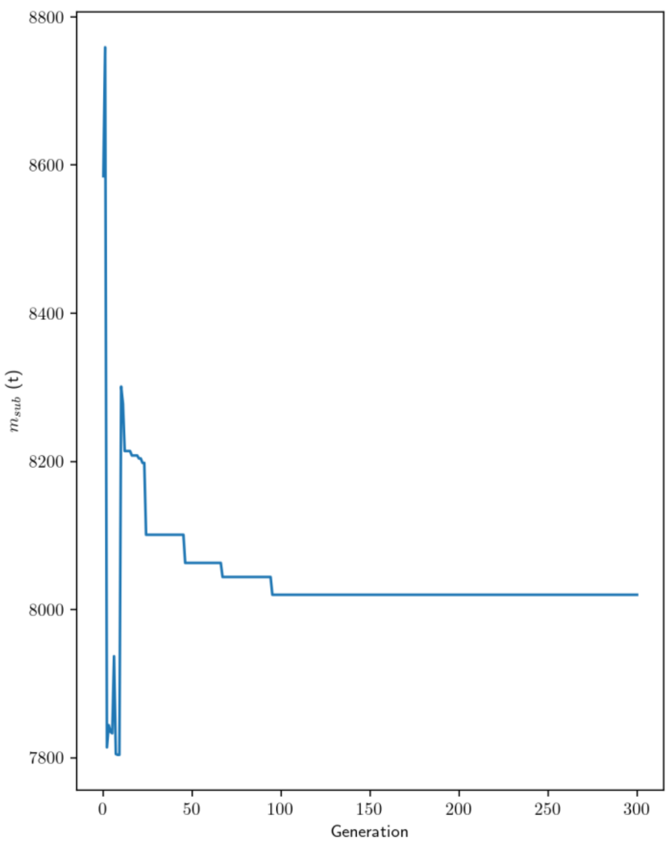

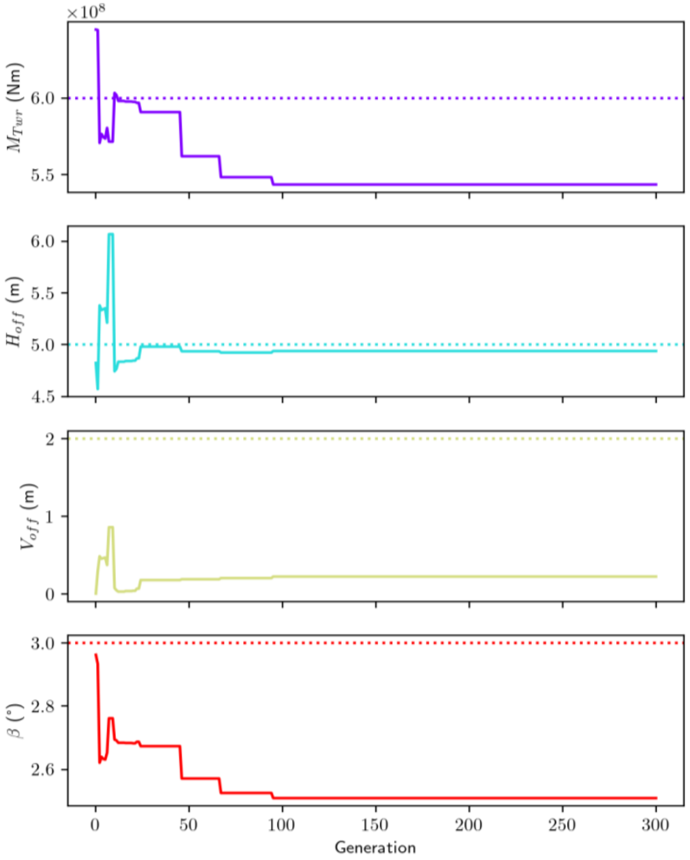

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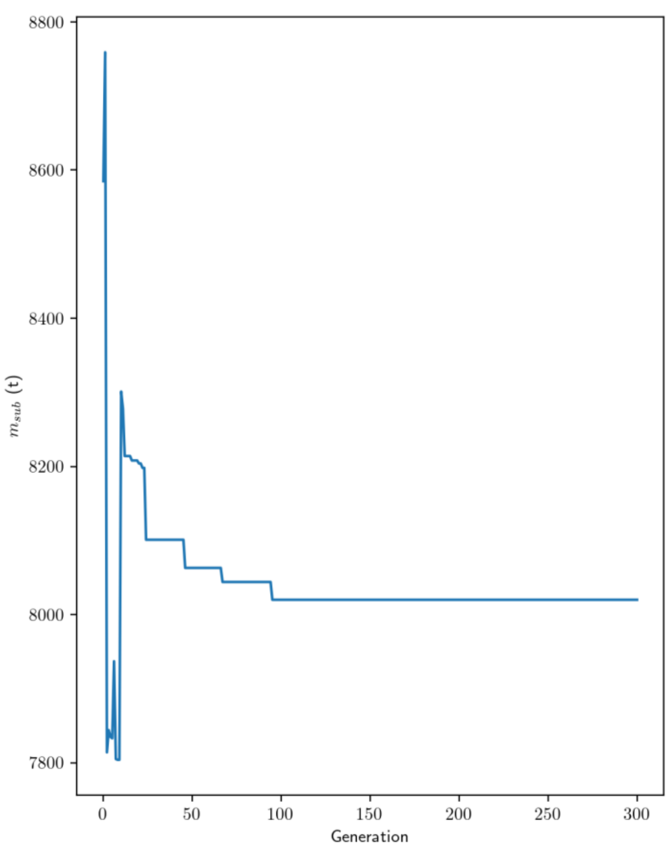

