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IOWTC 2025
INTERNATIONAL OFFSHORE WIND TECHNICAL CONFERENCE

UNIVERSITÉ DE TOULON
TOULON, FRANCE

Project success and competitive substructures through simultaneously efficient and accurate FOWT fatigue direct computation

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Paper co-authors

Project success and competitive substructures through simultaneously efficient and accurate FOWT fatigue direct computation

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Presentation Overview

- Introduction
- Floating wind design and the specifics of substructures fatigue
- Design phases and integrated solutions
- Focus on FOWT structural calculation and fatigue assessment
- Conclusion and key takeaway

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EKIUM
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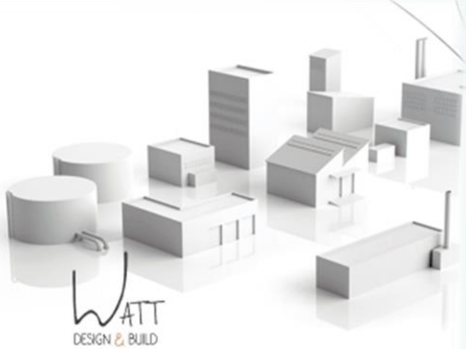
1. SNEF Group and EKIUM

SNEF Group

A major player in services for the industry

2.2
Billion euros
in revenue

14,000
Employees
worldwide



SNEF – Energy

FOURÉ LAGADEC – Mechanical Engineering

EKIUM – Engineering

WATT DESIGN & BUILD – Office Design & Layout

visiativ – CAD & PLM

iQANTO – Digital & Robotics

abgi – Innovation Management

EKIUM

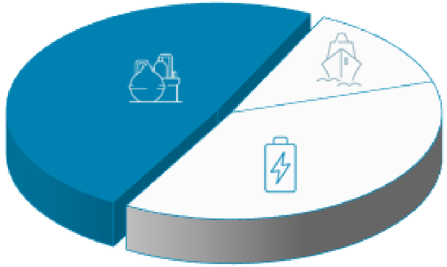
French leader and European player in industrial engineering

300 Millions of euros in sales

2 500 Employees

15 Countries

31 Locations in France



49% Industry

- 14% Chemical & Petrochemicals
- 16% Life sciences
- 2% Paper
- 4% Metallurgy & steel
- 4% Automotive
- 9% Other industries (Aerospace, Food, Materials, Mining, Glass)

17% Naval Civil & Military

34% Energies

- 15% Nuclear power
- 14% Oil & Gas
- 5% Energy / Environment

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2. EKIUM and Offshore Wind

Key player in the energy transition and decarbonisation

Acquisition of Sofresid Engineering in 2023

➡ Strengthened EKIUM's position as a naval engineering leader

➢Floating Offshore Wind

- 15 years of experience with Naval Energies and Saipem, with **major projects from conceptual to FEED phases**
- Dedicated FOWT calculation chain
- Concepts screening, optimization & design to cost
- Expertise in coupled simulation, time domain fatigue calculations, structure and mooring
- Fabrication & Assembly, Transport & Installation execution plan
- ***Some of our clients include***

SAIPEM
Ekwil
seaway7
T.EN
Dragados Offshore
BOUYGUES TRAVAUX PUBLICS
EDF
CHANTIERS DE L'ATLANTIQUE

➢Bottom-fixed foundations

- Design from basic to detailed engineering, with experience in MP and GBS
- T&I Engineering & Operations
- 2 major references: FECAMP & COURSEULLES windfarms EPCI
- TP (Transition Piece) modularization and standardization (MEIR module)

➢Offshore Substations (OSS)

- Foundation and Topside Multidisciplinary engineering
- Expertise based on +30 years of O&G Living Quarters and Technical building know-how

TRACK RECORD: Over 20 OW projects worldwide from PRE-FEED to FEED and EPCI

3. Floating wind design paradigm shift

➢ New design mindset required:

- Substructure hosts a “living payload” (WTG) vs. static topsides in O&G
- Serial fabrication and installation considerations
- **Most operational life spent with turbine in production**
- System mechanics are strongly coupled

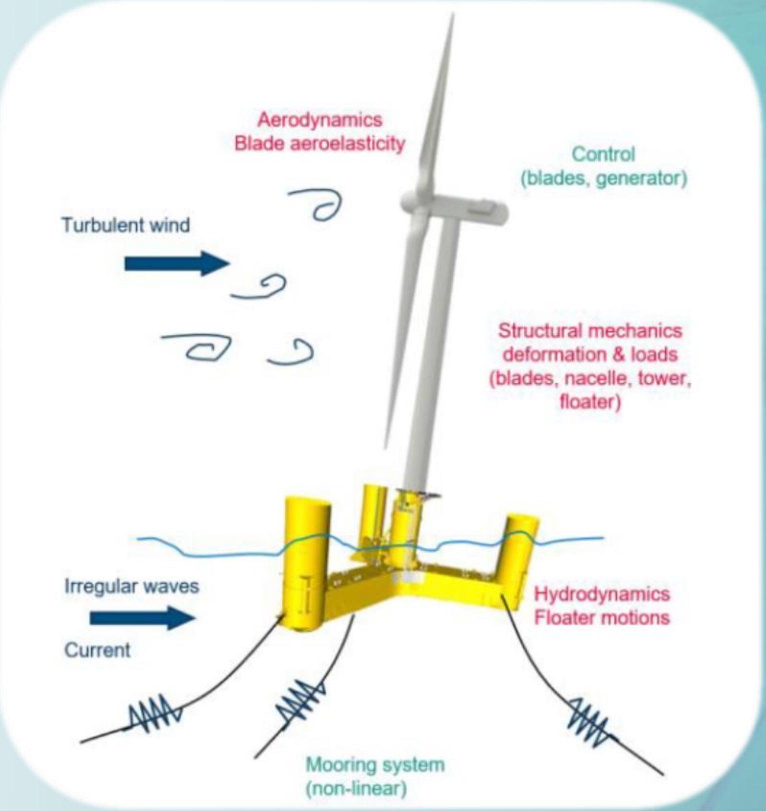
➢ Key loading differences:

- Wind becomes an important loading process
- Vibration from WTG aero-servo-elastic loads (3P/6P)
- **Strong non-linear coupling between WTG controller, hydrodynamics and mechanics**

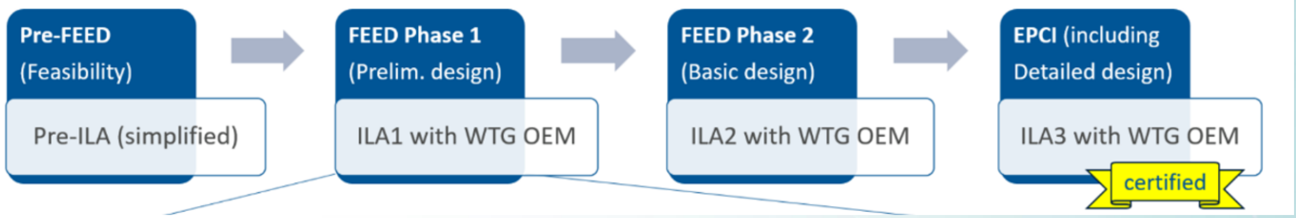
NEW ITEM	CONVENTIONAL FLOATING STRUCTURES	FOWT LOADING SIDE	FOWT RESPONSE SIDE
Detailed wind	Generally insensitive to wind loading details	Wind becomes an important loading process, high sensitivity to turbulence	Low-frequency cycles from wind: thrust, gravity actions due to inclination, mooring tensions
Vibration	No significant global vibrations (excluding ringing and springing)	WTG aero-servo-elastic loads, esp. 3P and 6P synchronous excitations below 1 Hz	Synchronous excitations introduce vibrations, amplified by fore-aft & side-side tower bending resonances
Coupling	Fairly decoupled loading processes, wave dominated	Strong coupling of all loadings through WTG controller and moving parts	Wave-induced motions and wind turbulence affect control, which has knock-on effects on motions and vibrations Aerodynamic damping from revolving rotor & control

4. Fatigue challenges in FOWT substructures

- **Critical design drivers**
  - **Fatigue governs** design of major steel structures and mooring components
  - Can impact structure mass by **up to 30%**
  - Must be incorporated **early** and robustly
  - Existence of potential "vicious cycles" in design
- **Complexity factors**
  - Mechanical flexibility sensitivity
  - Structural damping effects
  - Cyclic loads emerge from coupled dynamics
  - **Thousands of time-domain** Design Load Cases (DLCs) required
- **Calculation requirements**
  - Time-domain coupled analysis mandatory per certification bodies (IEC, DNV, BV)
  - Full time series processing for damage computation
  - Both **time** and **CPU-intensive (up to weeks)**



5. Design phases and calculation chain requirements



➢ Different phases, different needs : this calls for an adaptive workflow

- From simplified methods in early phases…
- … to comprehensive and detailed stress calculation later
- **Need for global FOWT or local design loops (structural/mooring)**
- As phases progress further, calculation needs **grow exponentially** : need for **scalable** calculation tools and solutions

➢ Technical requirements : demanding standards, even more for fatigue

- Thousands of DLCs with long simulation times (**ULS : 1-3h** ; **FLS : ~30mn vs. 10mn for bottom-fixed**)
- High sampling rate for blade passing harmonics (>0.6 Hz), as insufficient sampling can lead to 40% underprediction of damage
- Structural stress resolution: in critical details ~50-100mm and tens of millions of time stamps
- Full shell model interrogation at each finite-element panel

➢ Process requirements : an automated alliance of disciplines, not a sum of silos

- **Automation** and **repeatability** for parametric optimization
- **Consistency** between models and calculations
- **Efficiency** for early design phase application, **scalability** for detailed design phases

