Summary of LIFES50+ project results: from the Design Basis to the floating concepts industrialization

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Qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50m

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Outline

LIFES50+

- LIFES50+ project overview
- Project development and results
  - First stage
  - Second stage
- Summary of results

LIFES50+ project overview

Qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50m

OBJECTIVES:

- Optimize and qualify to a TRL 5, of two innovative substructure designs for 10MW turbines
- Develop a streamlined KPI-based methodology for the evaluation and qualification process of floating substructures

Grant Agreement: H2020-LCE-2014-1-640741)

FOCUS:

- Floating wind turbines installed in water depths from 50m to 200m
- Offshore wind farms of large wind turbines (10MW) – identified to be the most effective way of reducing cost of energy in short term

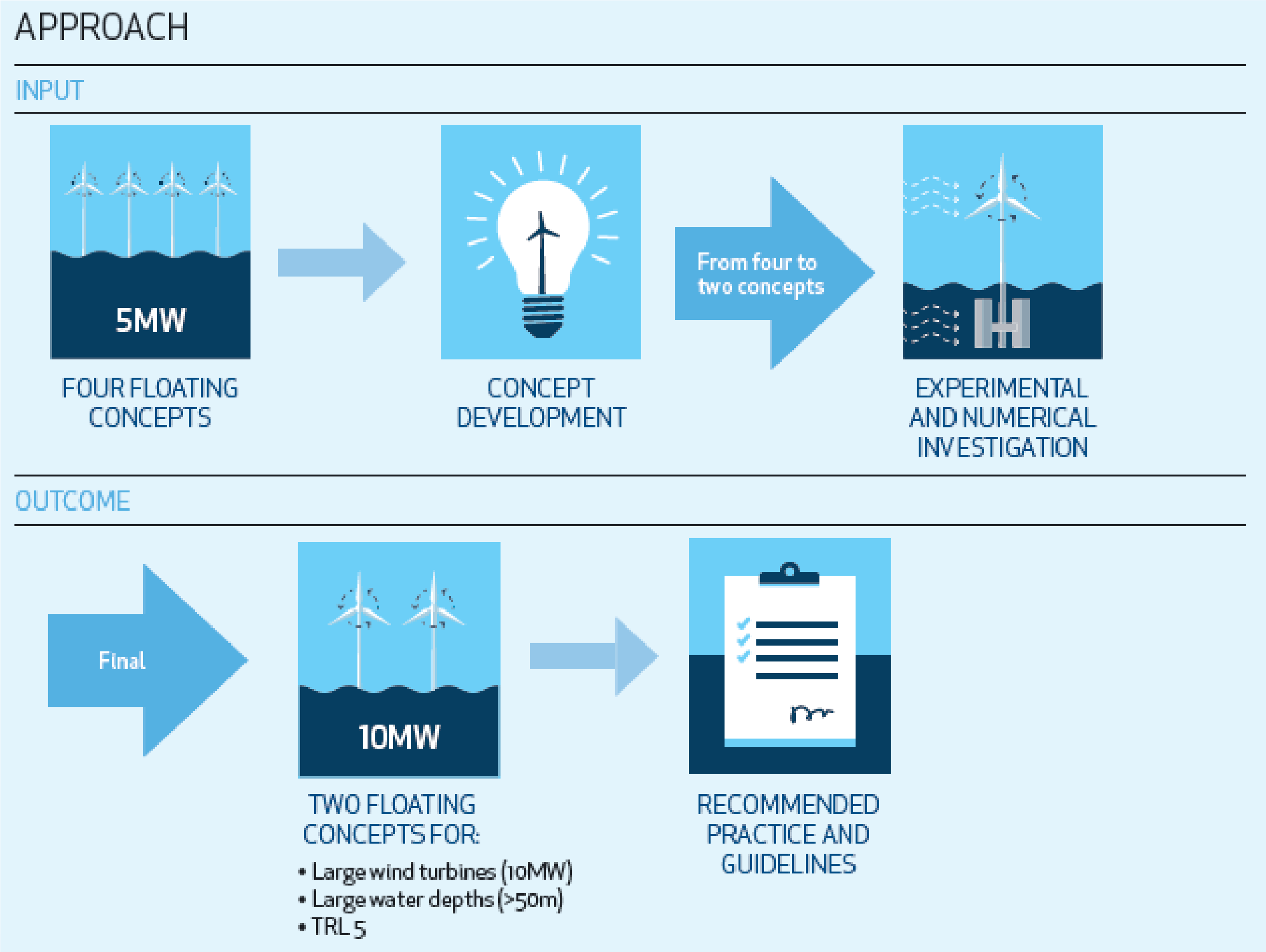
BUDGET: 7.3 M€

DATES: 47 months duration, from 01 June 2015 to 30 April 2019.

Project leader: SINTEF Ocean

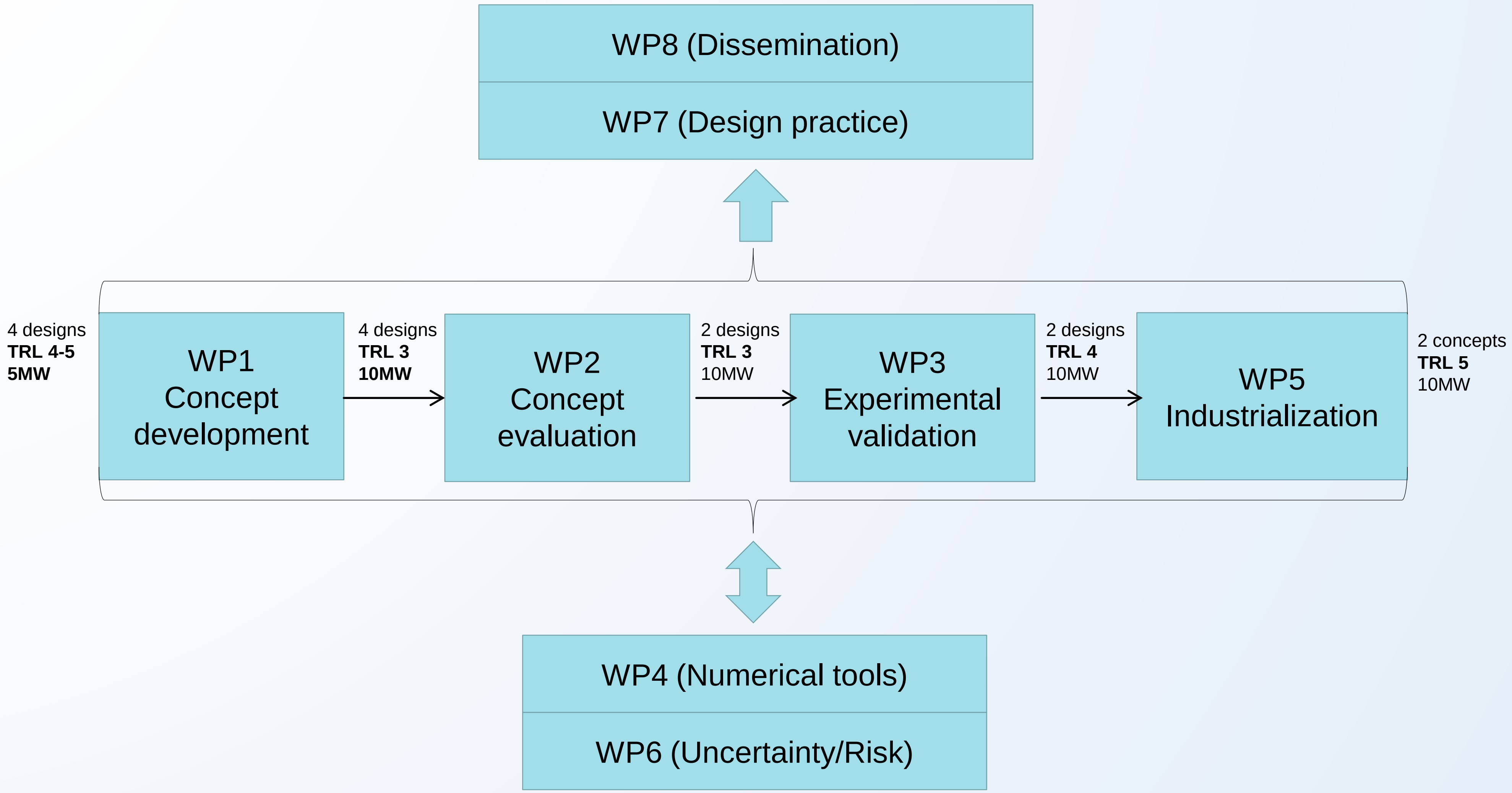
LIFES50+ project approach

First stage:
concepts design and evaluation



Second stage:
numerical modelling and experiments; recommended practice and guidelines

Project work plan



Project development and results: first stage

First stage of the project focused on concepts design & evaluation…

- Definition of the Design Basis for the concepts design:
  - Identification of three sites and collection of information
  - Definition of the Wind Turbine reference model
  - Design requirements and load cases – DLCs
- Definition of the framework for the concepts assessment:
  - Scope and development of the tools for the LCOE, LCA and risk analysis evaluation
  - Agreement on the evaluation procedure
  - Information for the concepts assessment
- Concepts design
  - Sizing and structural design, mooring design, aero-hydrodynamic simulations
  - Adaptation of the WT controller
  - Analysis of marine operations, including manufacturing strategy

… and preparation of the experiments, and design practices

- Overview of current design procedures, numerical models, tools, methodologies and standards
- Preparation of the experiments:
  - Development of the Real-Time Hybrid Model testing for the wave tank experiments
  - Development of the wind tunnel experiments: hexapod and reduced scale wind turbine
- First steps in the concepts industrialization

