Demonstrator of the DTU wind turbine blade real time Digital Twin based on Simcenter platform

Presenters: Emilio Di Lorenzo, Silvia Vettori
Siemens Industry Software NV

Our history

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Ingenuity for life

UGS acquisition establishes software foundation for product development

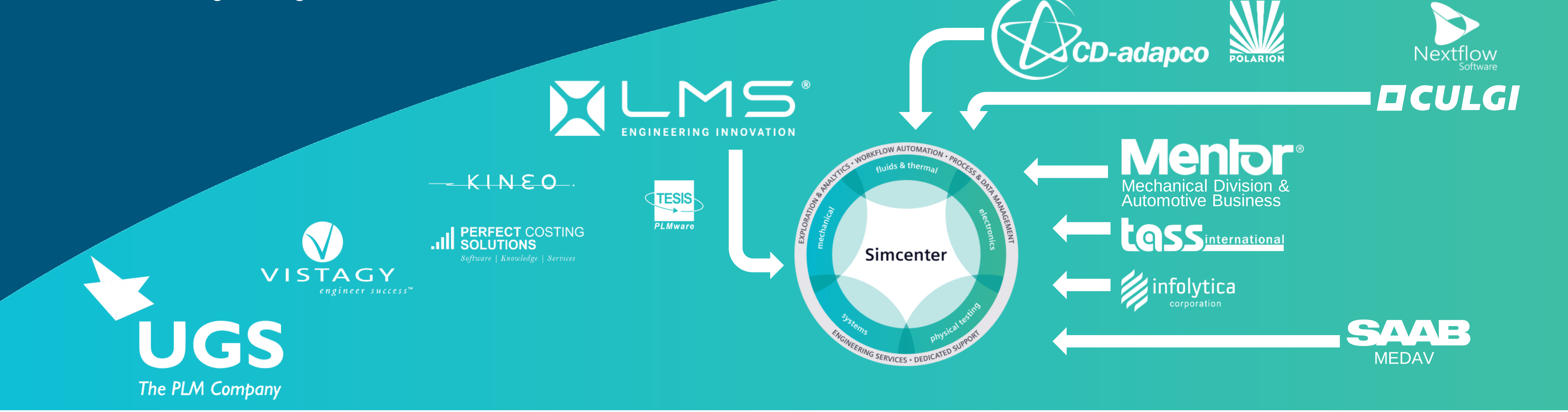
Acquisition of LMS expands strategy for verification and validation of systems

Siemens establishes leadership in product and process simulation to enable digitalization

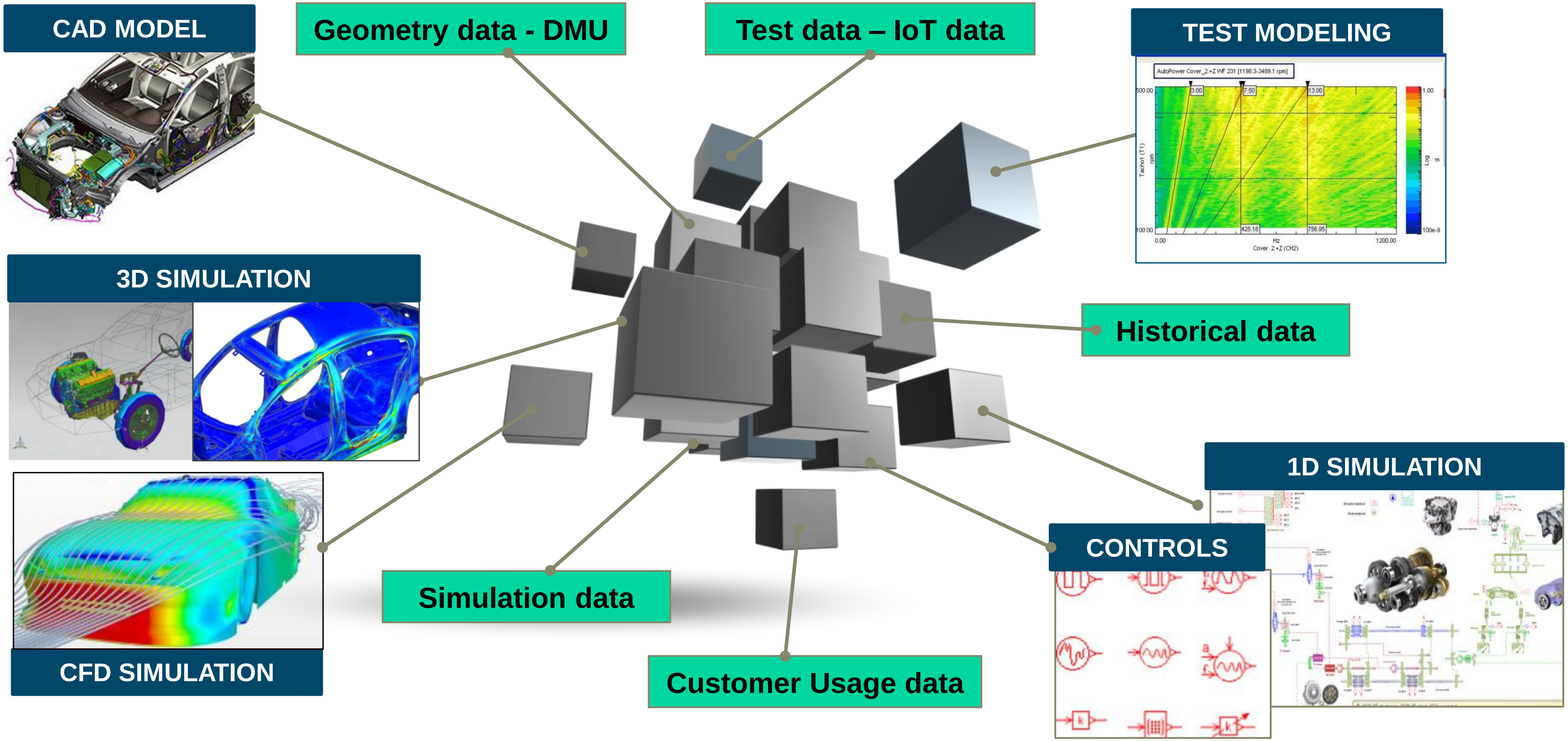
2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

Orsi Innotec | ETM | Active IBS | Preactor | Camstar | Bentley Systems

Production engineering and execution



From Disconnected Models and Data …



… to “Digital Twins” enabling Predictive Engineering Analytics

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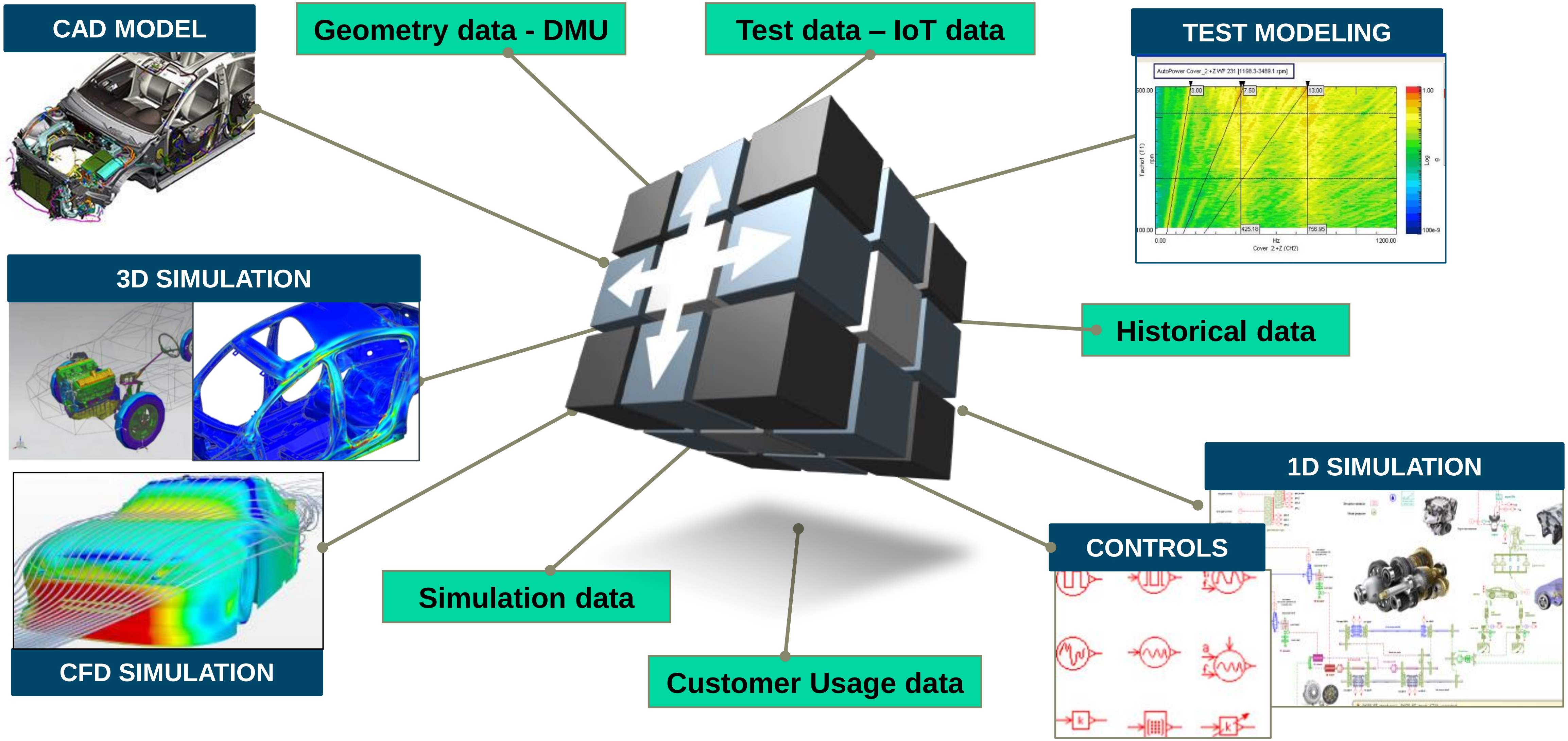