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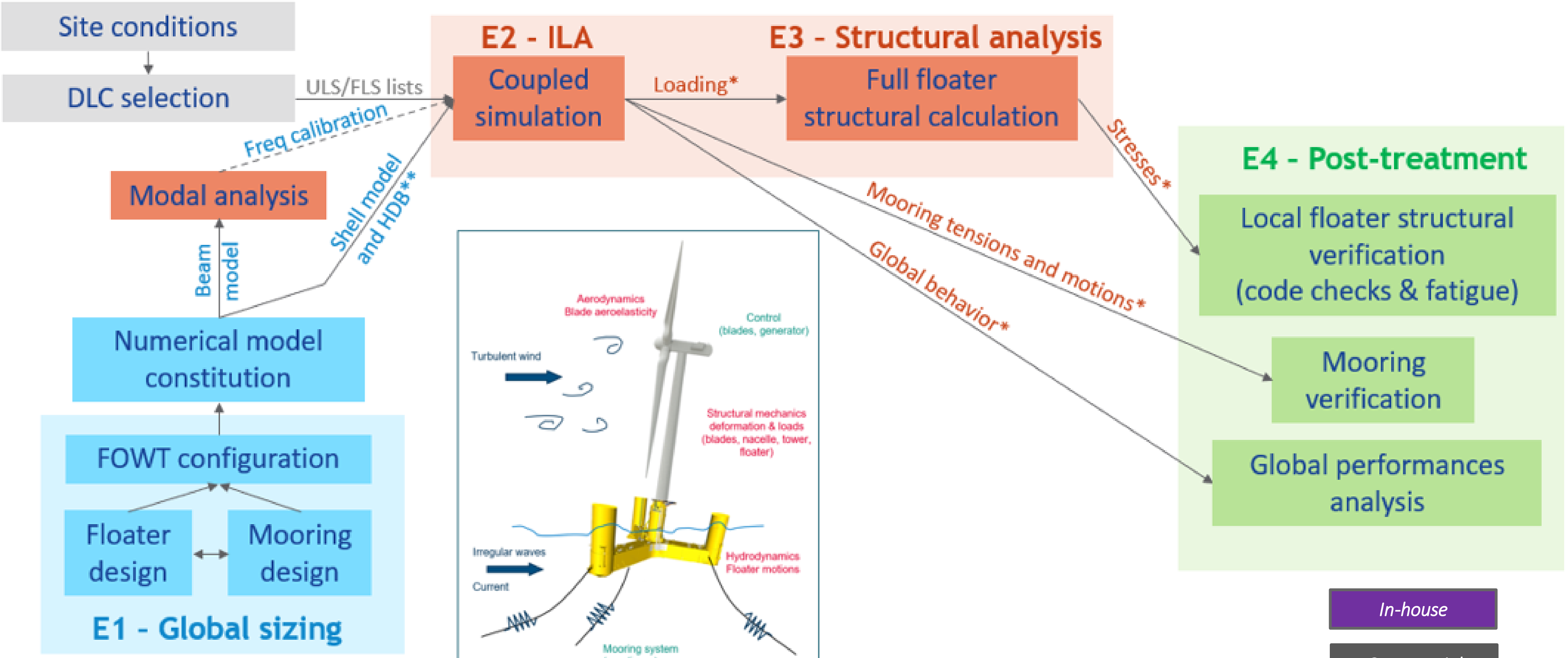
6. EKIUM's integrated workflow and solutions

Environmental Data + FOWT config. ➔ DLC + Models ➔ ILA: Coupled simulation aero/hydro/servo/elastic ➔ Structural ➔ Post-treatment



*Time series (data intensive)

**HDB = Hydrodynamic Data Base from potential flow solver

In-house

Commercial

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Site conditions
DeciList/FaciList
DLC selection

ULS/FLS lists
Freq calibration
Shell model and HDB**
Beam model

Modal analysis

Numerical model constitution

E1 - Global sizing
- FOWT configuration
- Floater design ↔ Mooring design

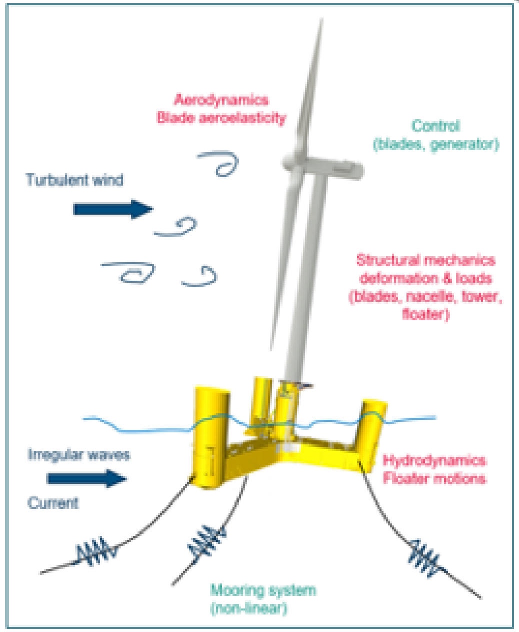
E2 - ILA
- Coupled simulation

Loading*

E3 - Structural analysis
- Full floater structural calculation

Stresses*
Mooring tensions and motions*
Global behavior*

E4 - Post-treatment
- Local floater structural verification (code checks & fatigue)
- Mooring verification
- Global performances analysis



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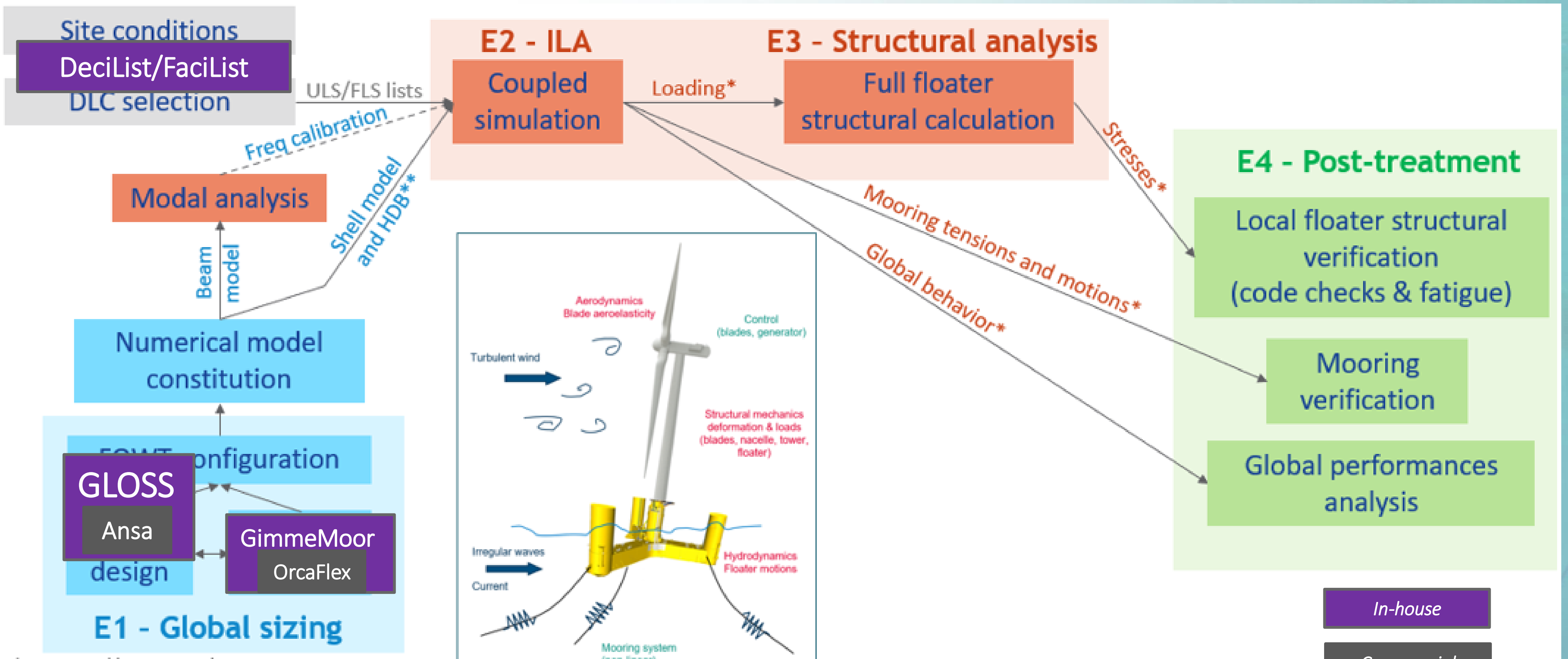