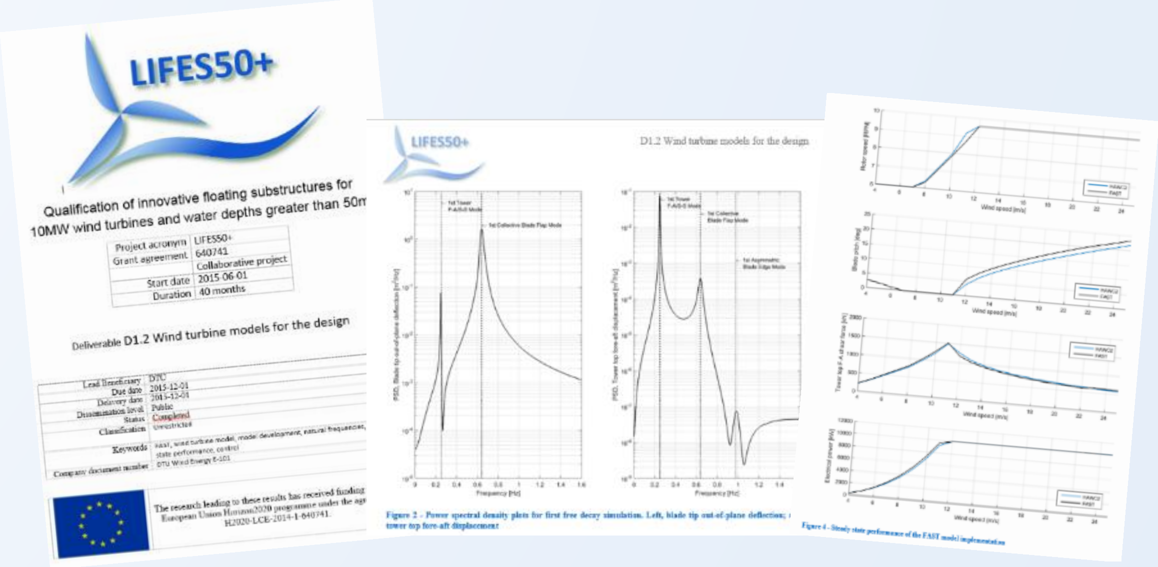
Information for the concepts design

Sites selection and information

	50-year wind at hub height [m/s]	50-year significant wave height [m]	50-year sea-state peak period [s]	50-year current [m/s]	Extreme water level range [m]	Design Depth [m]	Soil Type
Site A	37	7.5	8-11	0.9	1.13	70	Sand/Clay
Site B	44	10.9	9-16	1.13	4.3	130	Sand/Clay
Site C	50	15.6	12-18	1.82	4.2	100	Basalt

Wind Turbine information

- FAST model of DTU 10MW reference wind turbine
- Generic controller for the wind turbine.
- Tower reference design.



Design basis and DLCs

Main design criteria based on DNV-OS-J103

Public information available on the project's web site

Concepts design process

Concept developers used their own design procedures and codes, which were validated at different levels in the consortium, to ensure a common framework for their assessment.

Concepts design, driven by the information required for the evaluation:

- KPIs
- LCOE and LCA figures. Forms for 50 wind turbines wind farms -3 excel sheets-, one wind turbine -1 excel sheet- and 5 wind turbines -1 excel sheet-
- Uncertainty forms for each of the sites
- Information for risk analysis

LIFES50+ Design Process conditioned for the concepts assessment and evaluation:

1. Onshore benchmark to validate WT models
2. ‘Design references’ to select an justify the Load Cases for each site and each concept
3. Design Briefs to validate the design process and the assumptions

Design Basis

- Met-ocean conditions - DLCs
- Wind Turbine model, including WTG controller
- Standards
- Design restrictions and assumptions

SW becnhmark

- Definition of the benchmark: Load Cases
- Comparison of model results

Design Briefs

- Review of the design procedures
- Qualitative assessment of the modelling approach

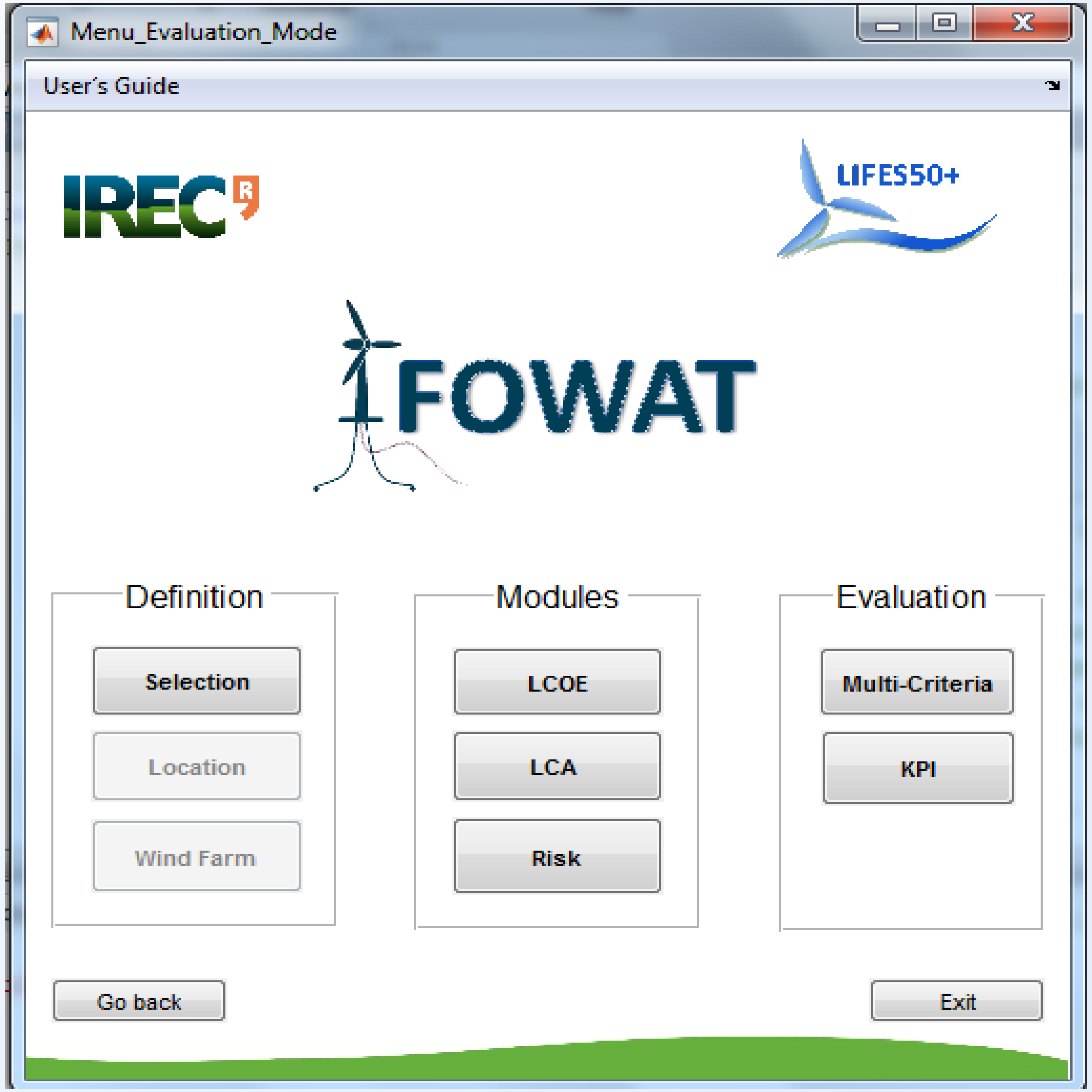
Concepts Design

- Design for the three sites
- Concept Developer provide figures: KPI, LCOE, LCA
- Evaluation Comittee review results and provide feedback
- Design summary collected in D1.3 to D1.5 deliverables

Concepts assessment

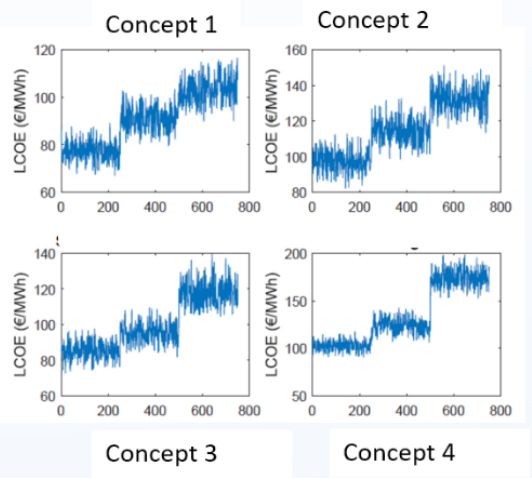
Development of **FOWAT** assessment tool:

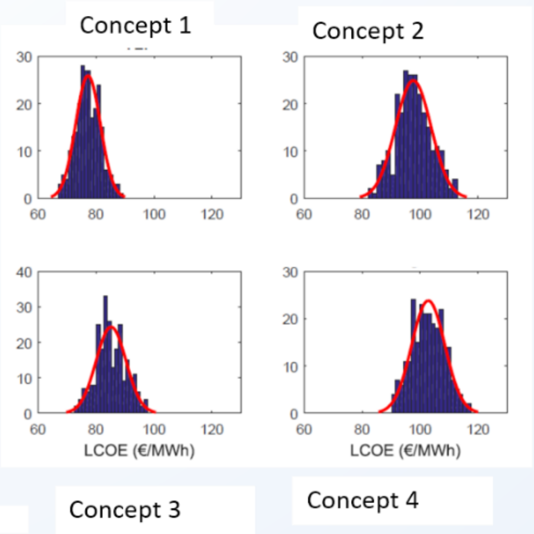
- LCOE (IREC)
- LCA (TECNALIA)
- Risk Assessment (ORE Catapult)
- Technical KPI report
- Comparison module using multi-criteria analysis considering uncertainty and statistical methods (IREC)



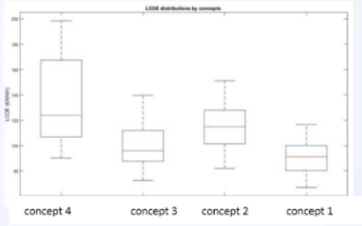
Concepts assessment

1. **General frame for the calculations:** Description of the methodology and assumptions taken to perform the Evaluation (Common costs data used for the calculations/Onshore substation location/LCA background data)
2. **Several information submissions** were stablished in order to facilitate the concepts evaluation and improve concepts design.
3. **Concept designs results calculation:** Reporting of the individual results obtained by each design at each site.
4. **Ranking results:** Perform two-way ANOVA statistical test to examine the influence of two different factors (i.e. **concept** and **site**) on one continuous variable (**LCOE**).
5. **Evaluation workshop** for the final selection of two concepts to be modelled and tested in the second stage. Hosted by IREC in Barcelona, 08-10 March 2017.

