30 August 2022 / WESE Workshop

Multi-Disciplinary, Simulation- and Reliability-Based Design Optimization of FOWT Systems

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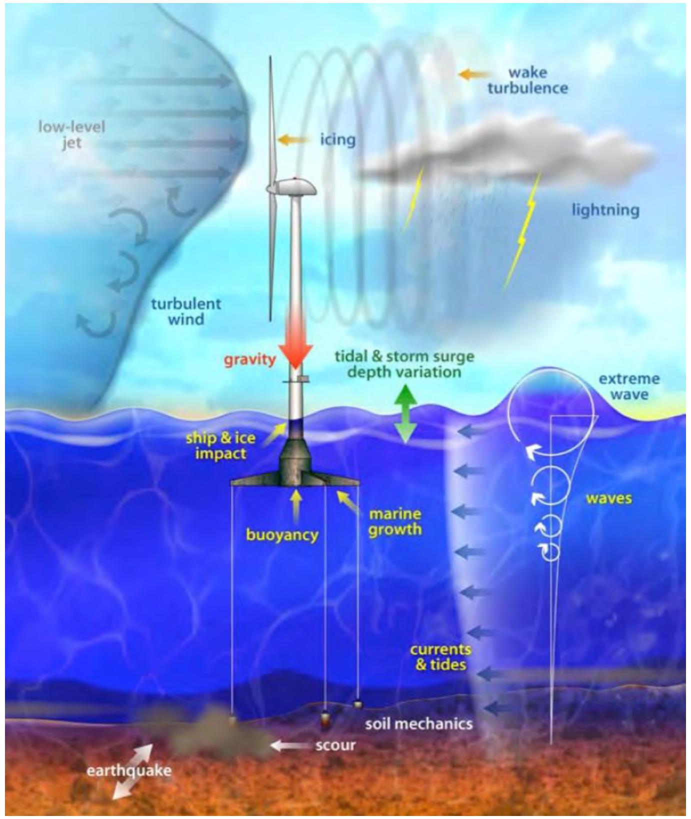
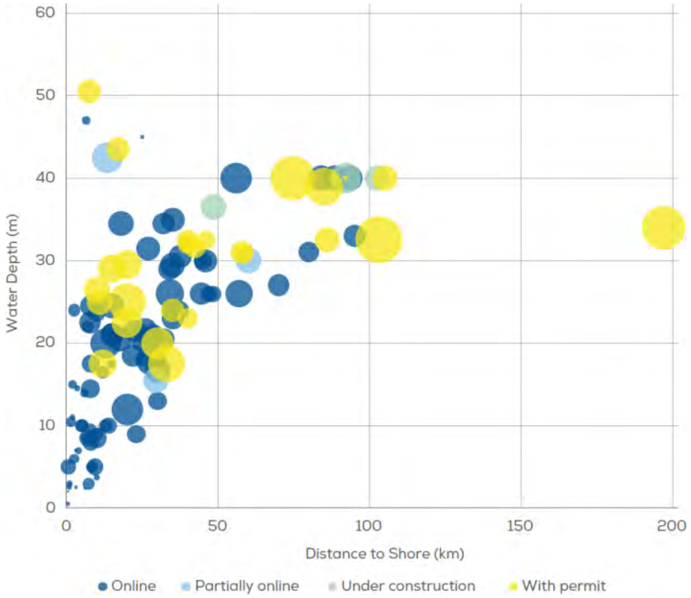
Challenges and developments within the offshore wind industry

Complex engineering systems



NREL/TP-5000-60573

Development towards floating systems and larger wind turbines



WindEurope, 2019. *Offshore Wind in Europe: Key Trends and Statistics 2018*

Resulting research needs

- Efficient maintenance strategies
- Emphasis on design process of such offshore structures
- **Focus on reliable systems ab initio**

Multi-disciplinary, simulation- and reliability-based design optimization of FOWT systems

- Numerical simulation and optimization environment
- Coupled design optimization and reliability analyses
- Results of an application example
- Conclusion and outlook