Executable Digital Twin Definition

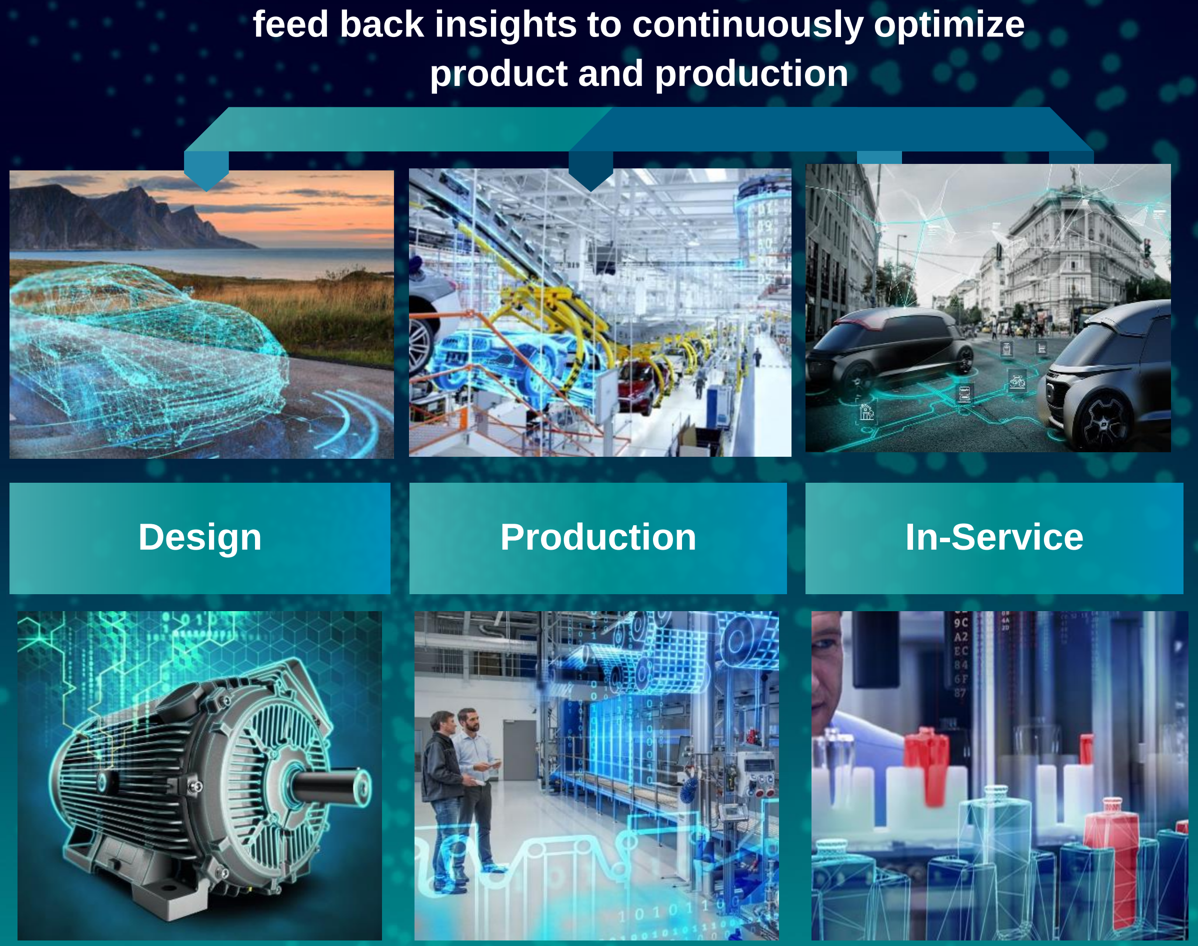
Precise virtual representation of a physical product or process

Used across its lifecycle to simulate, predict and optimize the product and production system

Made up of multiple representations or models for different aspects of physical behavior

An evolving object with a lifecycle that needs to be managed

Closed-loop digital twin provides for bi-directional connectivity between the physical asset and the virtual representation



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Executable Digital Twin Definition

For smarter products, systems, processes

Virtual
xDT
Physical

Self-contained executable digital behavior of an asset

Can be leveraged at any point in lifecycle

- developed, packaged & released by experts
- real time enabled
- leveraging AI and model order reduction techniques
- self adapting / calibrating
- leverageable by anyone one at any point in the product lifecycle on any certified device
- from edge to cloud

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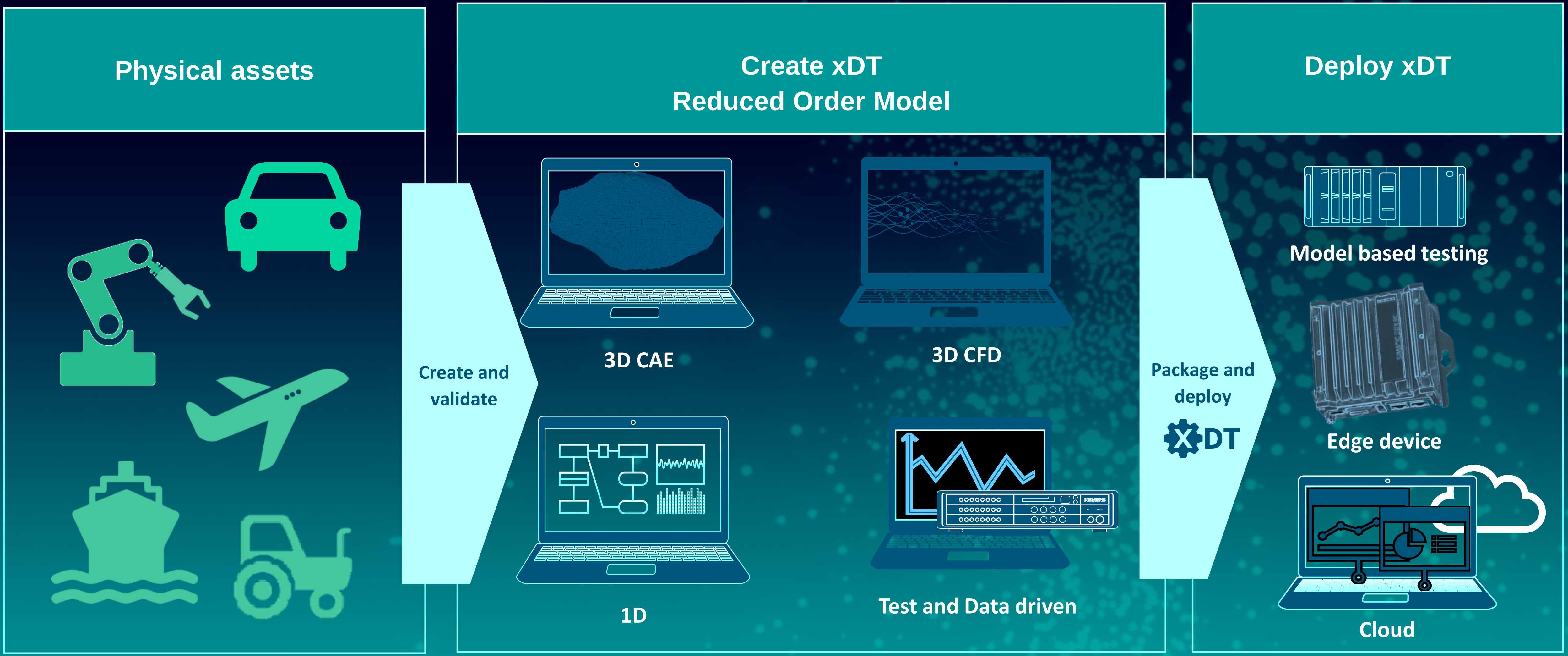
Executable Digital Twin
Creation and deployment process



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Executable Digital Twin
Measure the unmeasurable with smart virtual sensors