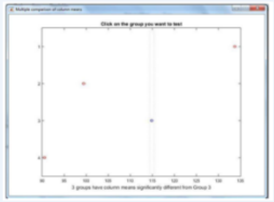




ANOVA test



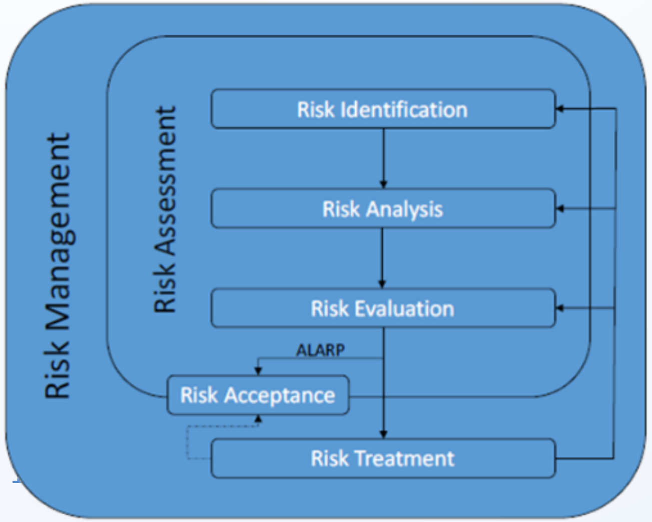
Tukey test

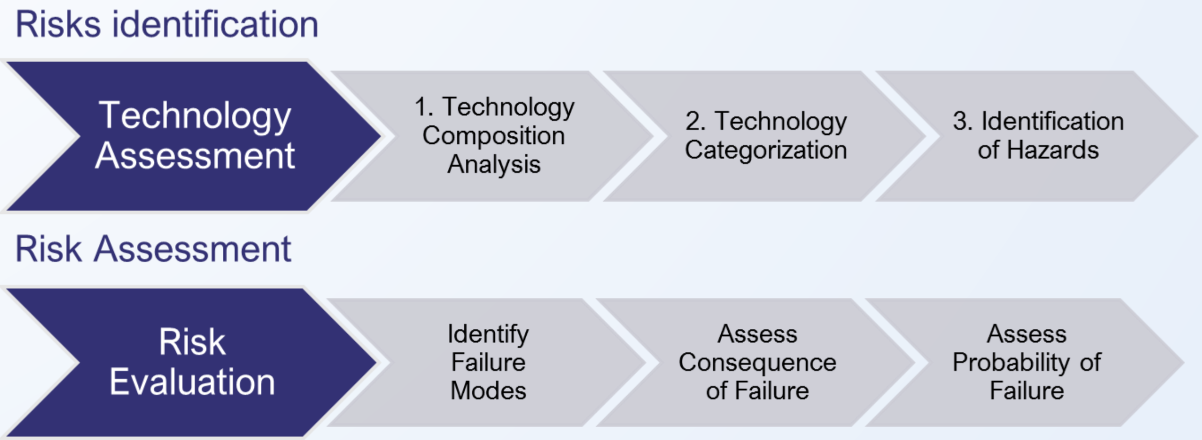


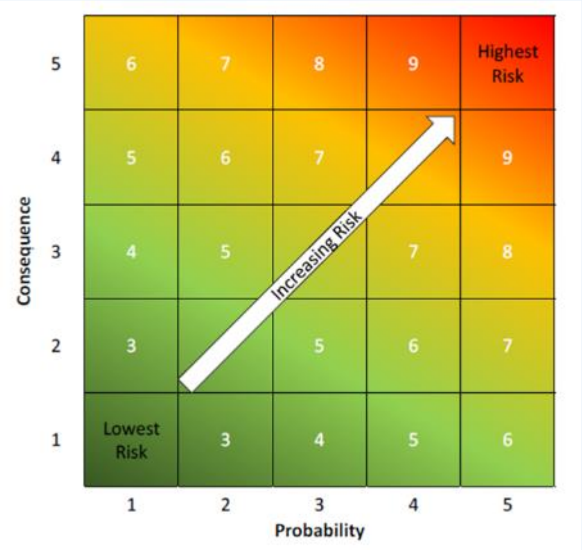
Risk assessment

Risk assessment as part of the concepts evaluation and for the future design optimization

- It was developed a **public methodology for risks assessment of floating offshore wind substructures** covering four areas: technical; health, safety and environment; manufacturing; commercialization.
- Risk register development, with some 100 risks for floating wind, covering all life cycle phases (Design, fabrication, transportation and storage, installation, commissioning, O&M, decommissioning) and different substructure types and primary materials, which was part of the concepts evaluation.
- **Data confidentiality and objectivity were the main challenges** to carry out the risk assessment To solve this 1-2-1 risk identification workshops were organized with each developer at their facilities.
- WP6 engaged the industry interviewing different types of stakeholders (finance, WT OEMs, technology providers, insurance, etc.) on commercial risk identification.





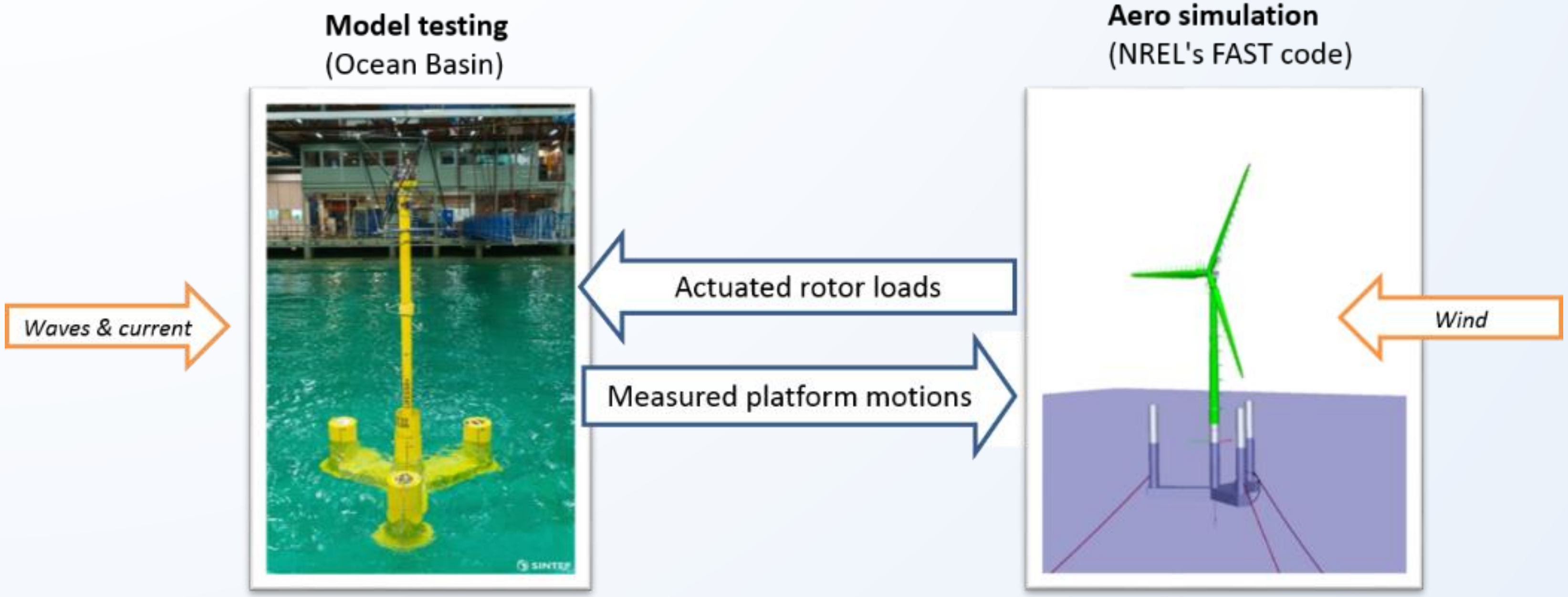


Experiments preparation

Wave Tank

Develop Real-Time Hybrid Model testing (Hardware in the Loop) for floating wind turbines:

- Controlled environment
- Flexibility
- Overcome Froude-Reynolds scaling issues



Physical model in ocean basin with physical waves coupled in real-time to aerodynamics simulations (FAST).

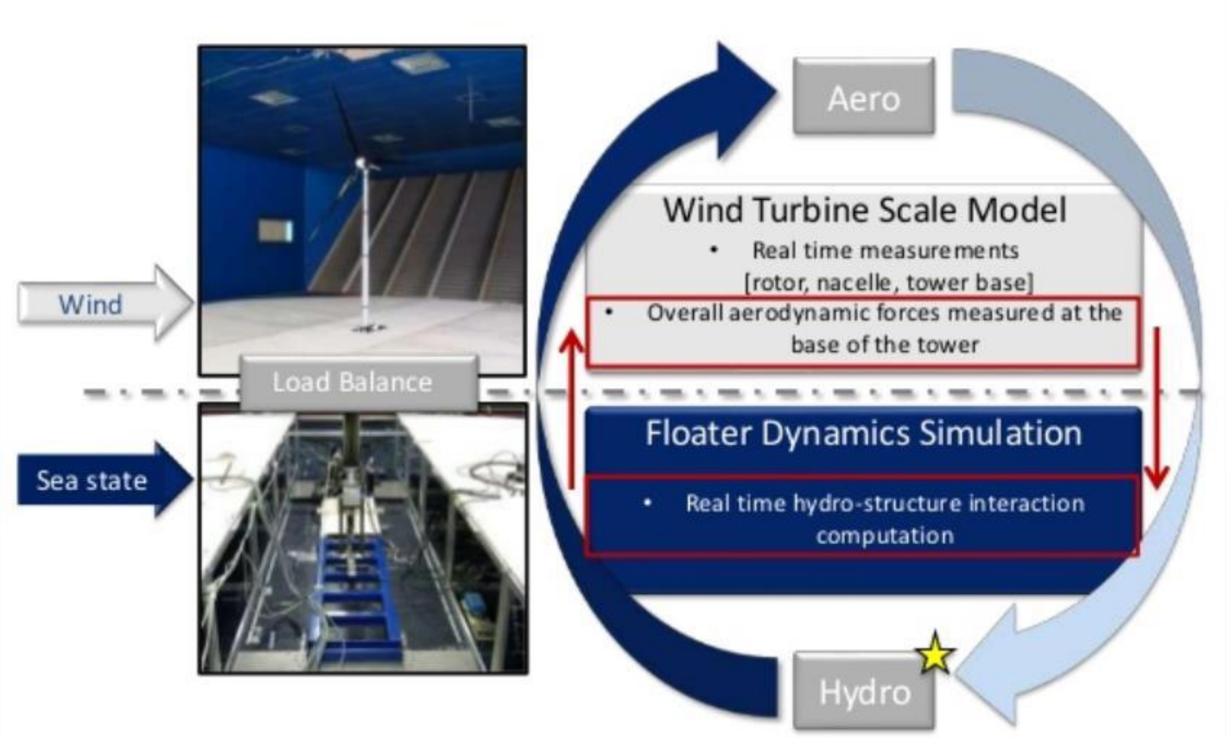
The aero loads are applied on the model by use of actuators and the position of the model is measured in the basin and used as input to the numerical simulations.