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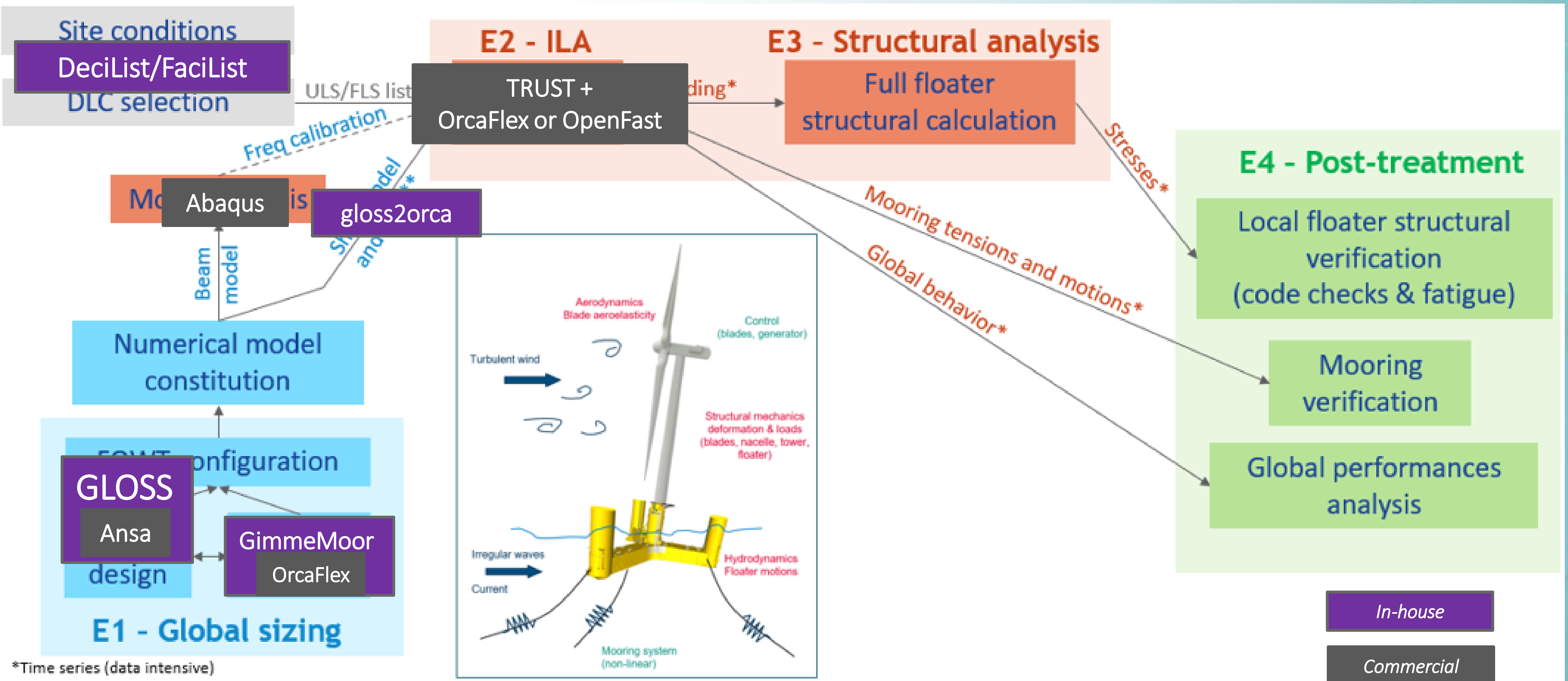