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Numerical simulation and optimization environment

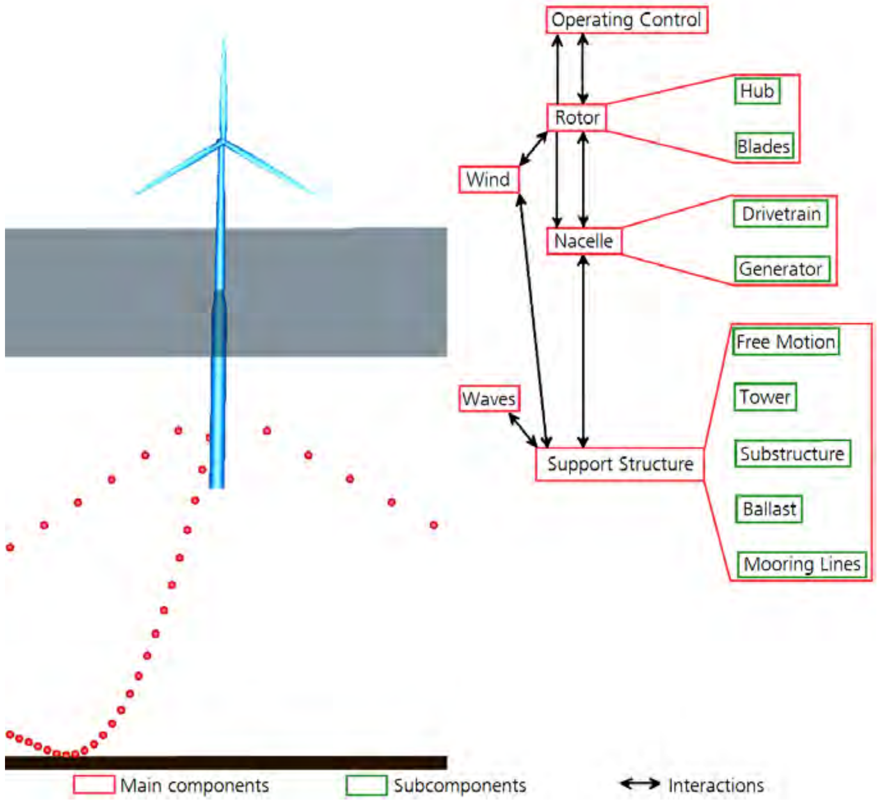
MoWiT – Modelica® library for Wind Turbines[1]

Modeling language Modelica® [2]

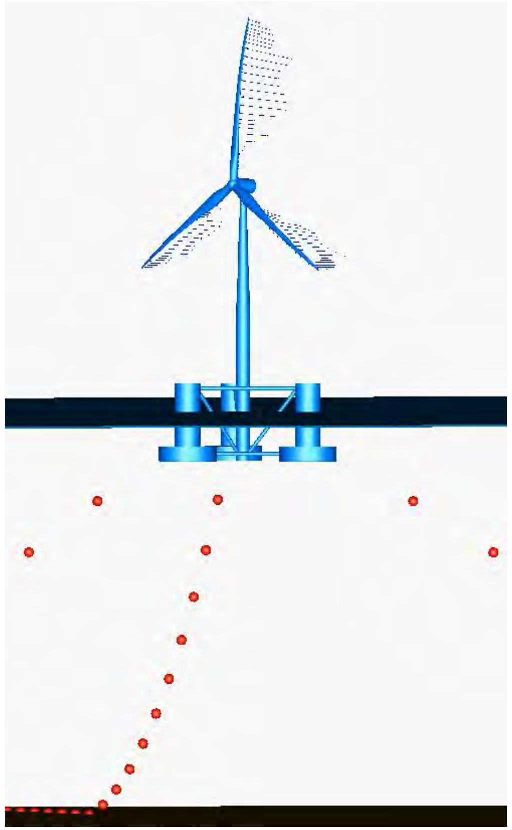
- Object-oriented
- Equation-based
- Hierarchical structure
- Multibody approach