Experiments preparation

Wind Tunnel

Physical wind and wind turbine connected in real time to numerical hydro simulator.

A 6DOF robot at the tower base imposes the simulated platform motions. The loads at base of tower measured in the wind tunnel are used as input to the numerical simulations. The output of the simulations is the floater position.



Industrialization

Design Brief describing procedures and methodologies that need to be addressed to develop an industrialized FOWT design process.

Identification of key design elements and challenges which are important for a FOWT design process to be addressed in order to arrive at an industrial reliable and efficient level applicable for industrial scale multiple-unit design.

Analysis of installation restrictions and simulation of different conditions regarding ports, distance to deployment site, types of vessels and weather windows. Identification of challenges and cost estimation.

FABRICATION - STEEL

Steel

Advantages	Challenges
• **Established** in the offshore wind industry: ○ Know-how existing ○ Proven solutions and standards exist to avoid issues related to corrosion due to saltwater and salty air, wind turbine load, etc. • **Assembly** can be executed **relatively fast** if components are pre-fabricated (consists of welding operations and positioning of the parts only) • **Lighter substructures** are possible (compared with concrete) • Possibility of serial production in **existing facilities** for offshore wind monopile or jacket manufacturing	• Expensive material, **price fluctuating**, planning difficult • **Specialized equipment** (e.g. large scale welding machines and cranes with sufficient lift capacity) required, shipyard preferable • Large dimension **components/parts**: ○ Need to be built at shipyards/factories, typically not at construction site, which is a challenge for mass production ○ Heavy/large parts need to be transported to construction site, suitable access (road, railways, waterways) required ○ Suitable storage area at port required

FABRICATION CONCRETE

Concrete

Advantages	Challenges
• **Concrete local supply** adaptable to local conditions and project requirements **(Local Content)** ○ Ready-mix concrete ○ Mobile batching plant ○ Installation of a stationary batching plant at the construction site • **No specialized equipment**, like large scale welding machines, required (construction at lower costs) • **Low costs of concrete** as a raw material • Ready-mix concrete only: **less storage area required** (no raw material has to be stored for batching at port)	• **Limited use in offshore wind** industry • **(Often) larger dimensions of concrete floaters** require large construction area for mass production • **High weight of concrete floaters** (restrictions to the bearing capacity and space) • Concrete cannot bear **tension loads**, therefore additional procedures (e.g. pre-tensioning, avoiding of upending actions) necessary • Wide range of **weather restrictions** for construction/drying process (e.g.no construction during frost or heavy rain) • Mixing process at the construction site possibly more inaccurate (additional quality assurance necessary)

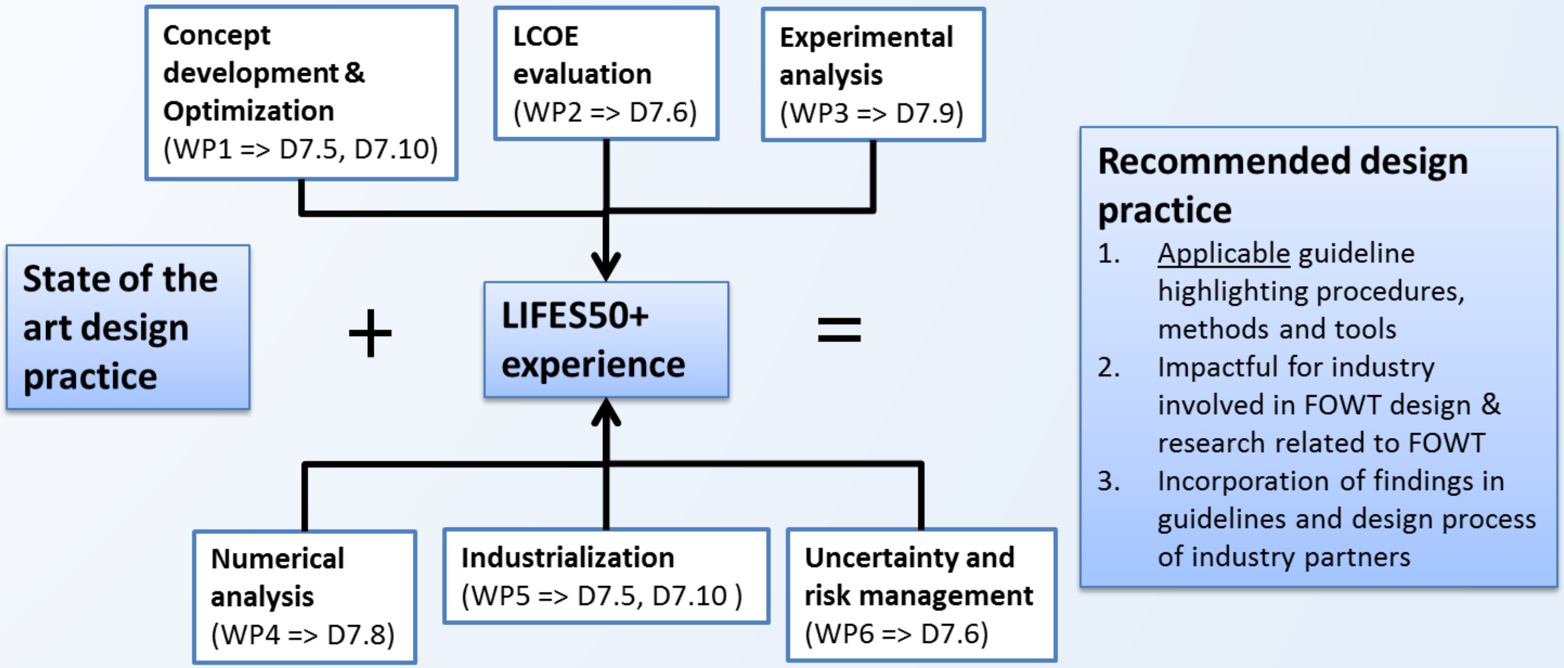
Design Practice and numerical models

The aim it to develop recommended practices for FOWT design based on the state of the art and the project achievements in the design, modelling and experimental validation of the concepts.

First stage work focused on the analysis of the state of the art on design procedures and numerical models…

- Concept developers design procedures and tools
- Overview of the numerical models used in the consortium and their qualification
- Standards (application the definition of the DLCs for the concepts design)

…to define an optimization framework and methodology for optimized floater design.



LIFES50+

Summary of results for stage one

1. Four concepts designed for the reference wind turbine and the selected sites (Design Basis), including all the information for the evaluation.
2. Concepts evaluation and selection of two of them for the second stage.
3. Preparation of the tools and methodologies for the experiments: Real-Time Hybrid Model testing for the wave tank experiments; hexapod and reduced scale wind turbine for the wind tunnel experiments.
4. Analysis of current design procedures, numerical models, tools, methodologies and standards.
5. Industrialization: performance evaluation of available simulation SW and existing design tools. Design Briefs.

Iberdrola - TLPWIND ®	IDEOL	NAUTILUS	Olav Olsen - OO-Star Wind Floater
Tension Leg Platform	Barge	Semi-Submersible	Semi-Submersible

Second Stage

Second stage of the project focused on experiments and numerical modelling investigation

- **Wave tank and wind tunnel experiments** using the selected concepts to:
  - Characterize the hydrodynamic and aeroelastic behavior of the two concepts
  - Validation of the Real-Time Hybrid Model testing
  - Validate the hardware in the loop methodology
- **Numerical modelling** and analysis of the experimental results to calibrate the models.
- Analysis of **advance modelling** to reduce computational time while maintaining the results accuracy.
- Selected **concepts industrialization** analysis and design optimization. Re-calculation of the LCOE and LCA figures for the optimized designs.
- **Recommended practices for FOWT design** based on the project achievements in the design, modelling and experimental campaigns.

Work ongoing with some interesting results so far.