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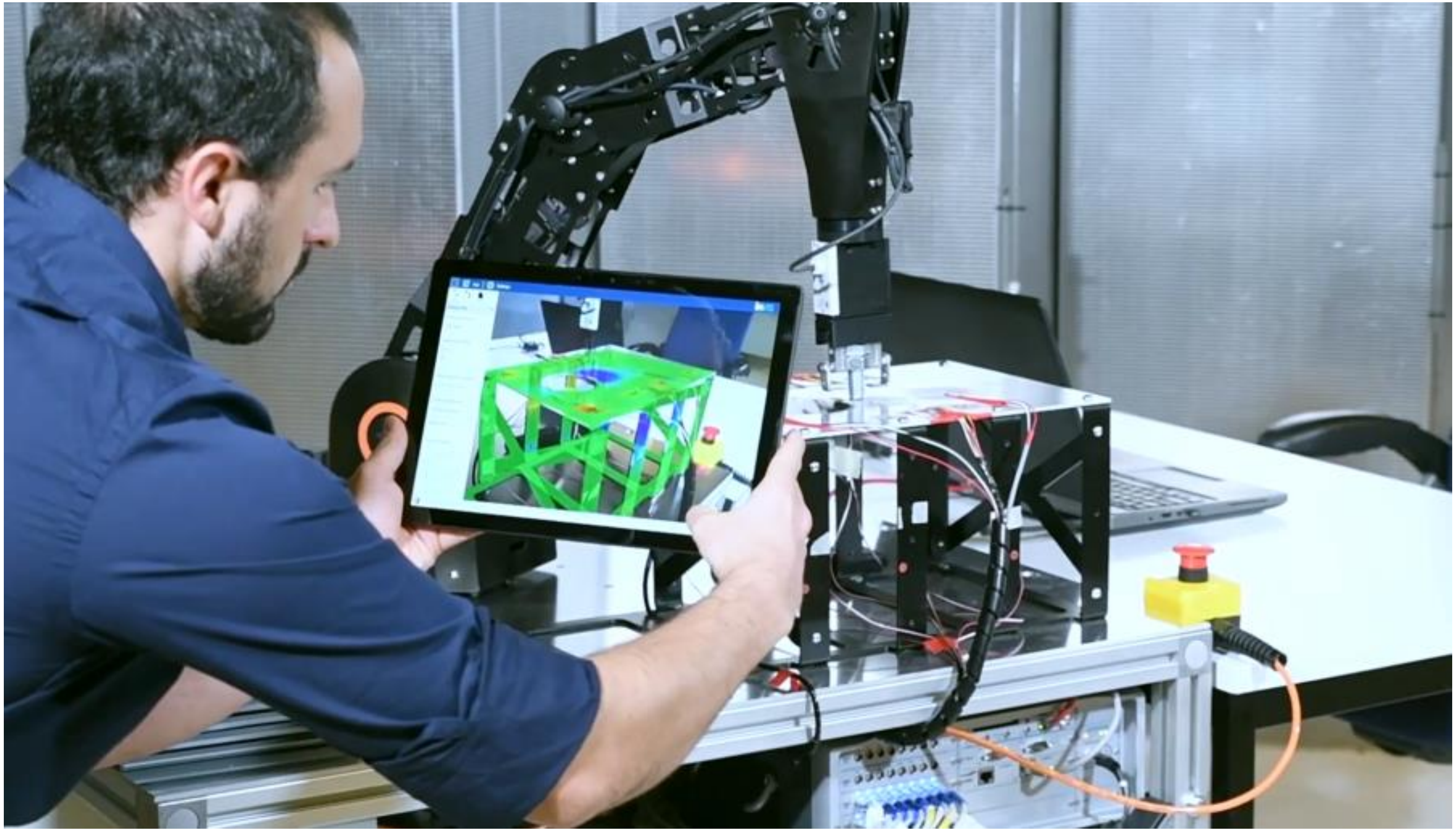

The Digital Twin
Creating value along the life cycle

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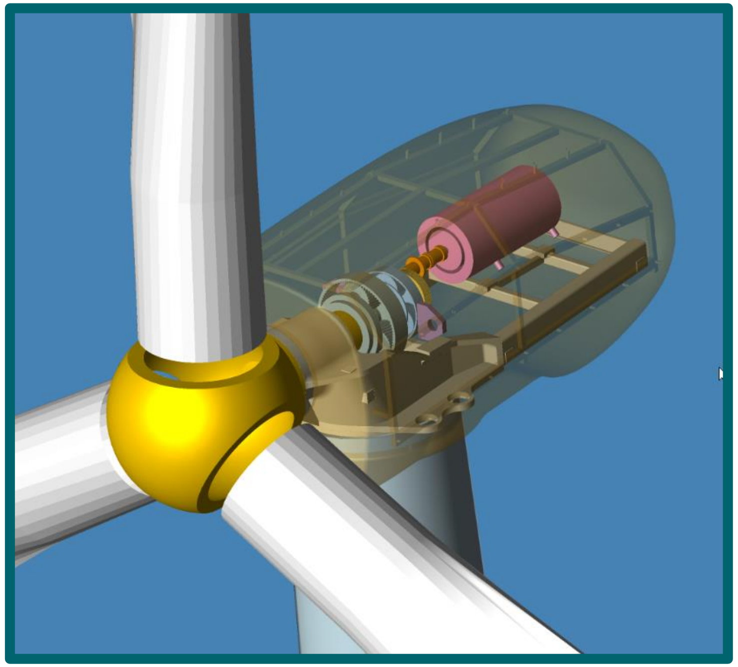
Ideation



Digital Product Twin

Realization

Digital Production Twin

Utilization

Digital Performance Twin

Simcenter Portfolio
Engineer Innovation for Wind Energy Performance

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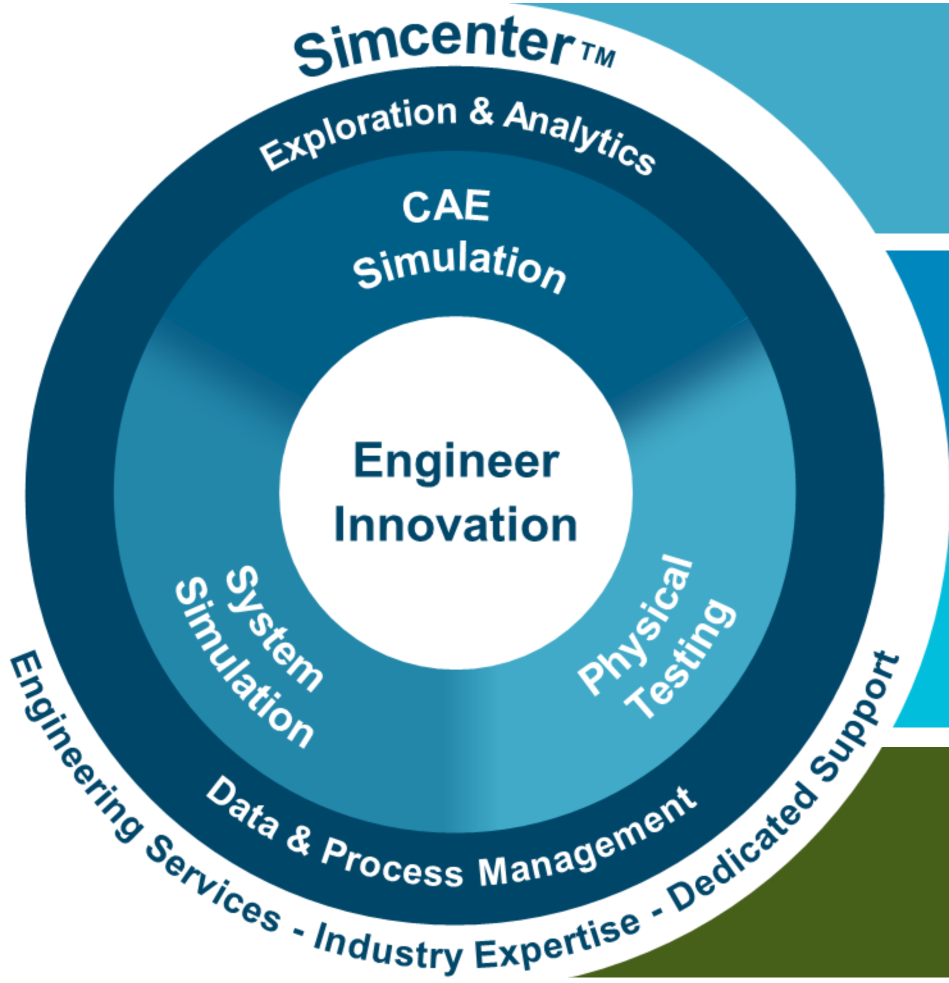


Systems Performance and Controls

Complete (sub) system optimization

Turbine detailed engineering

Loads cascading, Lifetime, Noise & Vibration, Magnetics

Asset Management & Reliability

Big Data, IoT, Remaining Useful Lifetime

Aero-dynamic performance

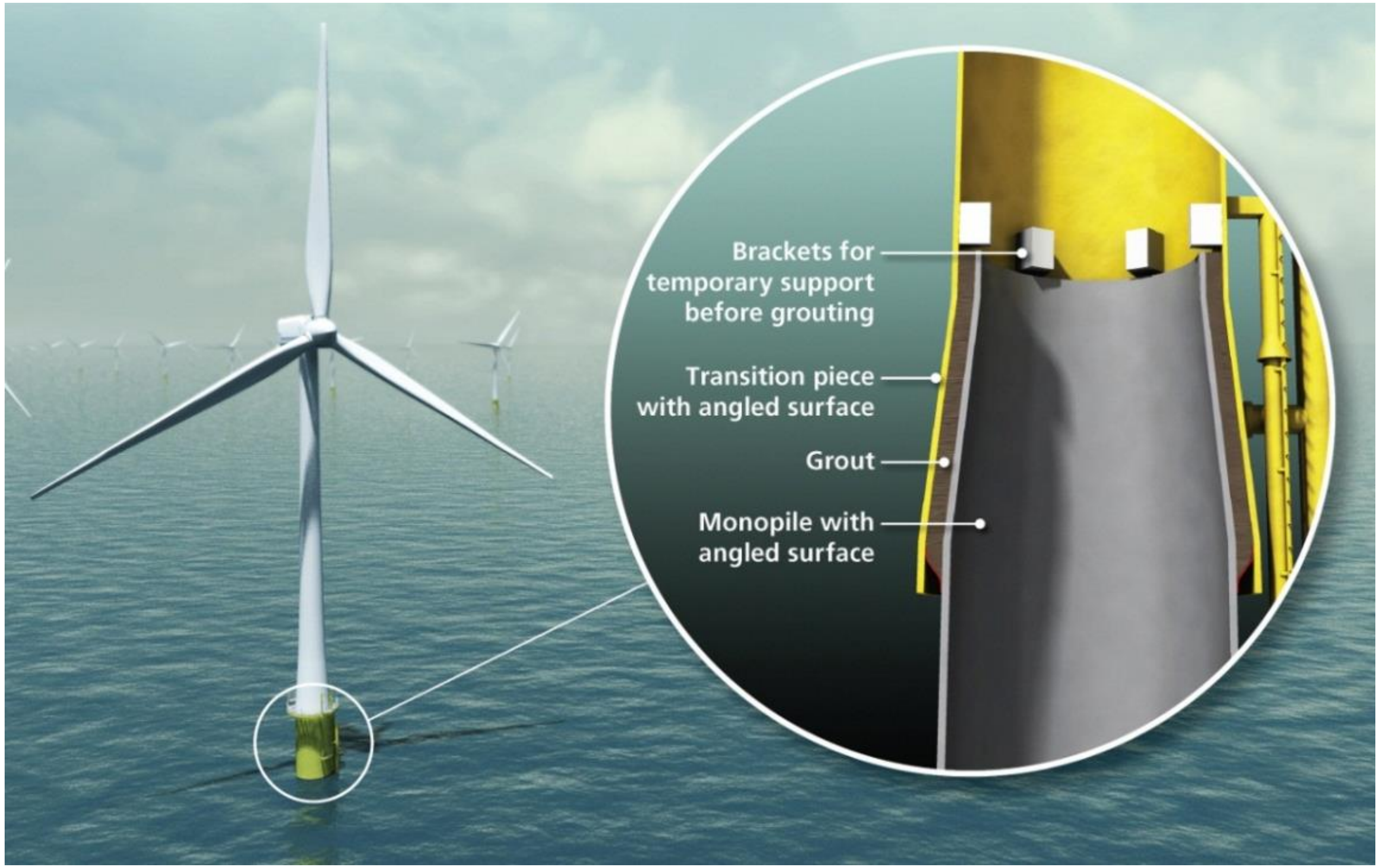
Wind loads, Wind farm layout, Blade yield optimization