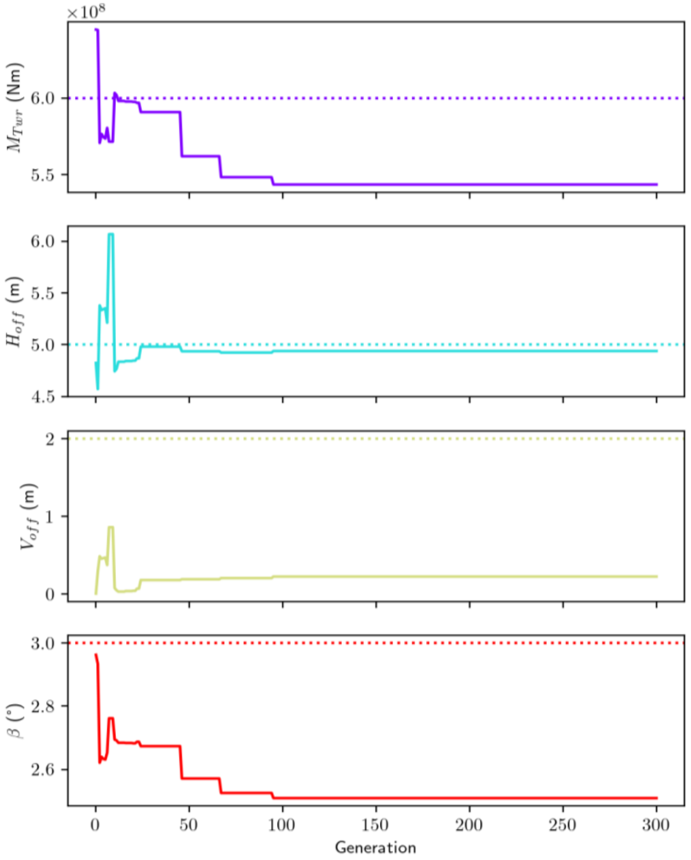

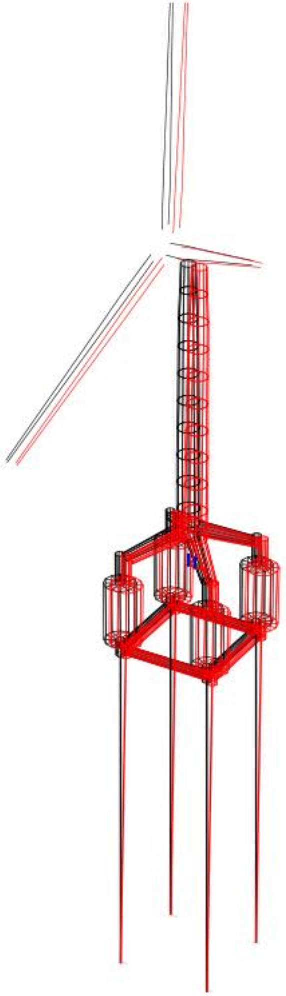

- L_{UBB} = 24 m
- D_{UBB} = 15 m
- Z_{UBB} = -24 m

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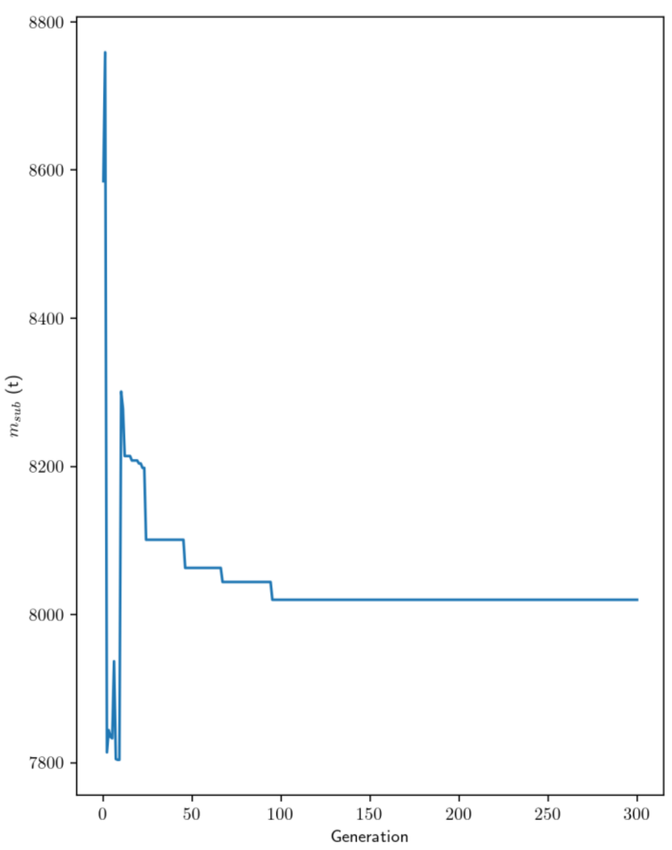