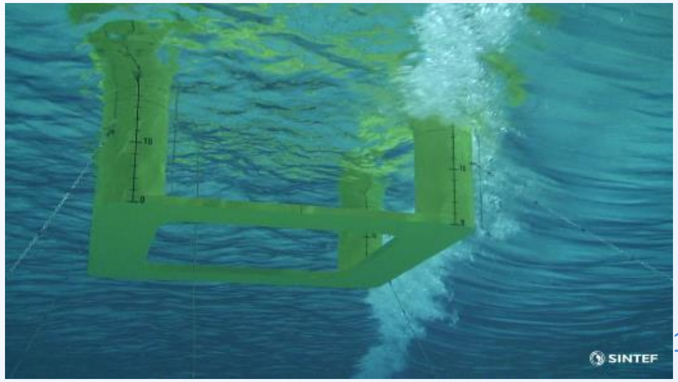
Wave tank experiments

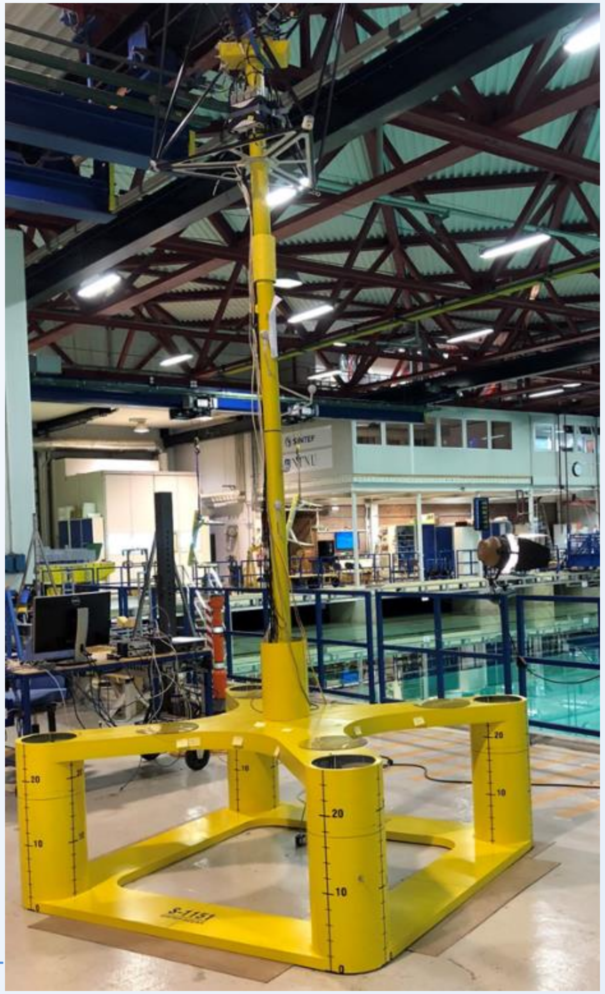
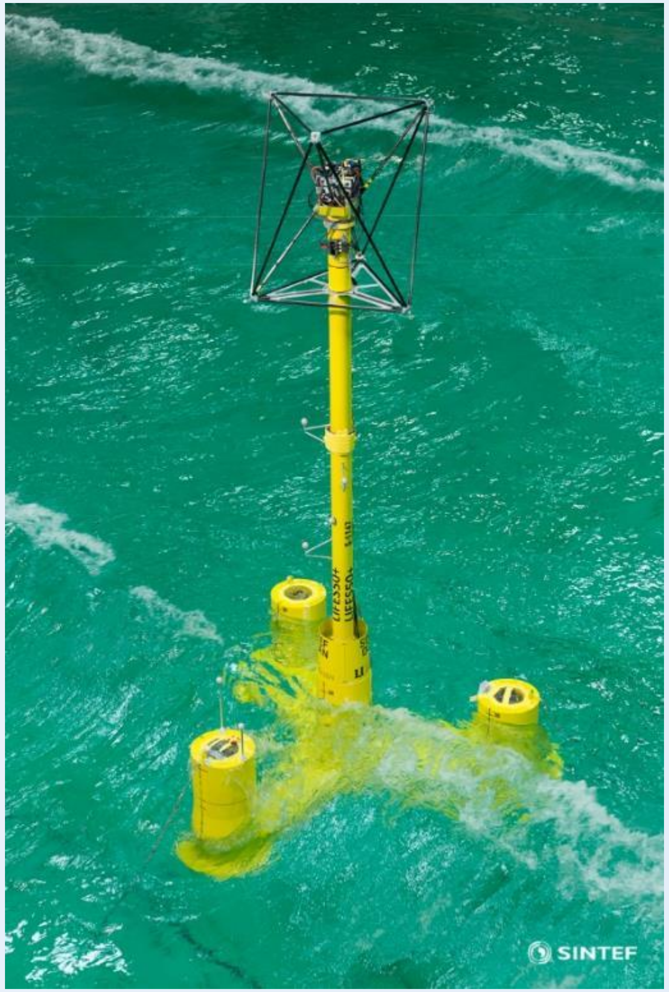
First step: scale models (1:36) preparation for Olav Olsen's OOstar and NAUTILUS semisubmersible concepts.

Numerical model adaptation for the Real-Time Hybrid Model testing (ReaTHM® testing) to generate realistic and controlled aerodynamic loads.

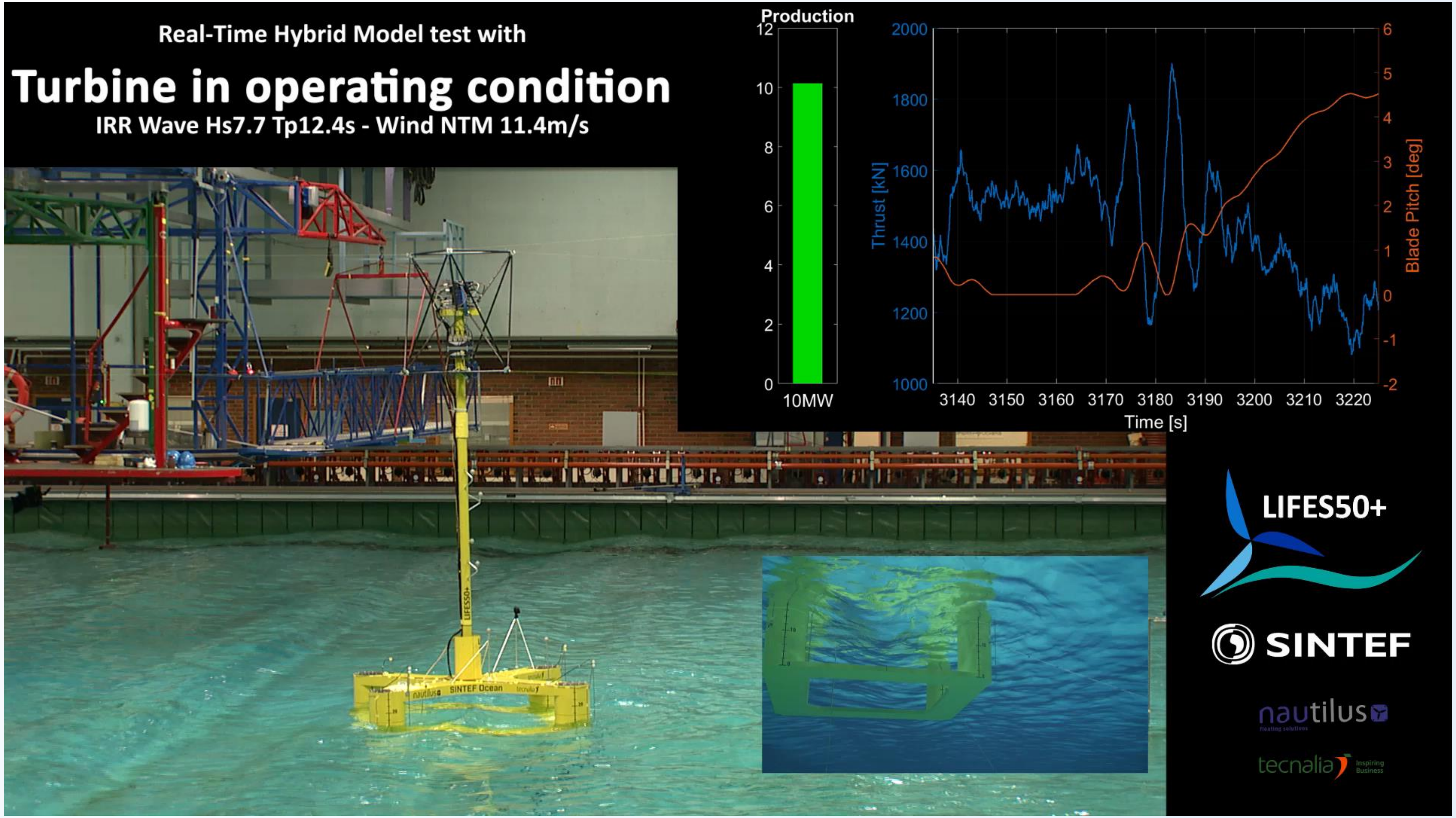
Load cases for the experiments.

- inclining tests,
- pullout tests,
- decay tests,
- pink noise (white noise) wave spectrum tests and regular wave,
- wind only tests,
- irregular wave tests



Wave tank experiments results



Wind tunnel experiments

First wind tunnel campaign carried out in July 2018 with Olav Olsen's OOStar concept.

Second wind tunnel campaign carried out in November 2018 with NAUTILUS concept.

Numerical modelling

Research on advanced numerical modelling.

Different numerical tools are required for different stages in the design of floating wind substructures.

First step: state of the art on numerical modelling

Public definition of selected floater concepts for the 10MW DTU WTG

- Public deliverable with the description of NAUTILUS steel semisubmersible and Olav Olsen concrete semisubmersible models for a 10MW wind turbine.
- FAST numerical models available on the project web site and DTU's repository.

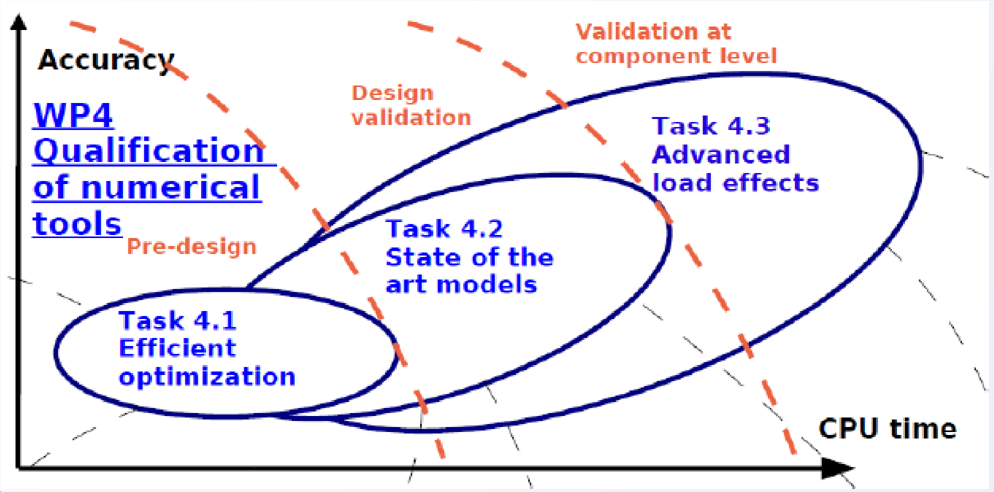
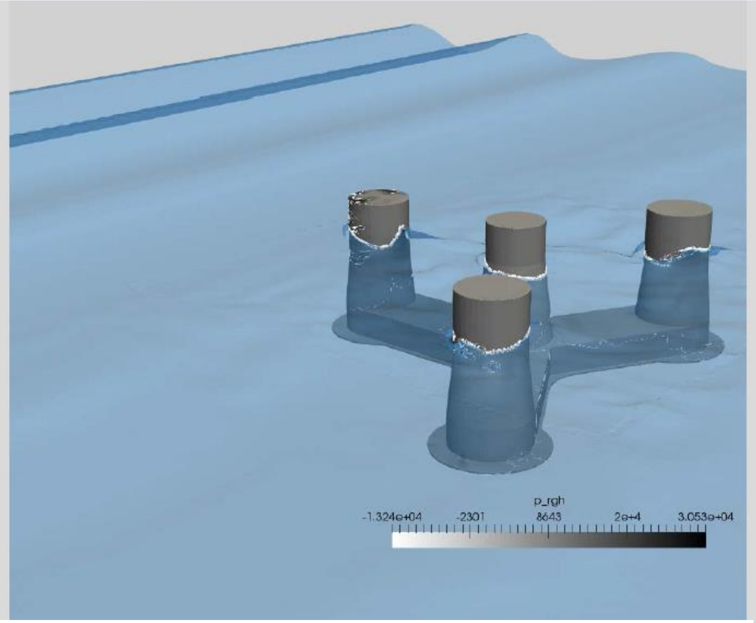


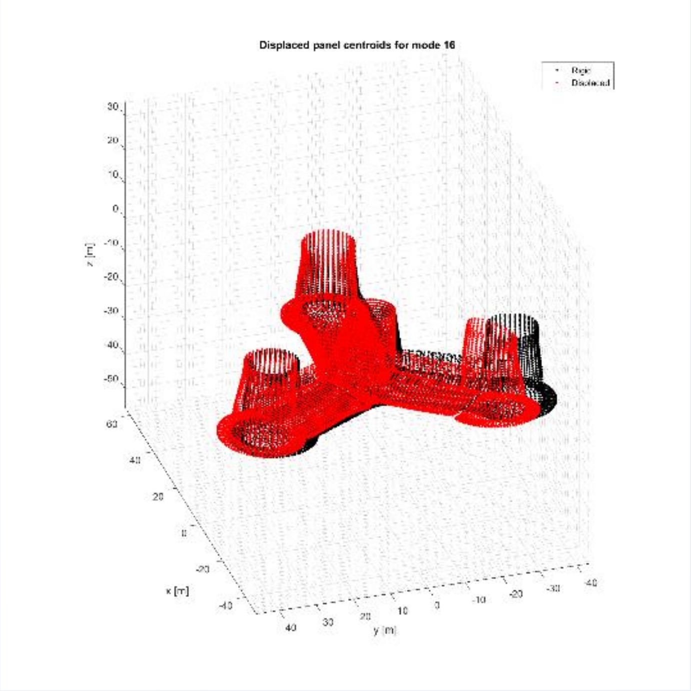
Figure 2: The OO-Star Semi floater (left) and the Nautilus floater (right). Figures provided by Dr.techn. Olav Olsen AS and Nautilus Floating Solutions, respectively.