Offshore Wind Turbine Foundation Monitoring

BSH (Bundesamt für Seeschifffahrt und Hydrographie), legally imposes a Foundation Condition Monitoring System (FCMS) on 10% of the turbines of each off-shore wind park.

Why? Example: Degradation of grout between monopile foundation and transition piece of steel tower in first off-shore turbines in Belgium.

- Towers tilted
- Huge repair costs



Offshore wind turbine foundation monitoring
Model-based structural health monitoring

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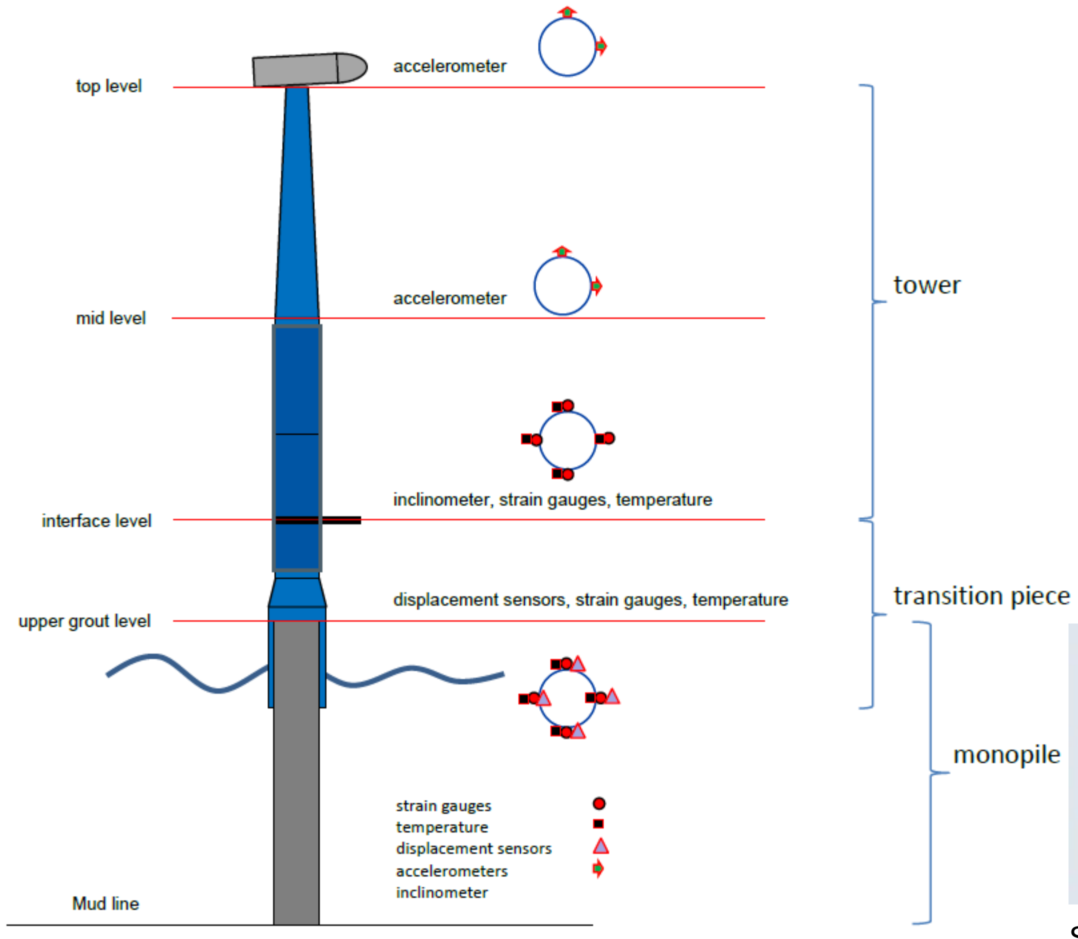
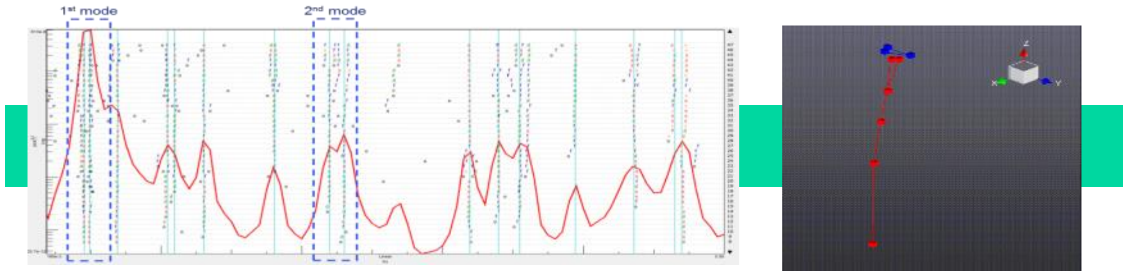
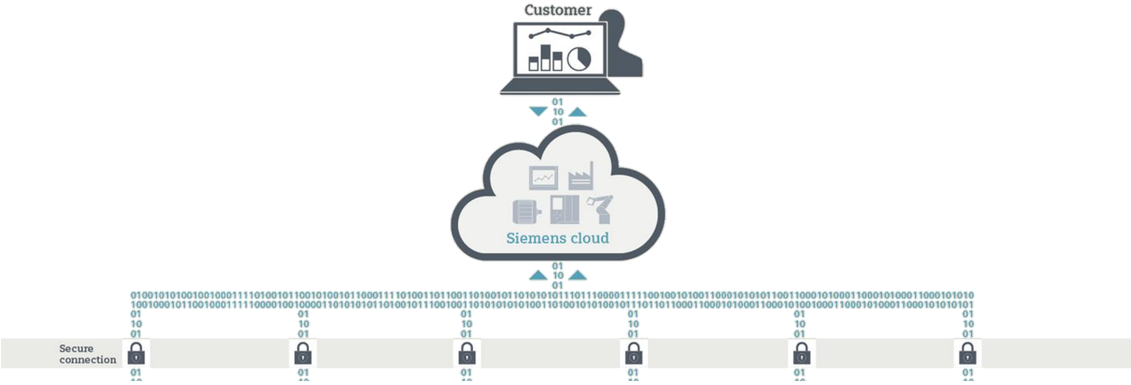