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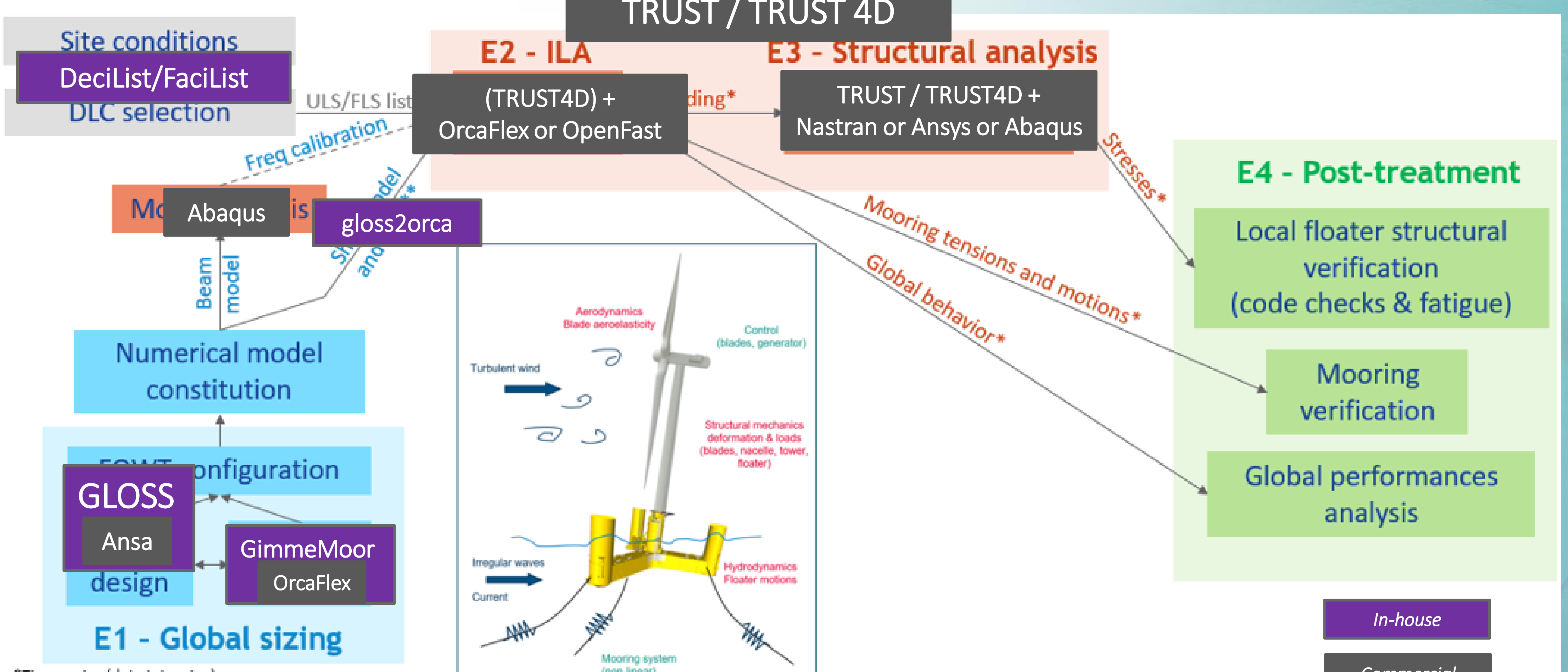

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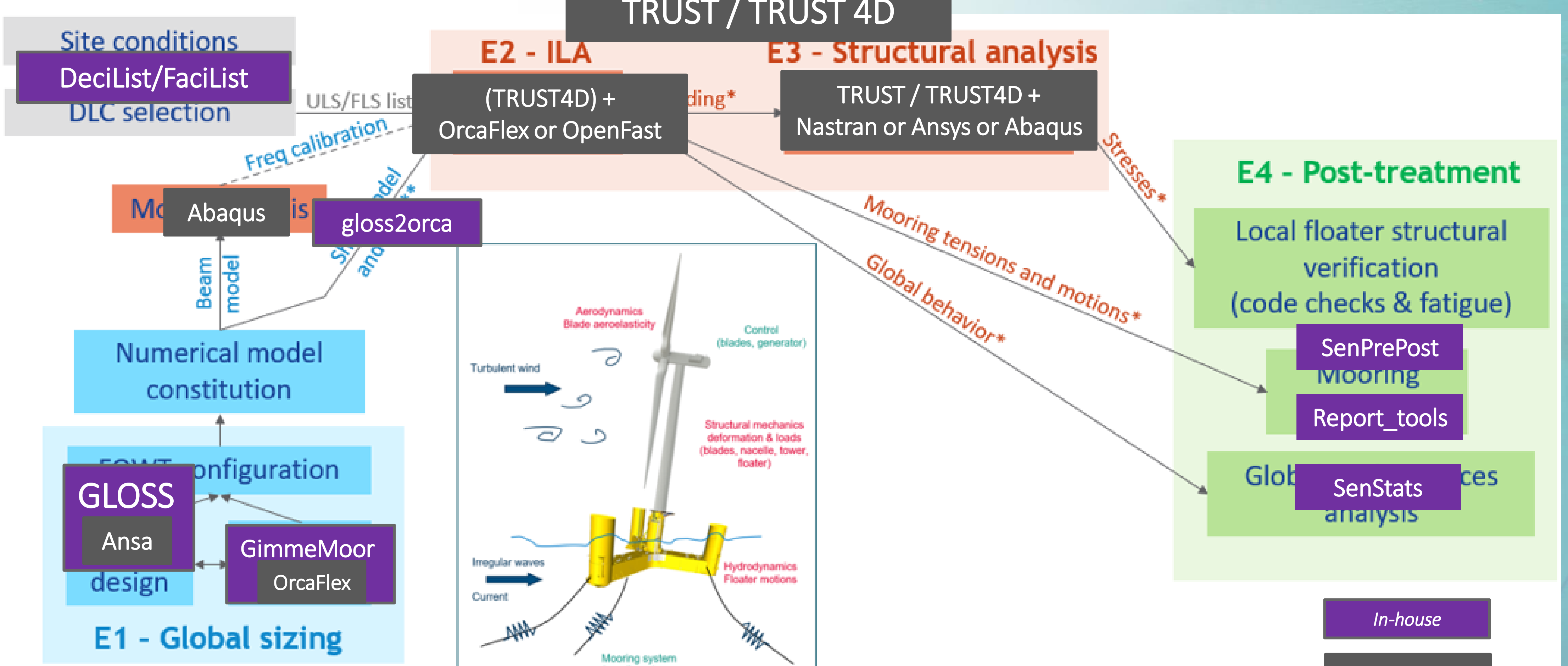

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6. EKIUM's integrated workflow and solutions