Component-based computational models

- Modeling of any state-of-the art wind turbine system
  - Onshore
  - Offshore bottom-fixed
  - Offshore floating
- Fully coupled aero-hydro-servo-elastic simulations
- Time-domain simulations in Dymola® [3]



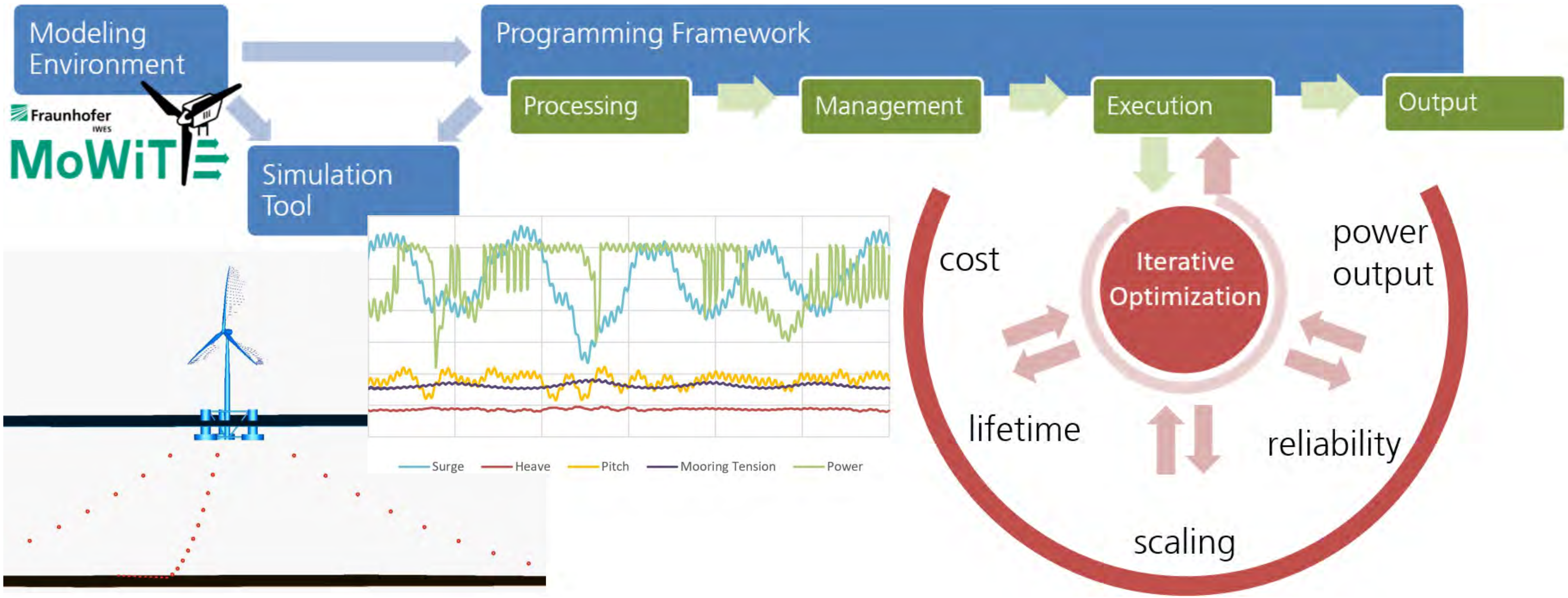
Adapted from Leimeister et al. (2017) doi: 10.3384/ecp17132633



[1] https://www.mowit.info/
[2] https://www.modelica.org/
[3] https://www.3ds.com/de/produkte-und-services/catia/produkte/dymola/

Numerical simulation and optimization environment

Framework for automated simulation and optimization



Adapted from Leimeister et al. (2020) doi: 10.5194/wes-2020-93 and Leimeister et al. (2021) doi: 10.3390/modelling2010006