SIPLUS CMS4000

App to assess structural health – remaining life time



Operational Modal Analysis example: On-shore wind turbine: bending modes



Multiple wind turbine foundations

Extend with models of damage and changing environmental conditions

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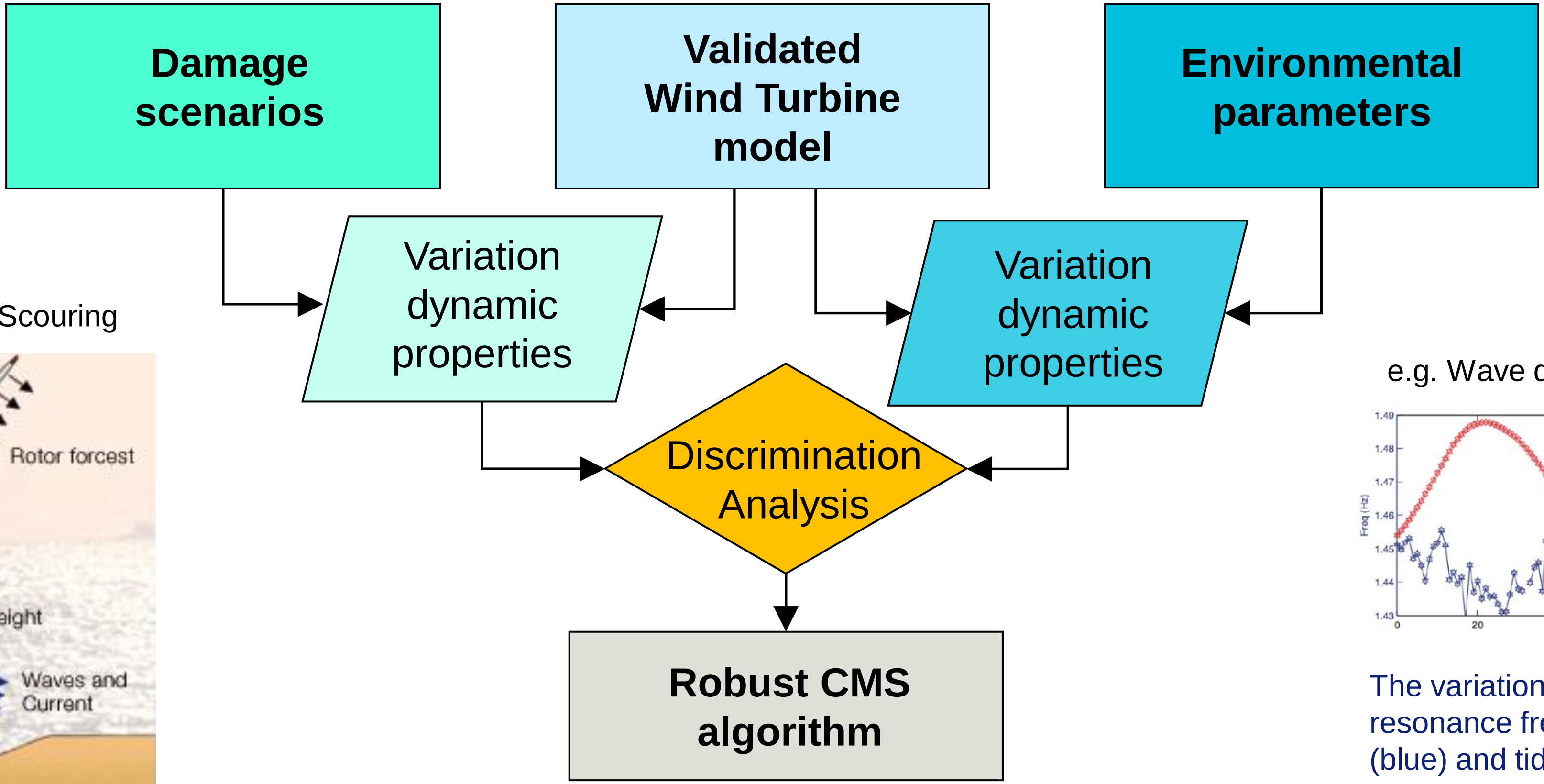
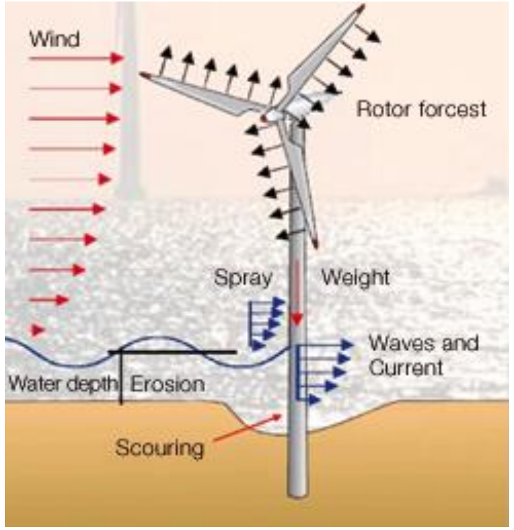
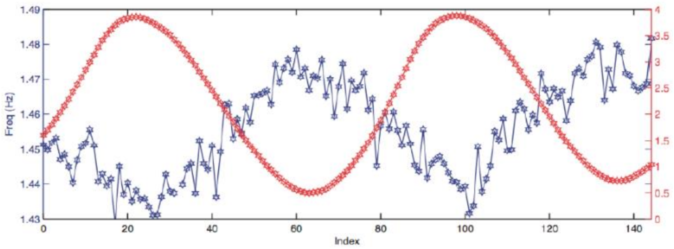


e.g. Damage scenario Scouring



e.g. Wave depth and tidal level



The variation during 24 hours of the resonance frequency (Hz) of mode SS2N (blue) and tidal level (m) (red)

Winergy
Predicting the remaining useful lifetime of each wind turbine gearbox

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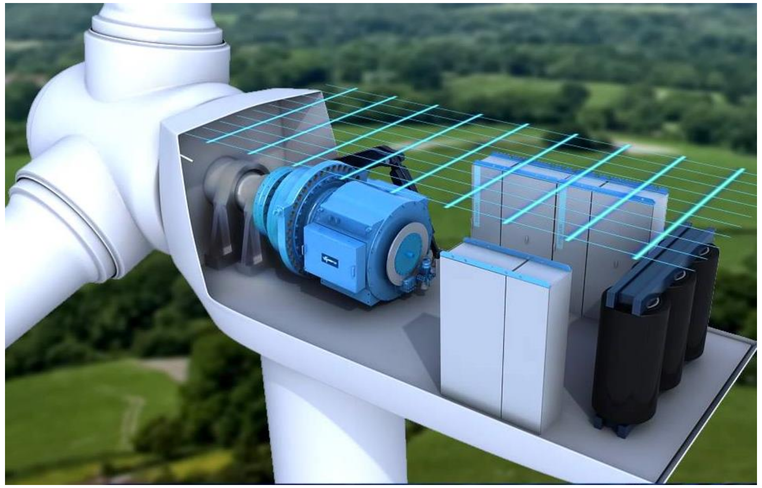
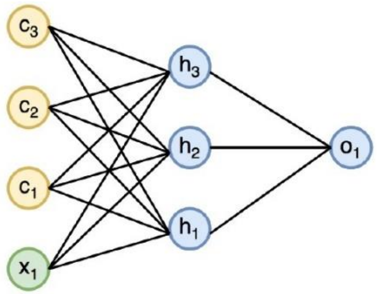


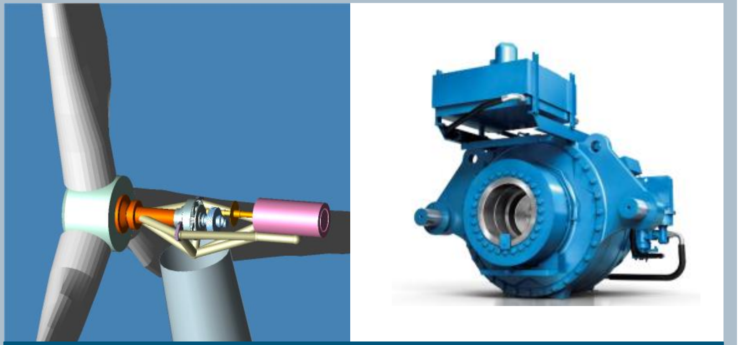
- **Optimize the maintenance planning of the wind turbine fleet**
- **Limit the number of spare parts**
- **Prediction and reduction of failures**
- **Feedback from the field into the development of wind turbine gearboxes**

Radical change in the Operations & Maintenance of the wind industry

Classify data using a trained neural network



Machine learning based approach



Individualized digital twin based approach

- Use operating data to train a neural network to detect and predict faults
- Sync the model with the operating condition to validate the digital twin

"We wanted to safeguard the functional performance of our gearboxes. Thanks to the Simcenter Engineering expertise, we can now predict the remaining useful lifetime of the bearings and gear teeth in each gearbox."

Edwin Hidding, Head of Customer Project Management

Dual Technical approach

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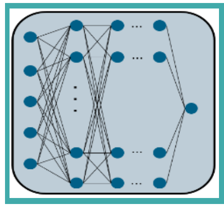
Monitoring data - 78 Wind Turbines (SCADA)
72 channels (wind speed, rpm, gearbox temp, faults, …)

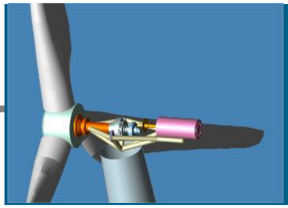
MindSphere



Machine learning

Training Neural Network

Failure prediction and detection



Turbine Model
(Digital Twin)

Digital Twin: Model creation and correlation

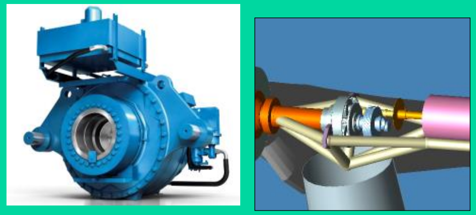
Accumulate load cases

Remaining lifetime of gears and bearings for each wind turbine gearbox

Lifetime prediction

Loads (per turbine)
As collected over Mindsphere

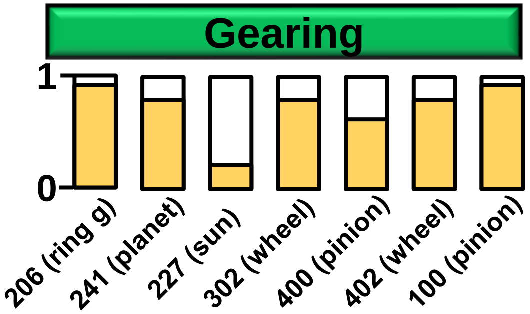
Load capacity – design life time
Material data, manufacturing data, design information, field data, supplier information



Digital Twin

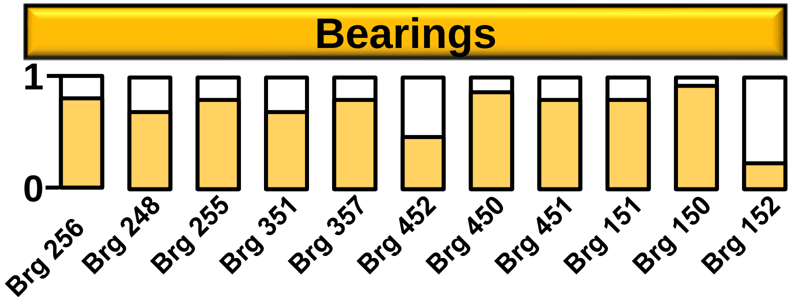
The "DigitalTwin" created <u>individually for each gearbox</u> and contains the connection between load and load capacity.