➢ Framework components

- Custom DLC selection tools : **DeciList /FaciList**
- In-house global sizing and scantling tool (**GLOSS**) for early designs and model building
- Custom mooring pre-design tool : **GimmeMoor**
- Custom automated post-treatment tools : **SenPrePost/SenStats/Report_tools**

➡ Pivotal to the quality and automated nature of the process

- ILA coupled simulation (with **OpenFast** or **OrcaFlex** through **gloss2orca**)
- **TRUST / TRUST 4D** software suite by **Front Energies**

➢ Key features

- Adaptive calculation methods calibrated to project phase
- **Dual-ILA (OpenFast or OrcaFlex)**
- Substructure flexibility incorporation in **modal analysis**
- TRUST's "Lodal" approach using linear combinations of unitary structural responses for ultra-fast structural resolution
- **End-to-end automation from wind-wave-current to local stresses (alliance of disciplines)**

7. Full floater structural calculation with TRUST

➢ TRUST's innovative "Lodal" Response Database

- **Unitary response approach** for computational efficiency
- **Linear combinations** of load patterns and amplitudes for scability

➢ Load components

- Point loads: mooring lines, tower boundaries
- Distributed loads: accelerations and gravity
- Hydrostatic and hydrodynamic load mapping
- Elastic mode loads

➢ Computational efficiency

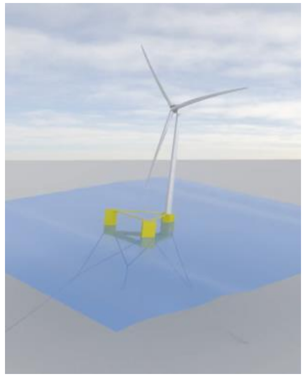
- Resolution at least **100x faster** than traditional time-domain methods, thus **allowing for time Domain fatigue calculation on all welds of the floater**
- **Selective response printing for fatigue assessment**
- Example: 30K elements from 1-hour simulation processed in <10 minutes
- 6,000 DLCs at 30K hotspots analyzed in <4 hours using parallel computing

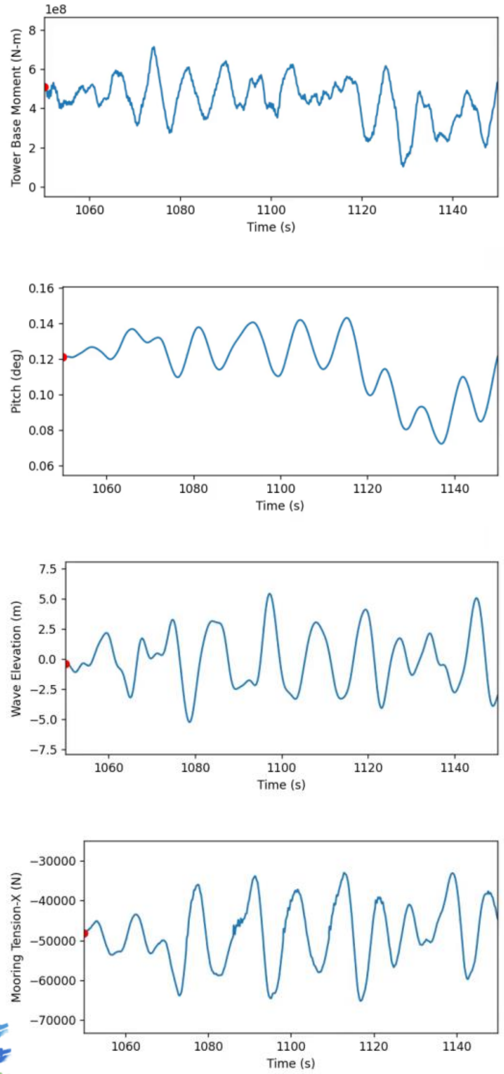
➢ ILA/Structural consistency checks for balanced models and validation

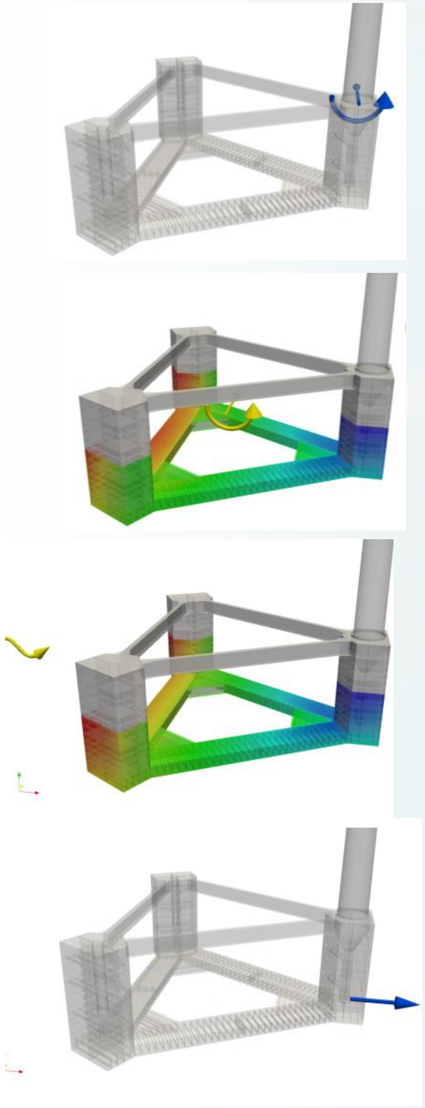
- Load recovery verification (>99% target)
- Resultant force monitoring at boundary conditions