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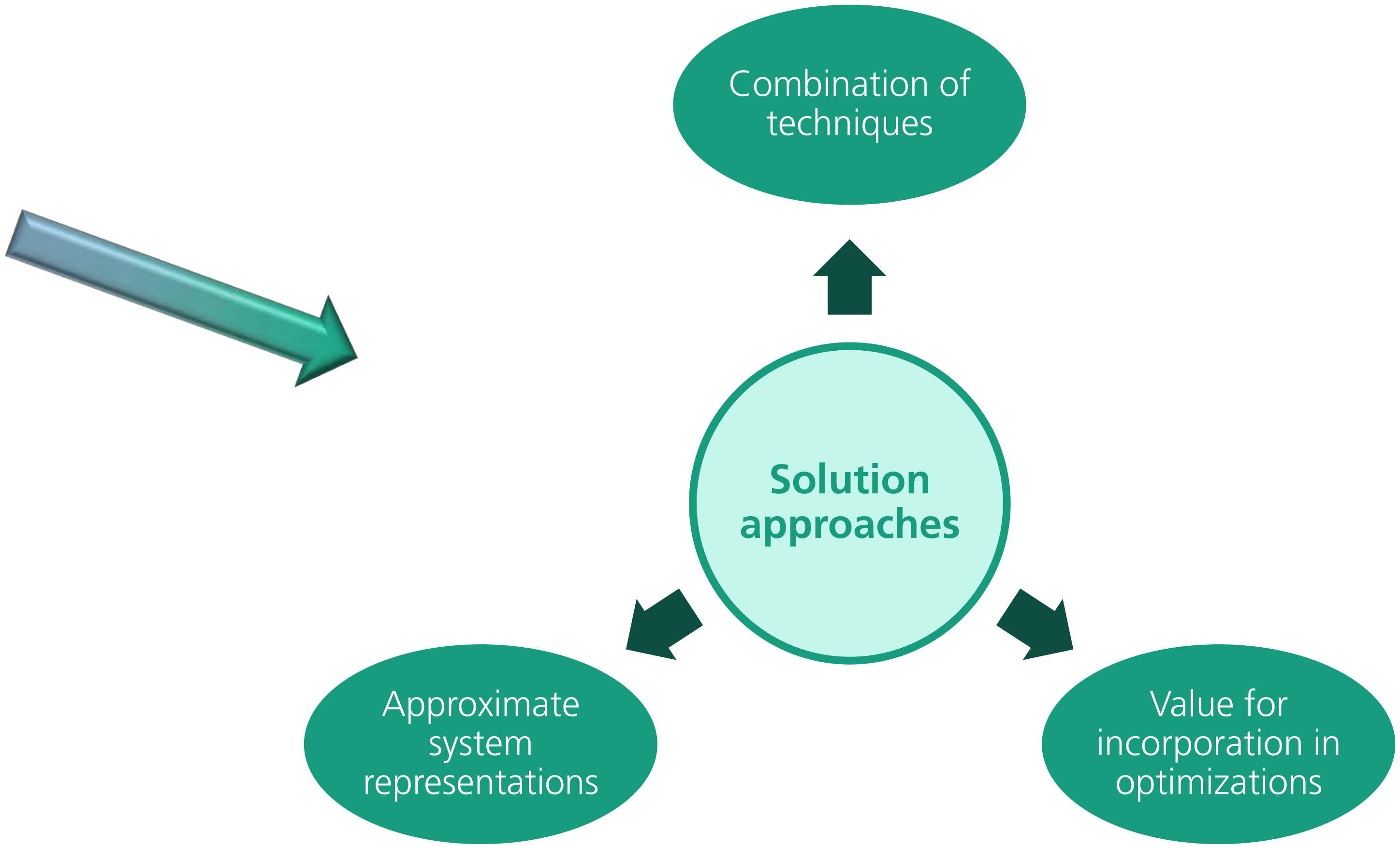
Coupled design optimization and reliability analyses