Output (per turbine)

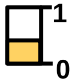


Generals

- ConsumedLoadCycles
- ConsumedLifeTime
- ExpectedLifeTime.
- RemainingYears
- …



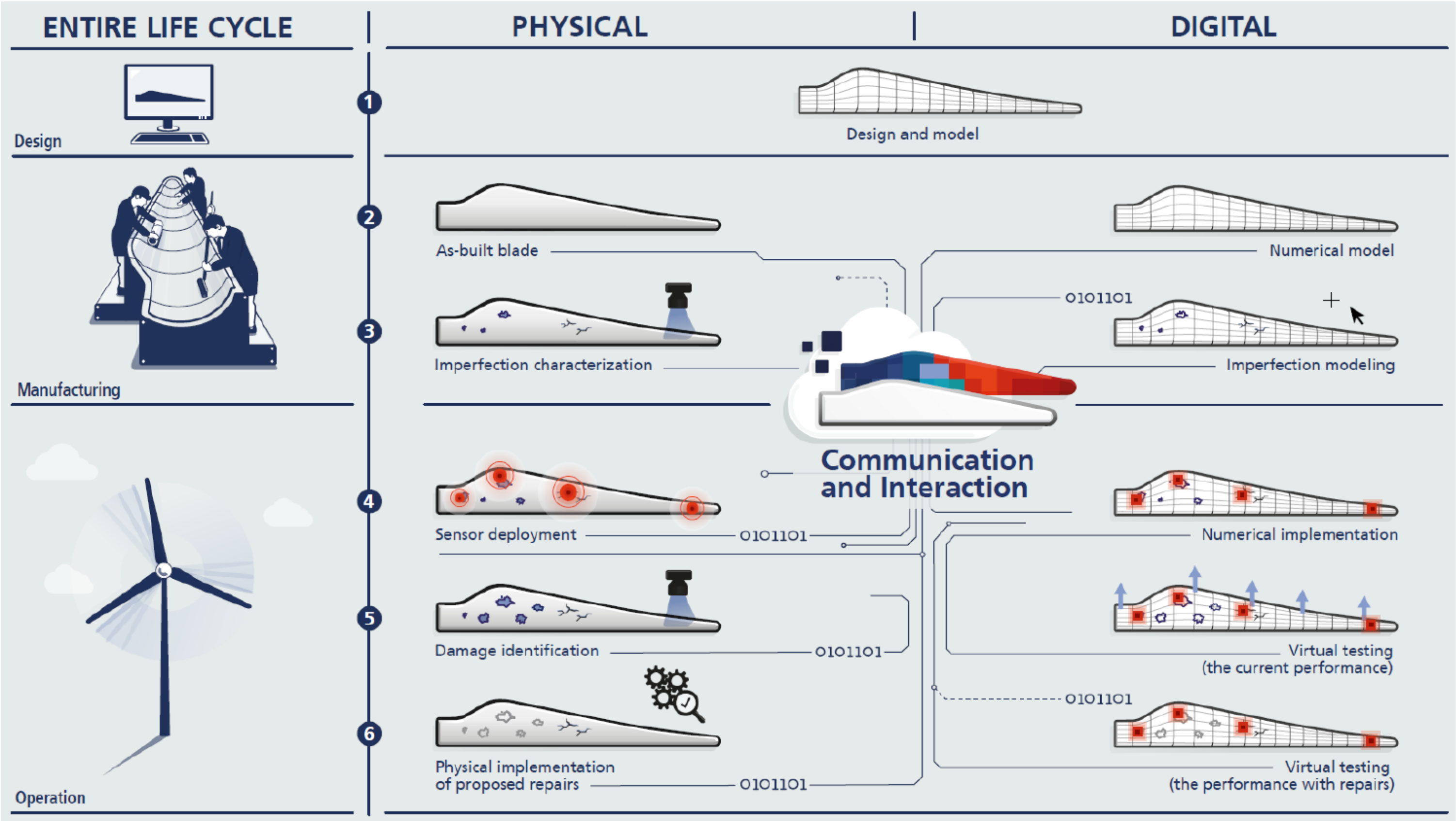
<u>Remaining Useful Life (RUL)</u>



*0 = new component

*1 = lifetime reached (theoretical failure)

ReliaBlade project description



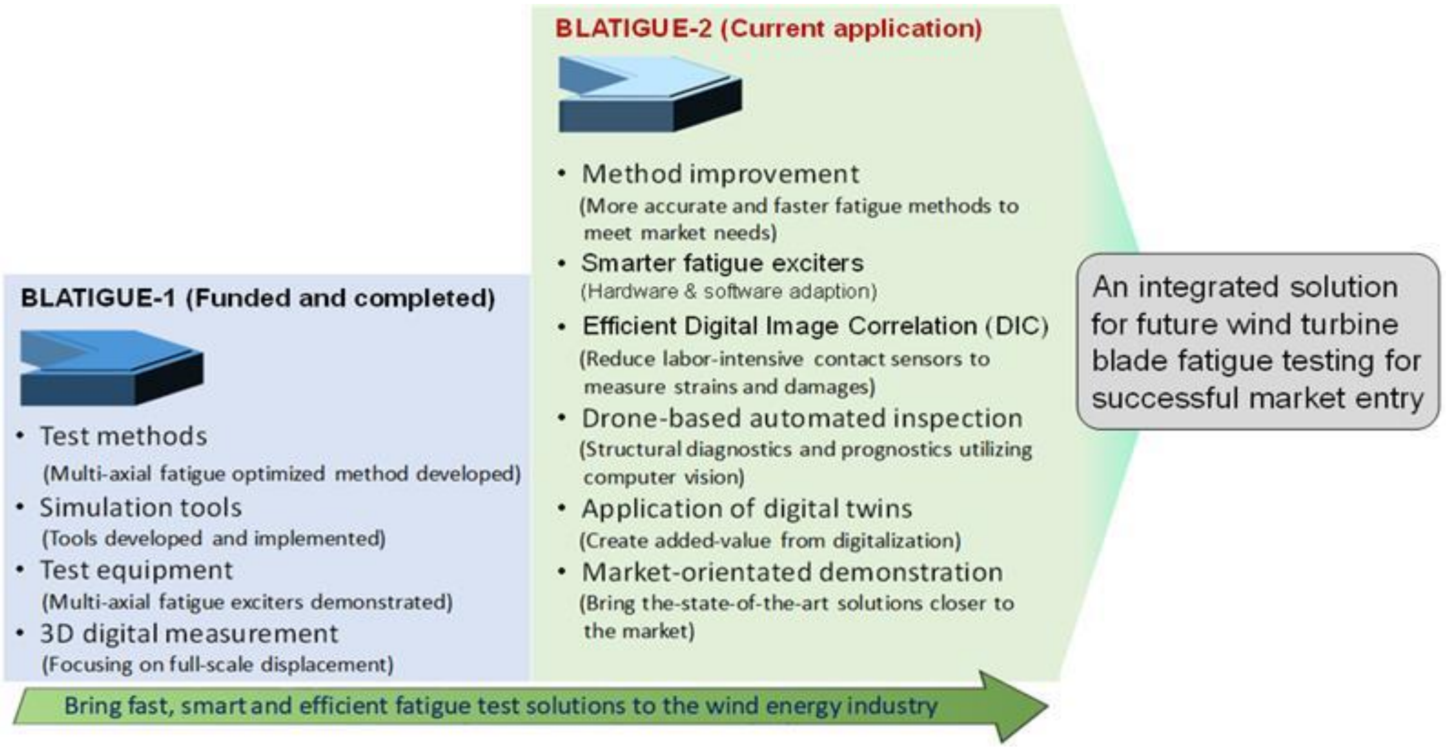
In close collaboration with DTU

- Contribute to WP1 – Digital platform integration
- Dynamic testing:
  - Baseline Test-validated Digital Twin at design stage
- Virtual Sensing

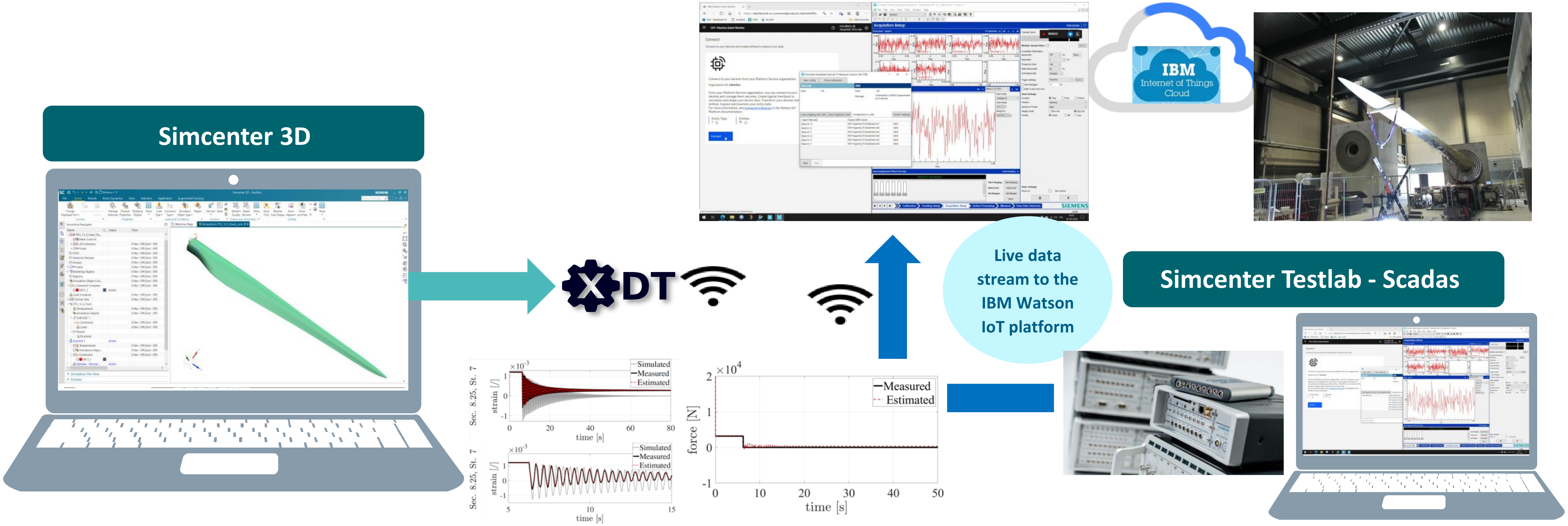
Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Blatigue2 project description

The purpose is to develop a suite of software, tools and methods to enable **significantly faster, realistic and more efficient fatigue testing** methods for large wind turbine blades. The combined solutions will increase the quality of blade testing to reduce unplanned blade repairs by an estimated 10% and reduce the time to market for new blade designs significantly.