7. Full floater structural calculation with TRUST (TD response)

Time history loads **Load components** **Load Mapping**





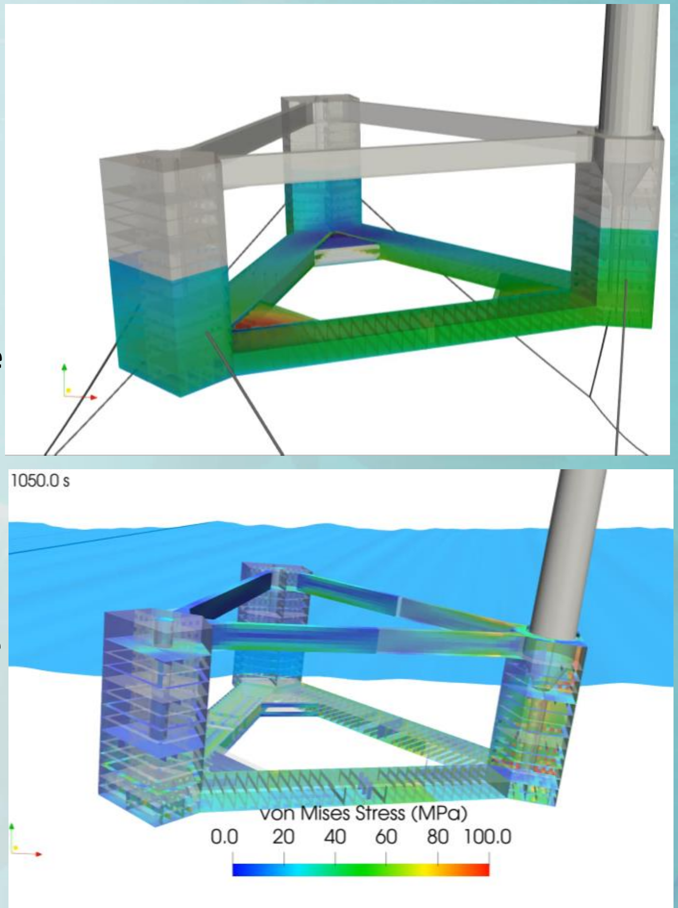


6 DOF conn. force

4 Hydrostatic Pressure
6 Inertia load
492 Radiation Pressure

82 Diffraction Pressure
36 Morison force

18 Mooring Force



Linear combination of 608 Load Components

48,000 FE Analyses (1 hr)
120,000 FE Analyses (3 hr)
34,320,000 FE Analyses (DLC 1.6)

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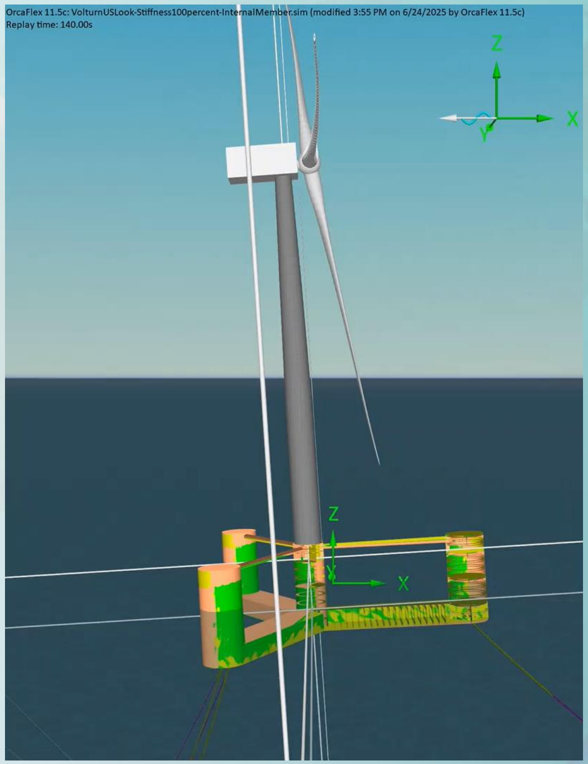
7. Full floater structural calculation with TRUST 4D (advanced)

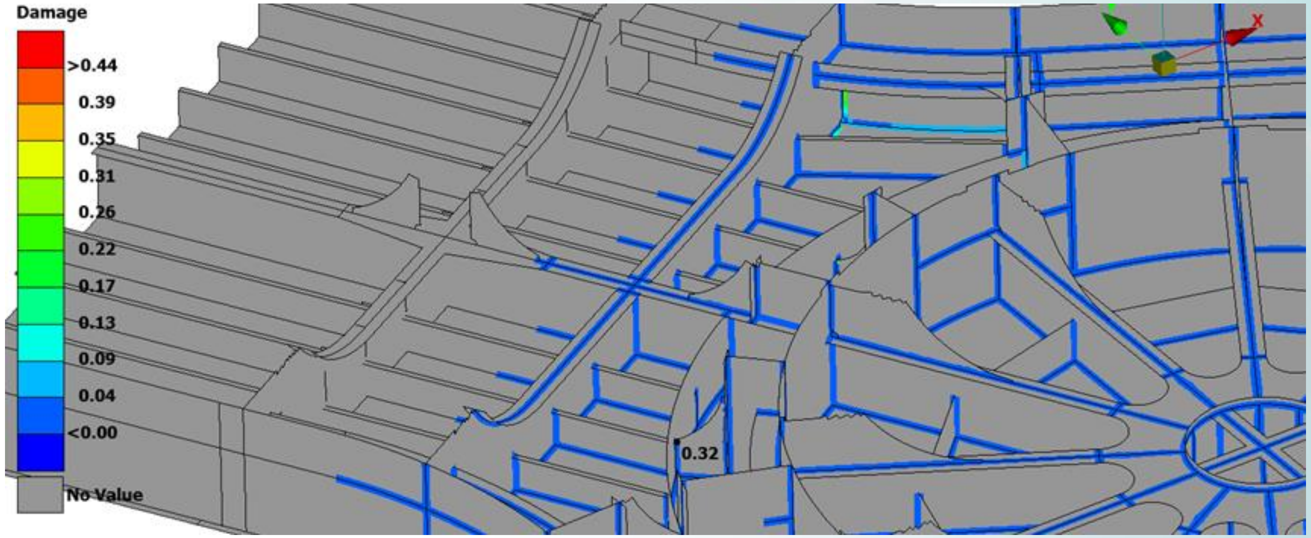
- **ILA are performed with rigid floater**
  - Implies tower frequency tuning
  - Larger/slender bodies are more prone to having eigenfrequencies close to turbine frequencies
  - The floater stiffness directly impacts the tower natural frequency
- **TRUST 4D allows for flexible floater during ILA**
  - No more tower frequency tuning
  - Accurate resonance check for 3P / 6P / 9P loading
  - Next-level structural optimization
  - Trade-off : longer process
- **Fully-automated dynamic structural analysis**
  - TRUST-like performance, more accuracy
- **Unmatched speed for TD dynamic structural analysis**
  - Less than 10 min for a 1-hour FLS DLC
  - Possible optimization through parallel computing
- **Best suited for specific design loops or detailed phases**