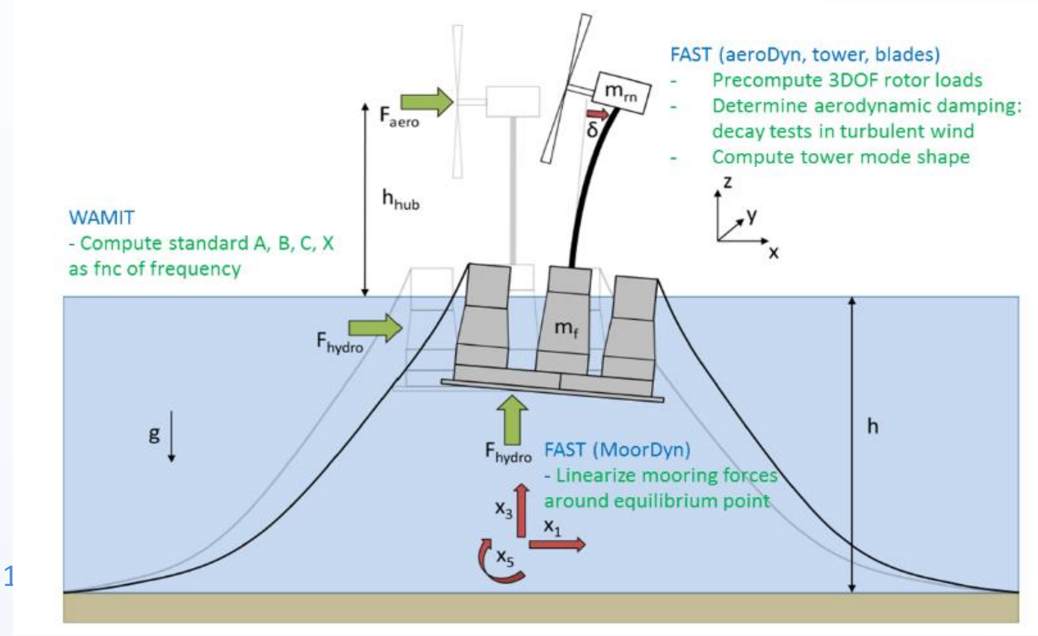
Numerical modelling

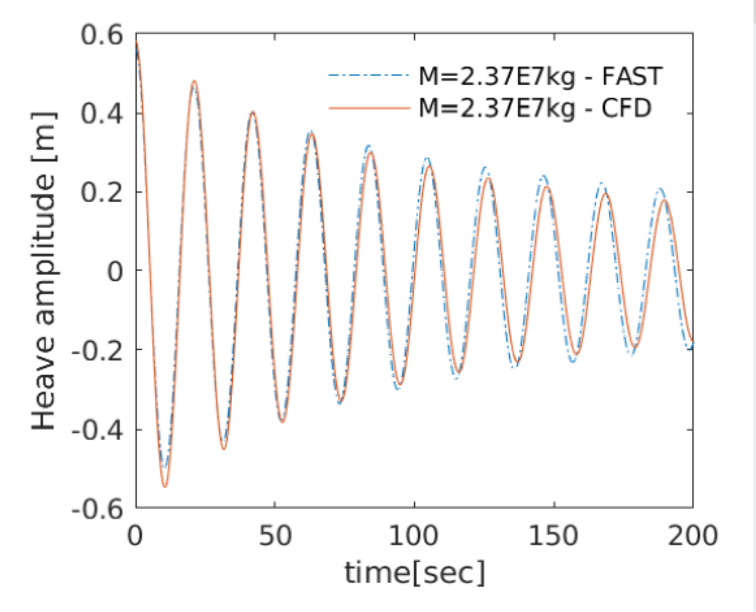
…to continue with simplified and advanced modelling applicable to different stages of the design process

- Modelling of floater flexibility and second order forcing
- Hydrodynamic CFD analysis
- QuLAF accelerated frequency domain model
    - 10% match for the analyzed cases
    - Accelerated model is ~1500 times faster than mother model





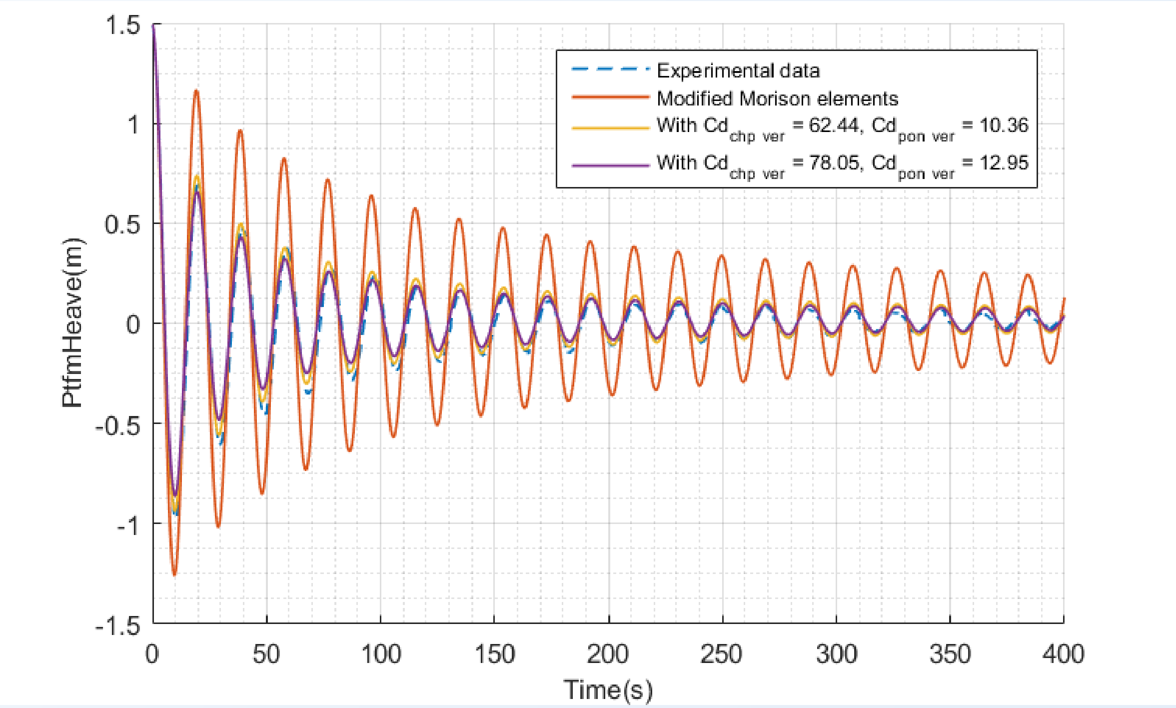




Numerical modelling

Numerical models calibration using experimental results

- Benchmark of the numerical tools against physical tests –wave tank-
- Assessment of the state-of-the-art and simplified numerical models for the two public floaters of the LIFES50+ project: Olav Olsen's OOStar and NAUTILUS semisubmersible floating structures.
- Identification of the driving design load cases –DDLCs- and calibration for those cases.
- Public deliverable: D4.6 Model validation against experiments and map of model accuracy across load cases.
    - Calibration of hydrodynamic coefficients in time domain simulation is essential to achieve sufficiently accurate load predictions.
    - Simplified QuLAF and SLOW models provide a big benefit for concept and design studies in the initial stages of the design.

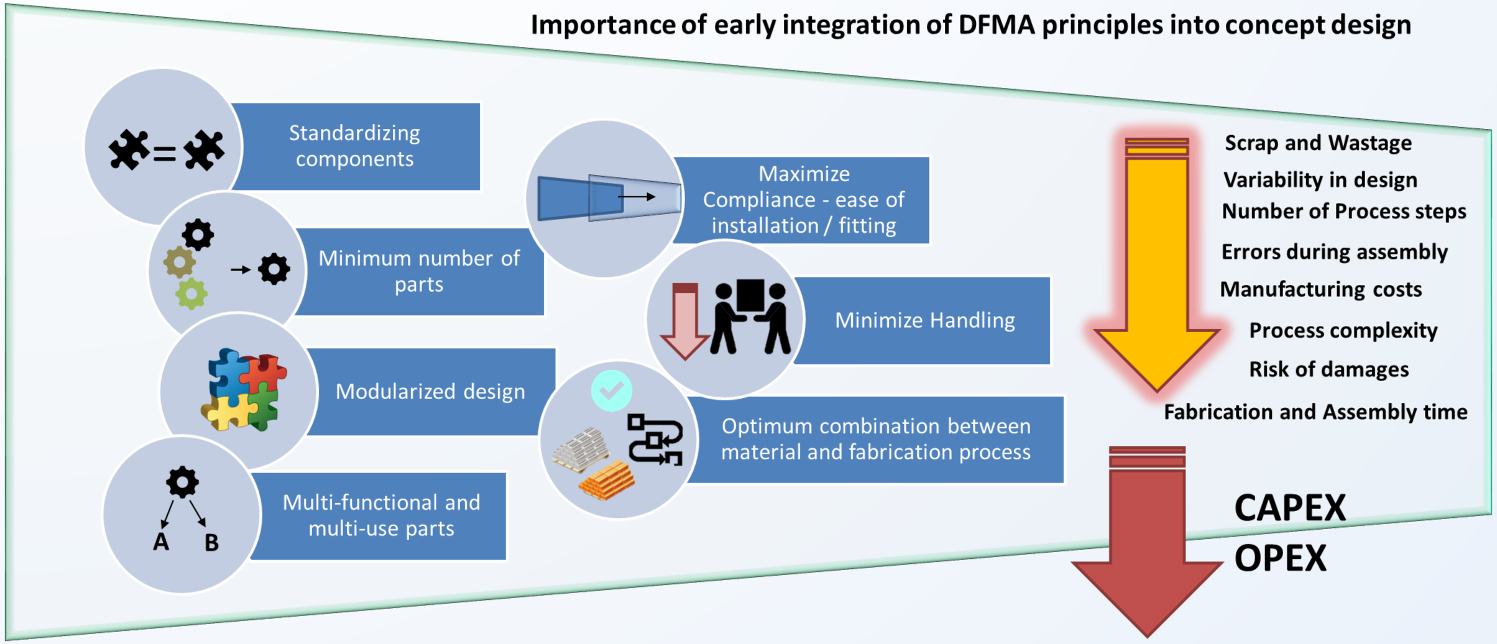


Comparison of heave decay simulation with experimental data for different FAST models –NAUTILUS concept-