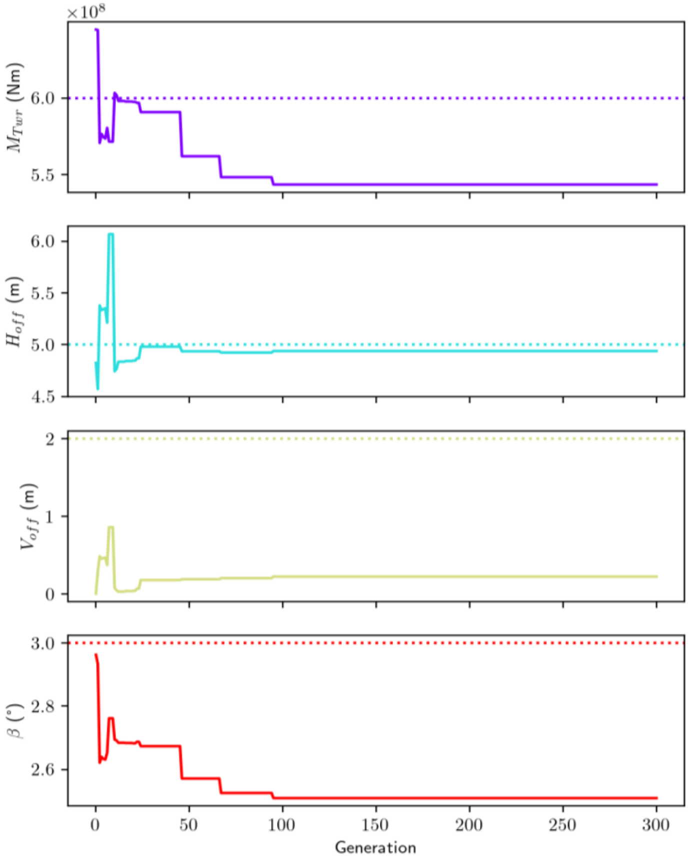

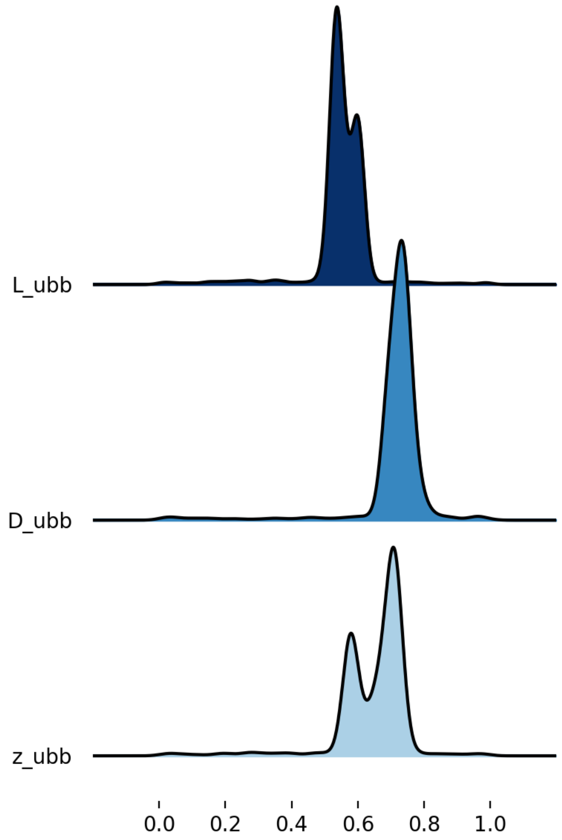

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LWET LEHRSTUHL WINDENERGIETECHNIK

FLOAWER FLOAting Wind Energy netwoRk

Conclusion & Outlook

- ✓ Model of the GICON-TLP with IEA 15 MW
- ✓ Asses its dynamic in the frequency domain using RAFT
- ✓ Design optimization framework coupling a genetic algorithm with RAFT
- ✓ Preliminary results with minimized material cost and verified constraints

- ➢ Enhance hydrodynamic model
- ➢ Compare numerical model with time domain model and experimental data
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