Challenges and solution approaches

Challenges

- Floating wind turbine system design
  - Complex
  - Time-demanding
  - Extensive
- Design optimization
  - Highly iterative
  - Complexity-dependent convergence rate
- Reliability analyses
  - Uncertainties
  - Additional simulations
  - Computationally intensive



Leimeister and Kolios (2018) doi: 10.1016/j.rser.2018.04.004

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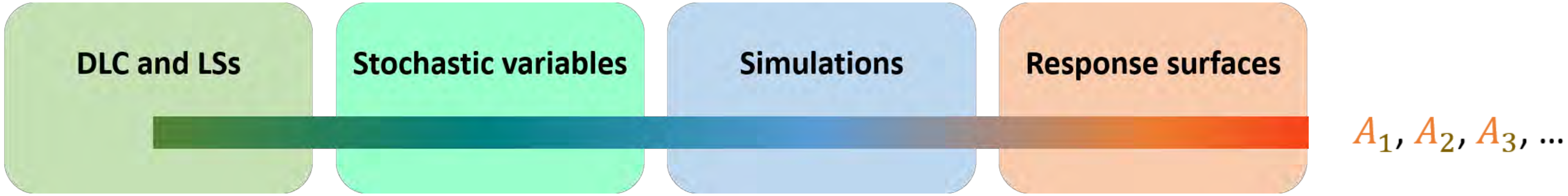
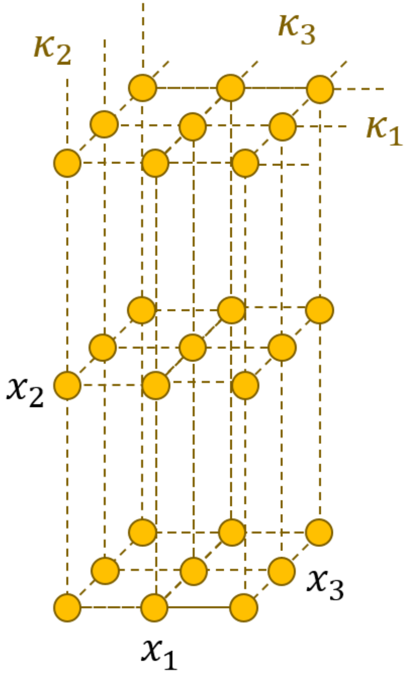
Coupled design optimization and reliability analyses

Pre-processing steps: Response surfaces in the optimization design space



- Selection of system geometries within the optimization design space
- Quadratic regression analysis

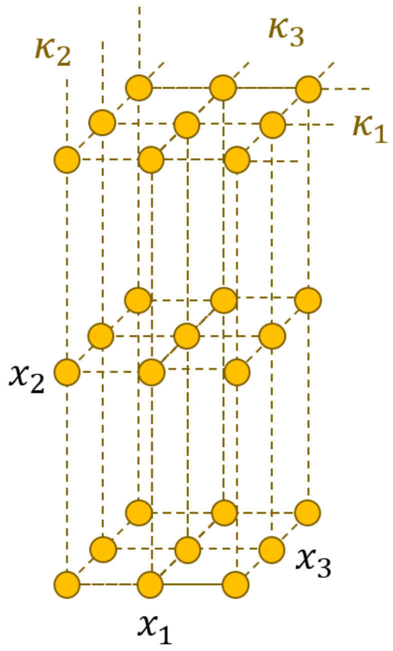


➢ Regression coefficient for specific designs, based on response surfaces with considered stochastic variables and specified limit states