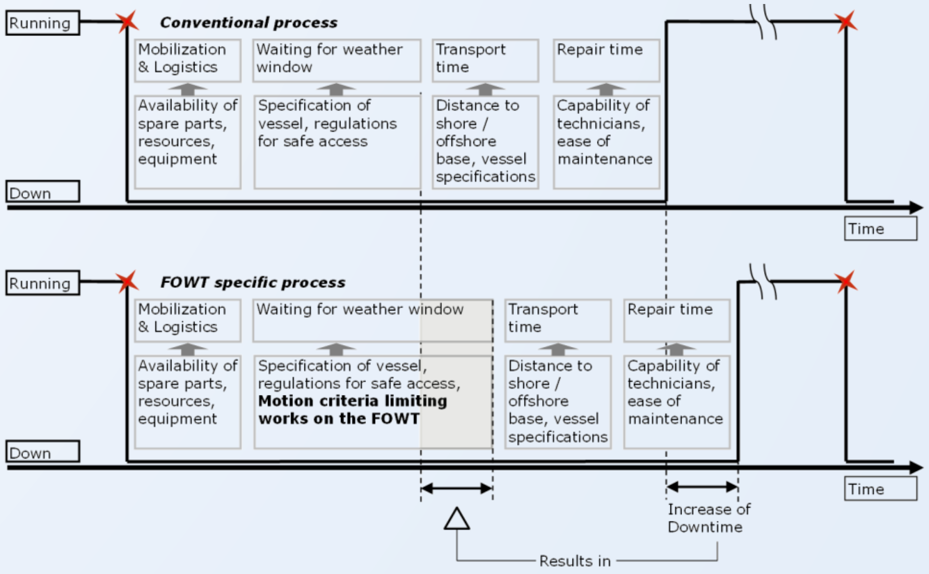
Industrialization

Ongoing work with two main objectives:

- **Industrialization of the two floating concepts** (OO Star and Nautilus) to reduce CAPEX/OPEX, considering floater mass production and identifying industrialization challenges.
- Development of an industry focused and cost-effective lean methodology for floater fabrication and installation, in close collaboration with concept developers, in order to improve manufacturing readiness - **MRL at the same level as TRL**-



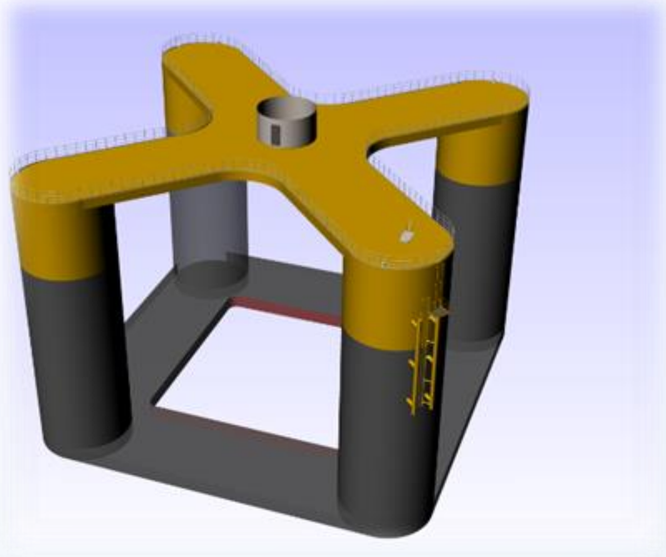
Workability study for FOWT O&M

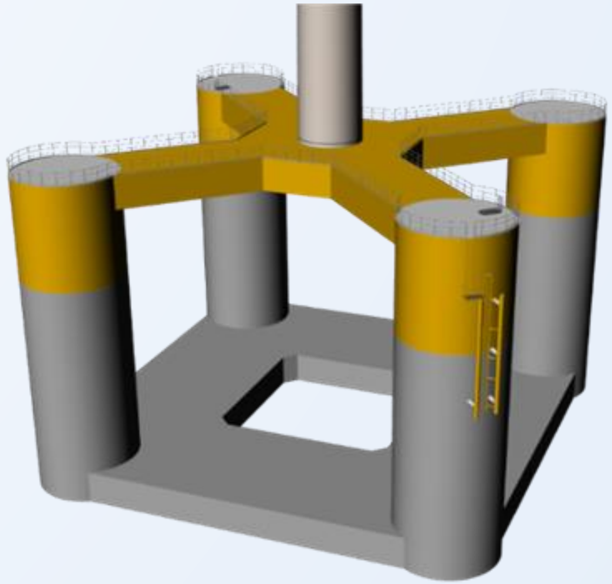


Concepts Design Optimization

Optimized design of the selected concepts:

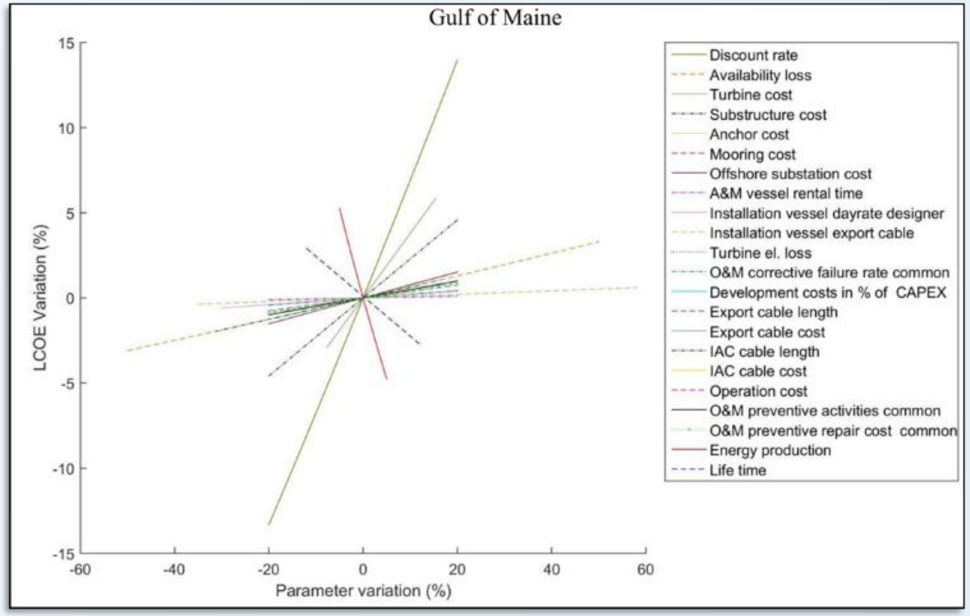
- Taking advantage of the project achievements in experiments, numerical modelling and industrialization.
- Re-design for one of the sites and extrapolation to the other two.
- Optimized design in terms of hull, mooring and tower sizing; serial manufacturing; T&I; O&M.
- Updated figures for the LCOE and LCA calculation.





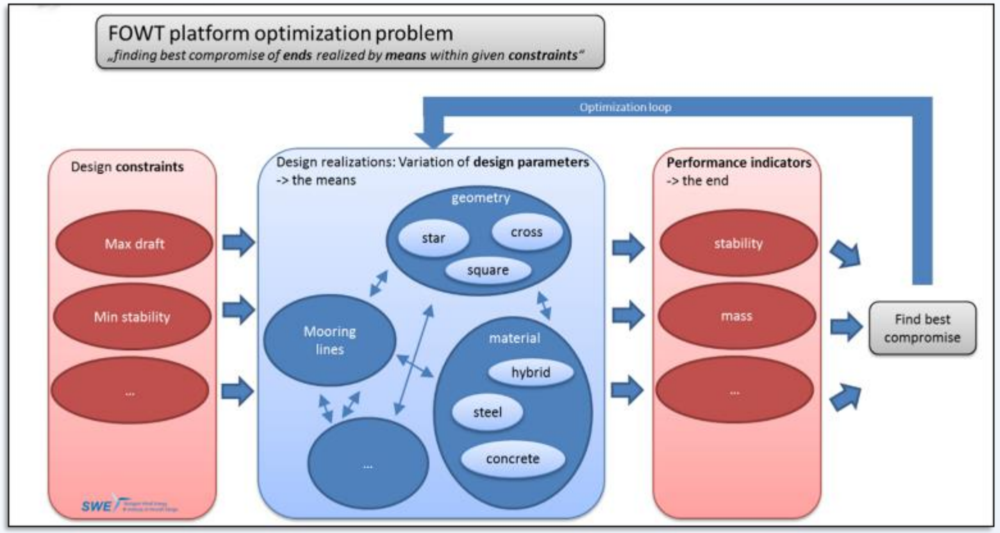
Design Practices

Several activities focused on the development of design practices for FOWT



Generalized LCOE assessment and sensitivity analysis across different platform concepts.