8. Fatigue assessment implementation

➢ Structural fatigue

- Fully integrated in TRUST : from loads to damage
- Direct mapping of long-term damage in all welds
- Optimization of steel plate thickness
- Weld type selection with appropriate S-N curves
- Selective stress printing along weld lines



➢ Impact on design

- Up to 30% of structural mass dictated by fatigue on steel floaters
- Significant cost implications

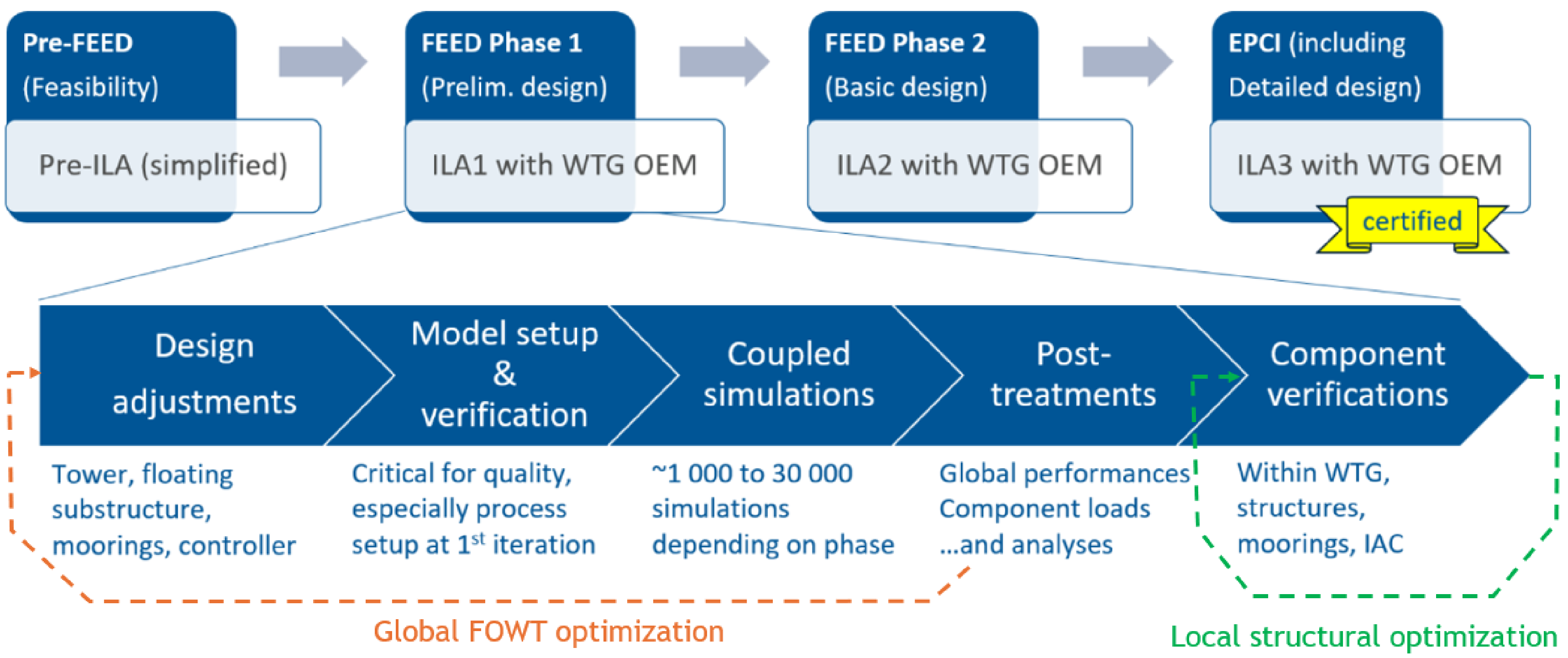
9. Conclusion and key takeaways

➢ Early access to critical information, including fatigue

- **Spectral-based DEL indicator at Global sizing or Pre-FEED stage**
- Detailed modal analysis in floating conditions
- Extreme loads and Damage Equivalent Loads (DELs)
- Extreme stresses and damage in every structural part
- Mooring component optimization data

➢ Design loops optimization

- **Global FOWT optimization** enablers
- **Local structural optimization** enablers
- Closed-loop design based on coupled simulations
- Prevention of diverging design phenomena



9. Conclusion and key takeaways

➢ Key takeaways

- End-to-end calculation chain **from coupled simulation to local stresses** with specific approach for efficient stress time series computation
- **Early fatigue assessment** from coupled simulations is critical and **enables design convergence**
- Reduced design cycles and avoidance of vicious cycles for **competitive and reliable floating wind system designs**