Leimeister and Kolios (2021) doi: 10.1016/j.ress.2021.107666

Coupled design optimization and reliability analyses

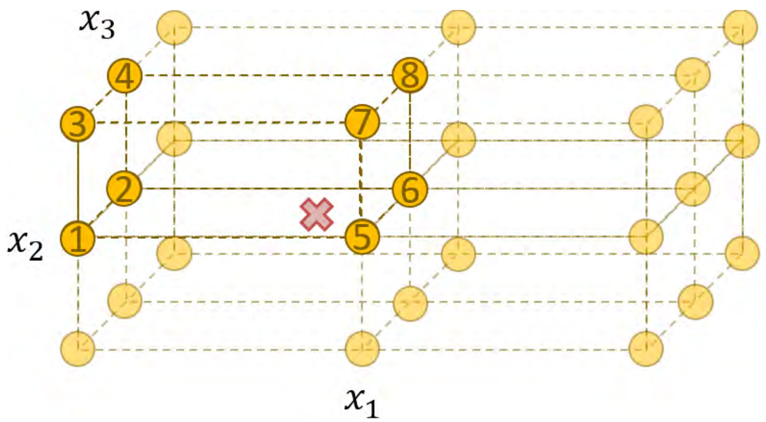
Integrated reliability assessment within the iterative design optimization process



Response surfaces

No additional simulations for considering stochastic variables

Interpolation approach



Regression coefficients of design X

MCS

Reliability assessment together with evaluation of constraints and objective functions

Reliability index

Leimeister and Kolios (2021) doi: 10.1016/j.ress.2021.107666

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Results of an application example