Digital platform integration



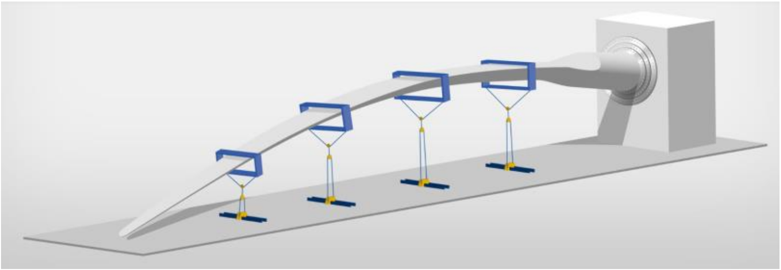
Wind turbine blade testing for certification

IEC 61400-23 standard for wind turbine blades certification

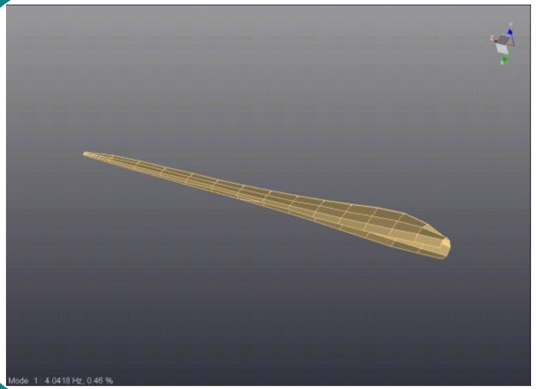
Static Tests:
verify the structural strength of the blade

Fatigue Tests:
ensure that the blade will be reaching the designed lifetime of about 25 years

Dynamic Tests:
limited to the identification of the first and second flapwise natural frequencies, and of the first edgewise one.



DTU Wind Energy Large Scale Facility



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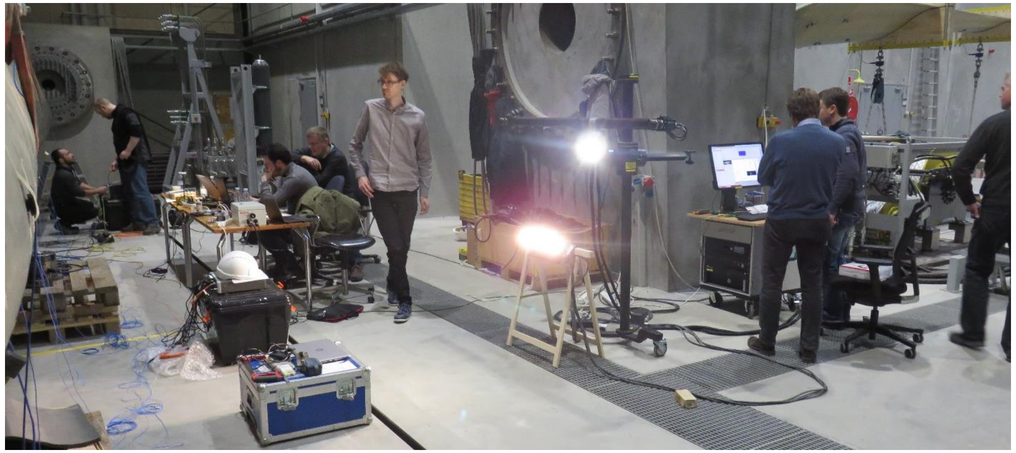
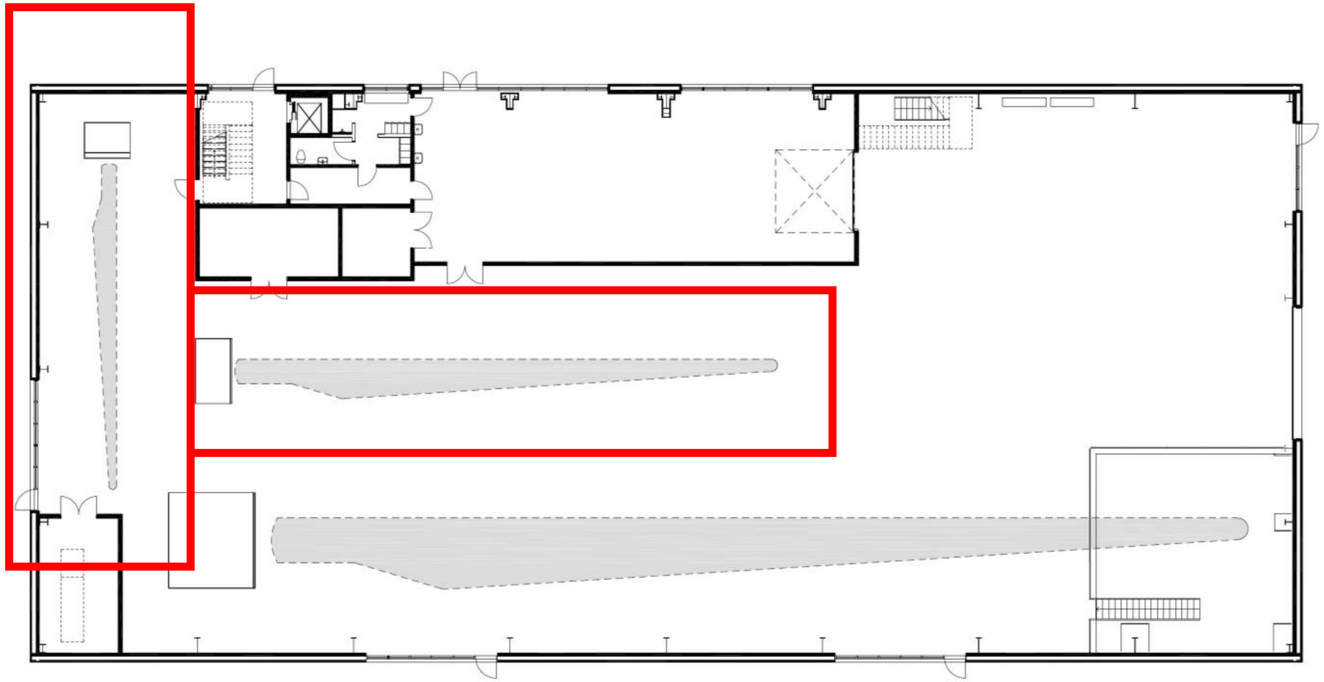
DTU Wind Energy Large Scale Test facility





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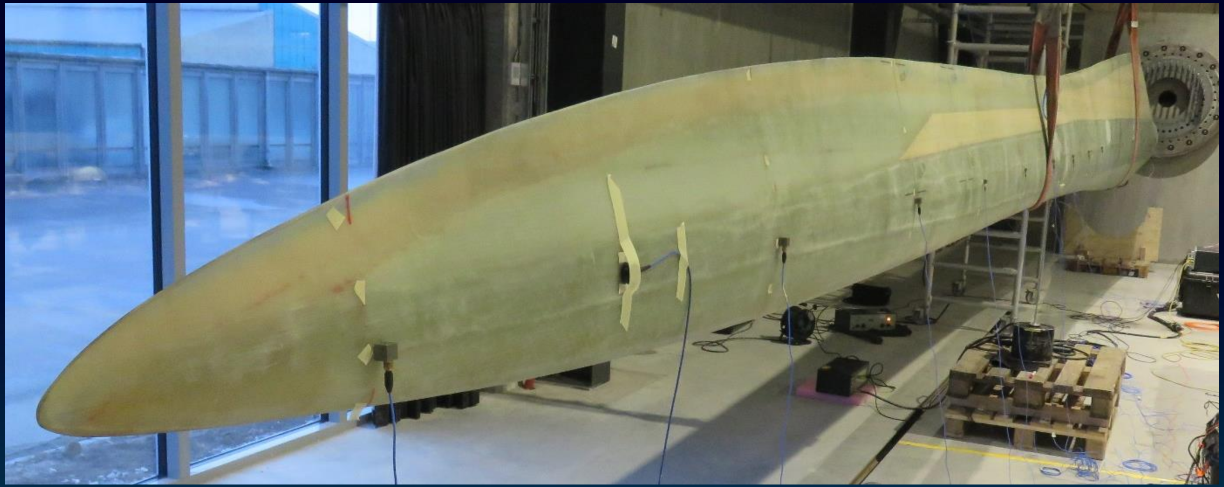
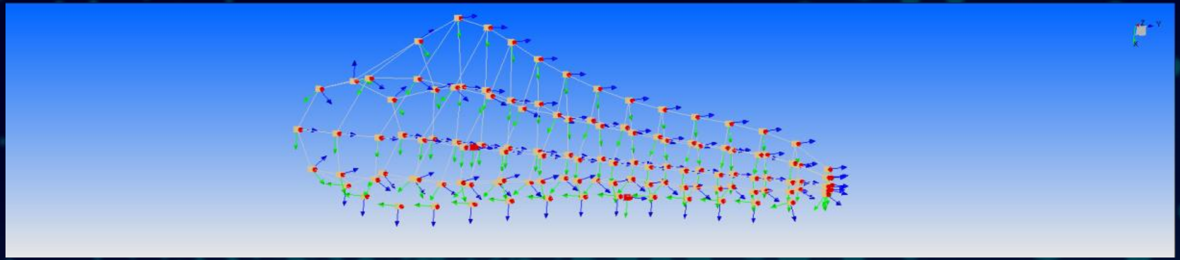
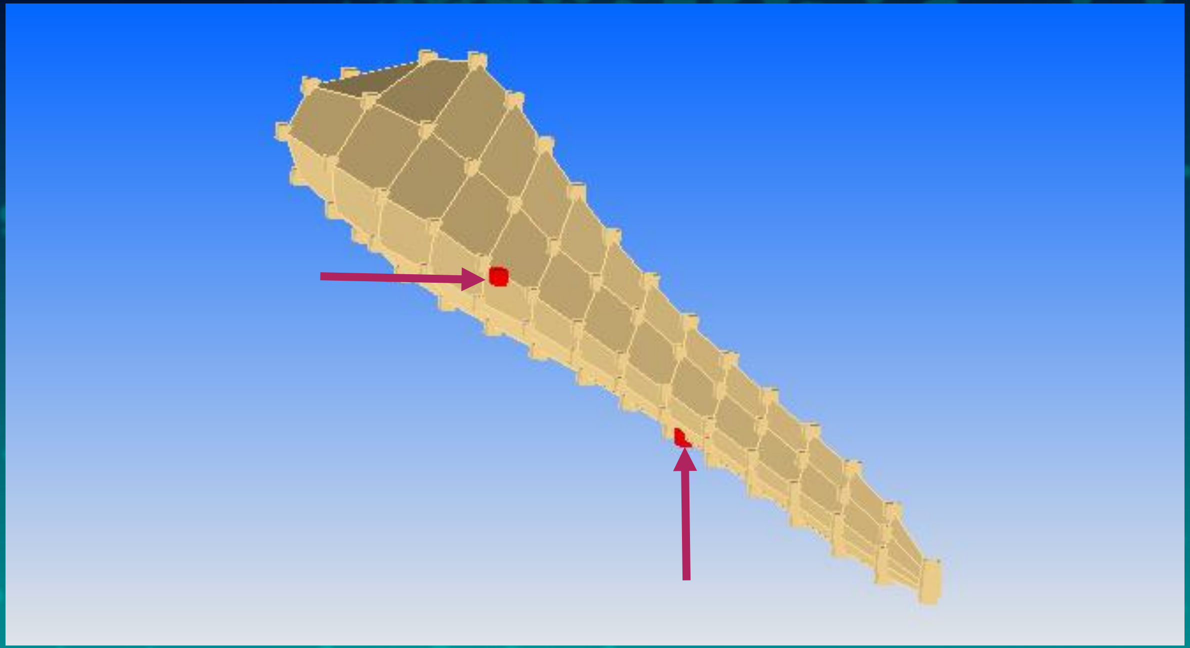
Test setup:
free-free boundary conditions for FE model validation