- Determination of most influencing parameters on different FOWT platforms
- Identification of design dependent parameters



Guidance on platform and mooring line selection, installation and marine operations

- Mooring design key findings (design, standards, tools, steel chain moorings, hybrid solutions, manufacturing, installation, etc.)
- Analysis on large wind turbines (dynamic cable, number of mooring lines, additional elements)

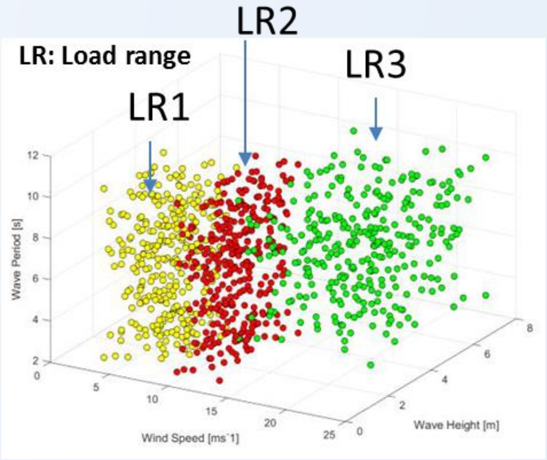
Design Practices

Sensitivity analysis & determination of relevant simulation settings / DLCs

- Goal: determine the critical environmental conditions across a wide range of variables, using FAST simulations & Monte Carlo sampling
- Results:

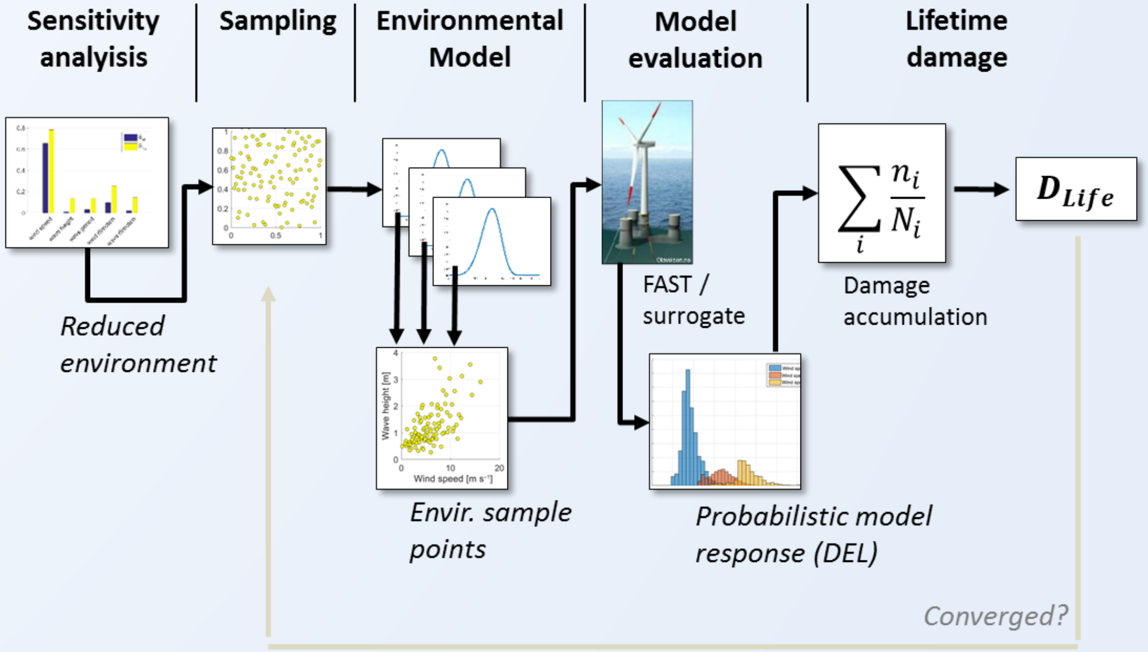
1) Small wind speeds: increase of fatigue loading dominated by wind speed
2) Larger wind speeds (>= rated): increase of fatigue loading dominated by increasing wave heights.
3) Large wave heights: added impact from wave period

Simulated events:



Probabilistic fatigue load assessment

- Goal: consider full uncertainty and reduce safety gap
- Results:
    1. FAST simulations & Monte Carlo sampling
        - High accuracy for given site and concept
    2. Surrogate model & Monte Carlo sampling
        - Fast results for arbitrary sites and given concept

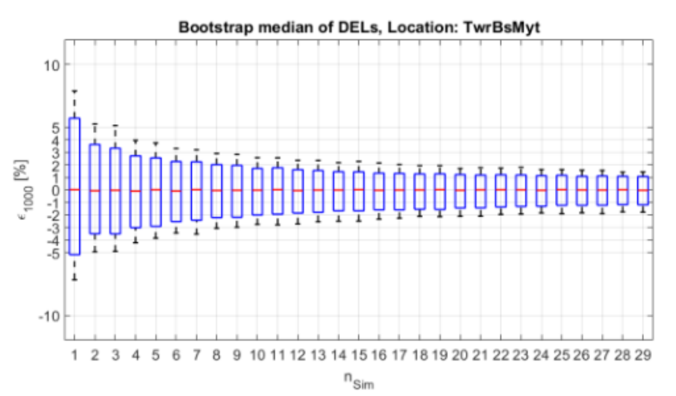


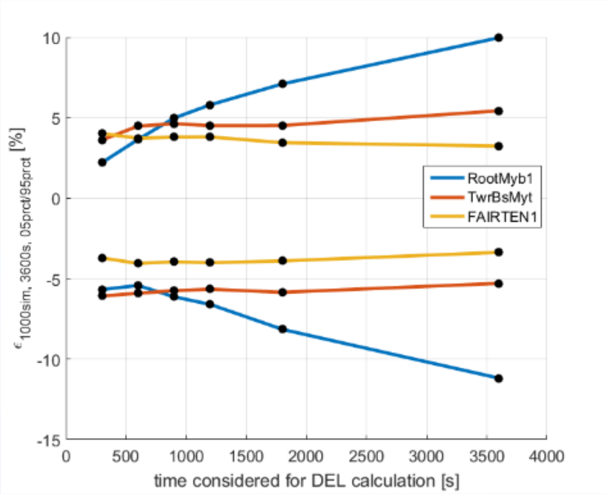
Design Practices

LIFES50+

Determination of relevant simulation settings

- Provides recommendations on how to verify the load simulation set up.
- Focus on DLC 1.2, 1.6, 6.1.
- Based on statistical analysis.
- Analysis of the effect of simulation length





1 - Pre-simulation initial conditions

- Set up of initial conditions for a simulation

2- Run-in time

- Simulation time to be later disregarded due to initial transients

3 - Sensitivity to environmental parameters

- Determination of the important parameters for load calculations
- Separate: peak shape parameter, marine growth

4 - Number of seeds needed

- Variation of seed for fatigue load calculations

5 - Effect of simulation length

- Trade-off between shorter simulations on the results of the ultimate and fatigue load

Summary of results and dissemination

68 deliverables, 39 of them being public, including numerical models of the two selected floaters and DTU's 10 MW wind turbine. Public deliverables available on the project web site www.lifes50plus.eu

More than 80 dissemination activities carried out so far including:

- Posters and presentations in conferences
- Articles in different types of journals
- Project newsletter on the web site
- Wave tank experiments presentation
- Press releases
- Youtube video
- … and much more coming soon!!

Concept development and optimization

Upscale innovative floating substructure concepts to a 10 MW wind turbine for water depths greater than 50 meters. During the process several reports regarding oceanographic and meteorological conditions for the design, wind turbine models for the design, concept design, wind turbine controller adapted to each concept, report on marine operations, up-scaling procedures, information for concepts evaluation and concept design optimization will be produced.

- Deliverable 1.1 Oceanographic and meteorological conditions for the design
- Deliverable 1.2 Wind turbine models for the design (Summary)
- Deliverable 1.6 Upscaling procedures (Summary)

Design practice

This work package will scrutinize, examine and summarize the process and activities of all work packages related to design questions throughout the entire project to develop a recommended (industry-) design practice (RDP) for the design and qualification of large FOWT substructures to support the innovative process of the technology by creating a document to guide the reader through the design. In order to fulfill that objective, initially a review of existing design practice and guidelines for floating offshore wind turbine substructures will be performed. Additionally, relevant information, lessons learned, key findings and new knowledge generated within all design related work packages will be continuously analyzed at important milestones of the other work packages.

- Deliverable 7.1 Review of FOWT guidelines and design practice (Summary)
- Deliverable 7.2 Design basis (Summary)
- Deliverable 7.4 State-of-the-Art FOWT design practice and guidelines (Summary)
- (Summary)
- ases (Summary)

Experimental studies

This work package verifies the feasibility, safety, and performance of two selected substructures out of the four designed in the first work package. The reliability of existing techniques for floating offshore wind turbines will be increased. During the experiments the numerical models will be calibrated. Moreover, this work package works out how wind tunnel and ocean basin tests can be combined in an optimal way to validate substructure concepts efficiently and more accurately than today.

- Deliverable 3.1 AeroDyn validated model (Summary)
- Deliverable 3.2 Wind turbine scaled model (Summary)
- Deliverable 3.5 Hexafloat robot (Summary)

Qualification of numerical tools

The work package focuses on the qualification of numerical models and their rational use in design optimization and design verification. A multi-fidelity approach is utilized, centered around state-of-the-art aero-elastic modelling which is nowadays used for design verification; simpler, efficient models which are turned into an optimizing pre-design tool, and advanced models at component level that predict physical load effects associated with large floaters beyond state-of-the-art. Schematically, these three levels of models are placed along the diagonal in the accuracy-CPU time diagram and the work package focuses on the increased efficiency of and accuracy potential associated with the combination and validation at models at all levels.

- Deliverable 4.1 Simple numerical models for upscaled design
- Deliverable 4.2 Public definition of the two LIFES50+ 10 MW floater concepts (Summary)
- Deliverable 4.3 Optimization framework and methodology for optimized floater design (Summary)
- Deliverable 4.4 Overview of the numerical models used in the consortium and their qualification (Summary)
- Deliverable 4.5 State-of-the-art models for the two LIFES50+ 10MW floater concepts (Summary)
- Deliverable 4.6 Model validation against experiments and map of model accuracy across load cases (Summary)
- Deliverable 4.7 Models for advanced load effects and loads at component level (Summary)

Final project workshop to present the results during WindEurope 2019 conference (3 April 2019, Bilbao)

Project Management

- LIFES50+ has been very ambitious with a high level of activity from the project kick-off.
- The competitive nature of the project –stage one- has provided an interesting dynamic driving the work forward and motivated the participants to do their best.
- Partners have delivered very good results and reached agreements on important topics, like the concepts evaluation.
- Good collaboration atmosphere and high quality results, with important public results –i.e. numerical models of two FOWT-
- A project extension has been granted: new end date 30 April 2019.
- Final project event during WindEurope 2019 conference.

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