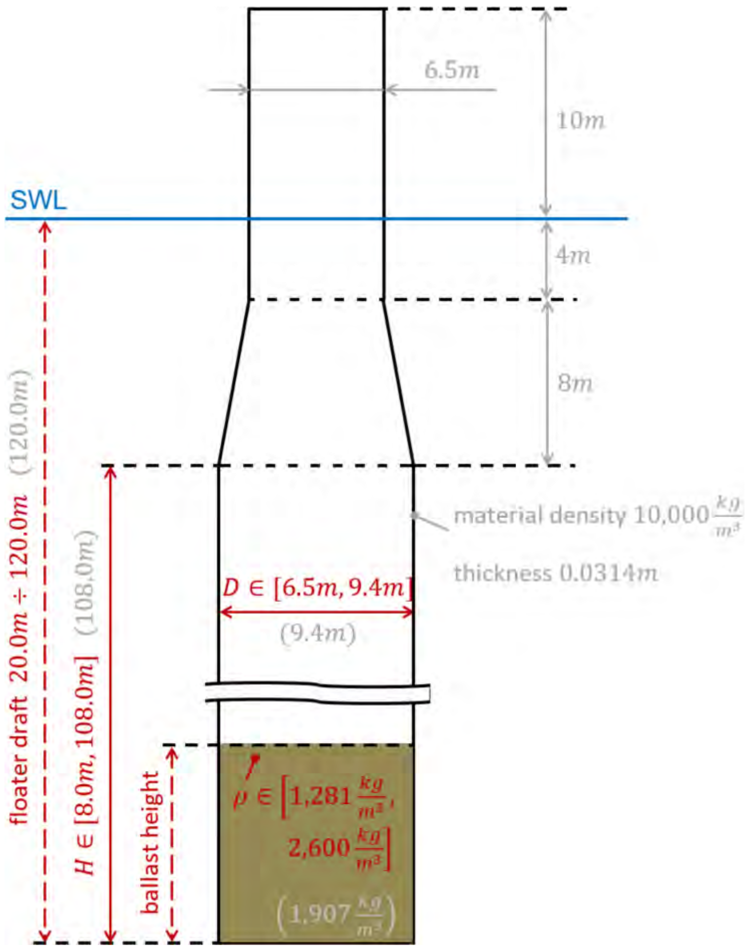
Design optimization task

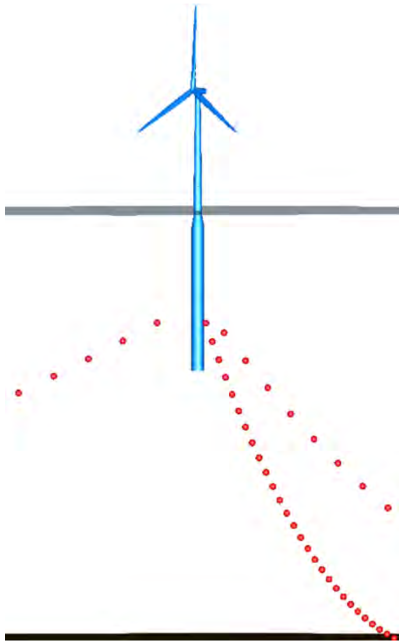
Reliability assessment parameters

- 2 stochastic variables
  - Wind speed
  - Significant wave height
- 4 limit states
  - Bending stress at tower base
  - Tensional stress of mooring lines at fairleads
- Reliability criterion: $\beta \geq 3.719$

Optimization problem

- 3 constrained design variables
- 3 global objectives
  - Acceleration at nacelle
  - System inclination
  - Dynamic translational motion
- 18 constraints
  - 10 on design variables and objectives
  - 8 on reliability indices and ultimate stress values





Optimization approach

- 1 pre-identified critical design load case
- Pre-simulations for 210 system geometries and 36 sample points
- Optimizer: NSGAII (Non-dominated Sorting Genetic Algorithm II)
- Iterative optimization process
  - 60 individuals per generation
  - 10,000 simulations in total

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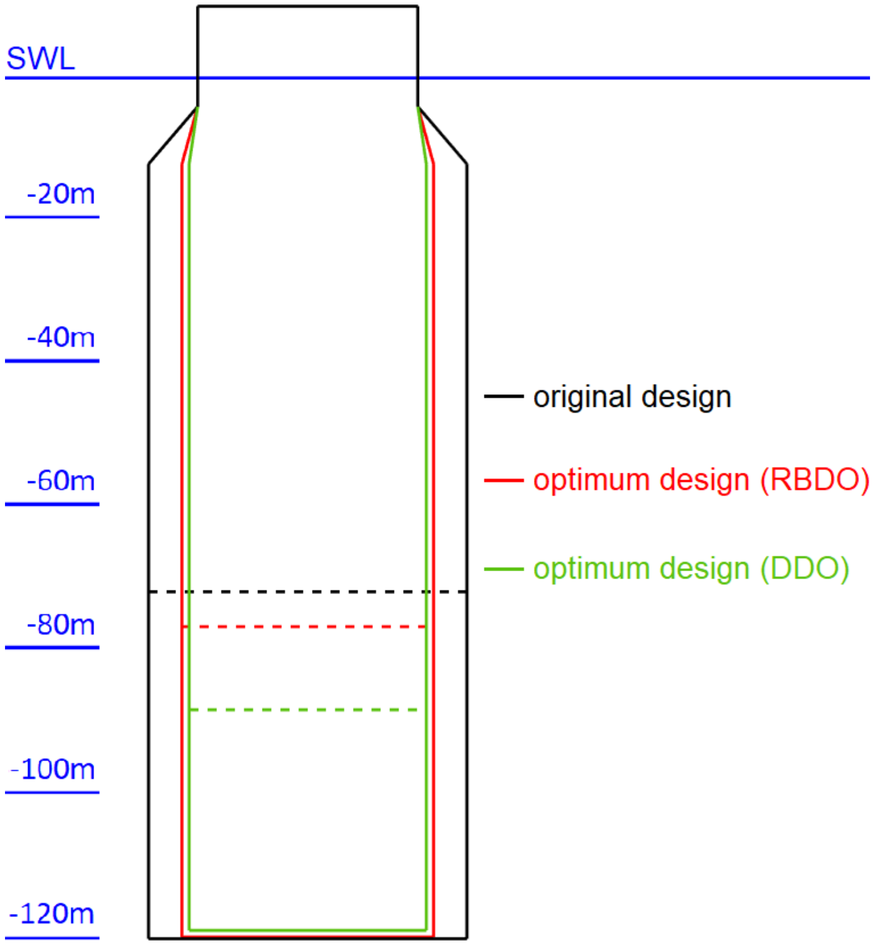
Results of an application example

Deterministic versus reliability-based design optimization

DDO

- 10 constraints
- 2,011 simulations
- Slightly higher reduction in outer dimensions



RBDO

- 18 constraints
- 10,000 simulations
- Less critical system performance parameters

- **Included reliability criteria and considered uncertainties**

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Conclusion and outlook

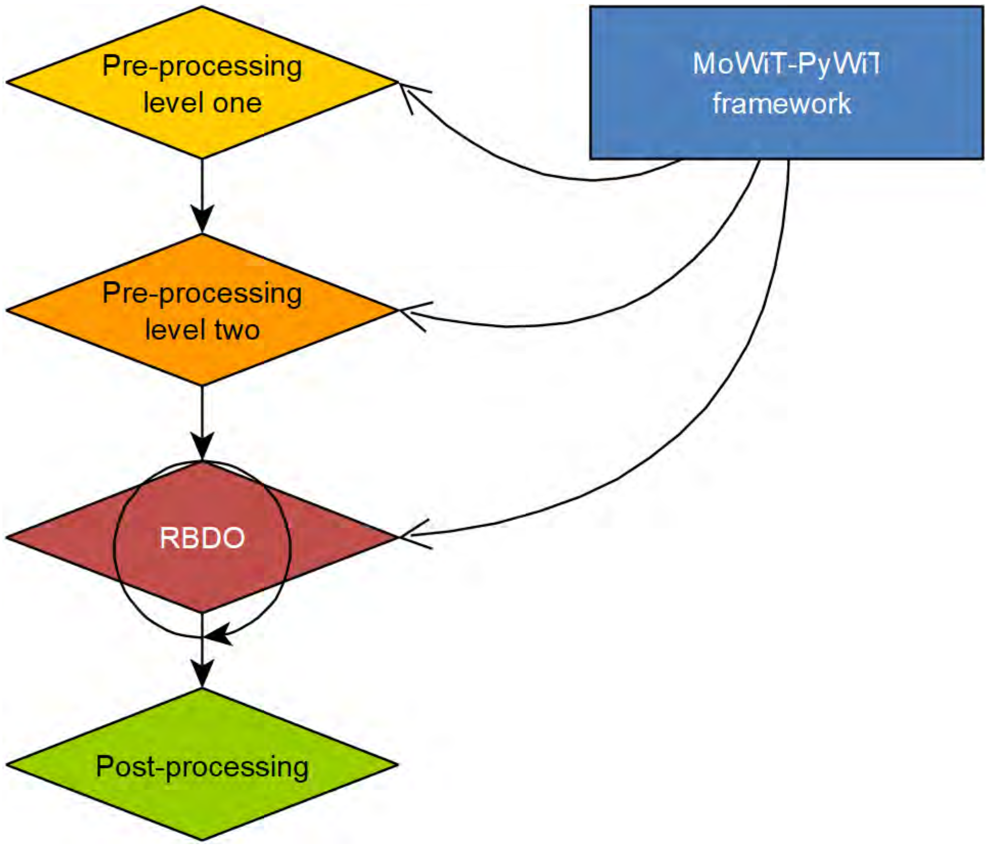
Reliability-based design optimization of floating wind turbine systems

Proven methodology

- Accounting for uncertainties in environmental conditions
- Reliability constraints on
  - Structure
  - Mooring lines
- Interpolation approach
  - Based on response surfaces
  - Time- and computationally efficient

Future applications

- Digital twins
  - Development through measurement-based optimization of numerical model
  - Suitability for assessing system condition and estimating, e.g., damage or remaining lifetime
- Reliability-based design optimization of FOWT systems focusing on
  - Lifetime-related aspects
  - Reduced maintenance and repair work required



Fricke et al. (2022) doi: 3384/ecp21181403 Leimeister and Kolios (2021) doi: 10.1016/j.ress.2021.107666

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Thanks a lot for your attention!

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