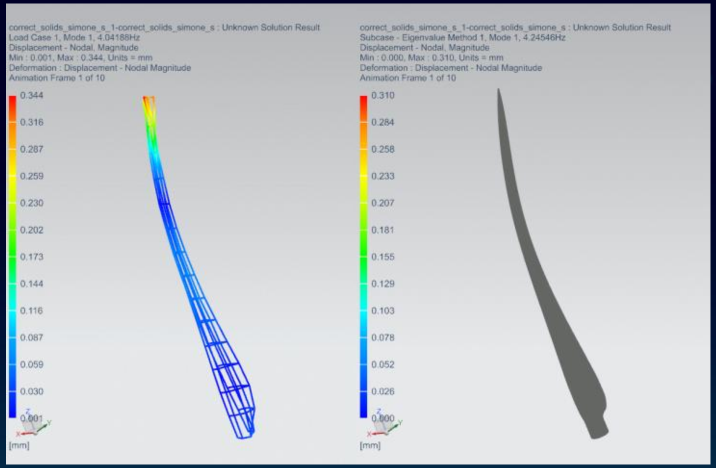




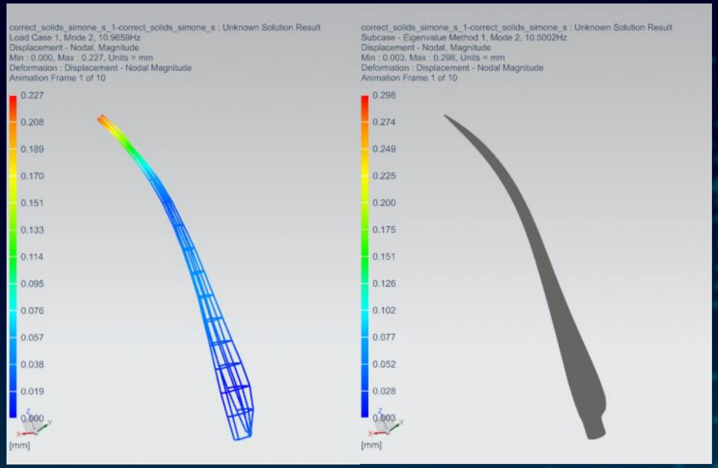


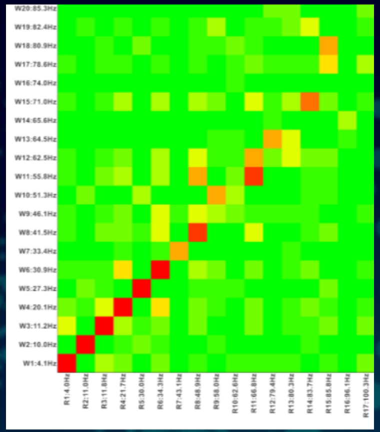
Correlation: Test vs FE model

Mode 1 – 1st flapwise mode

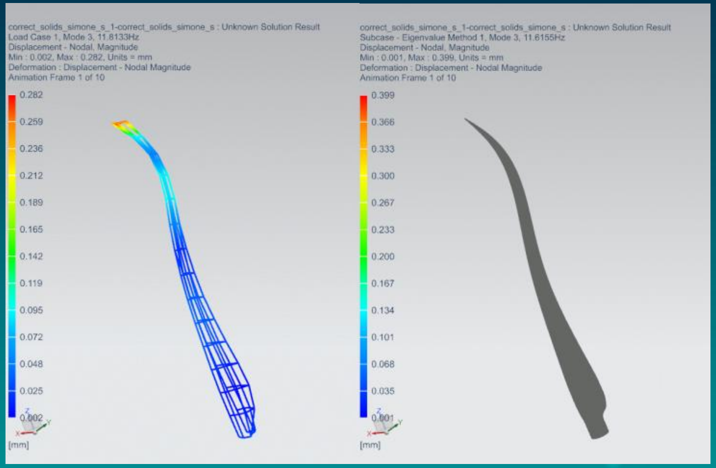


Mode 2 – 1st edgewise mode

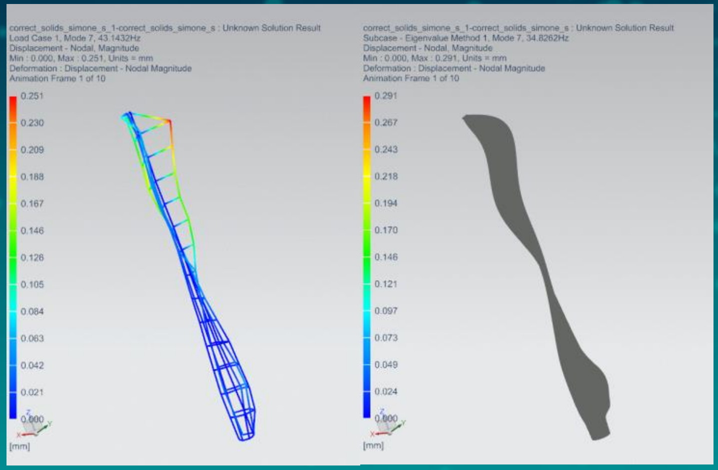


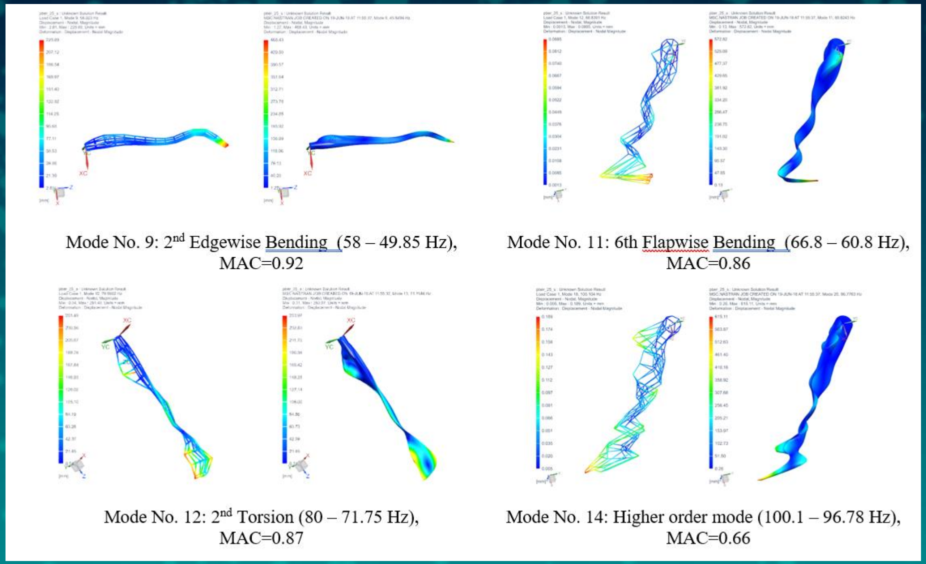


Mode 3 – 2nd flapwise mode



Mode 7 – torsional mode





Mode No. 9: 2nd Edgewise Bending (58 – 49.85 Hz), MAC=0.92

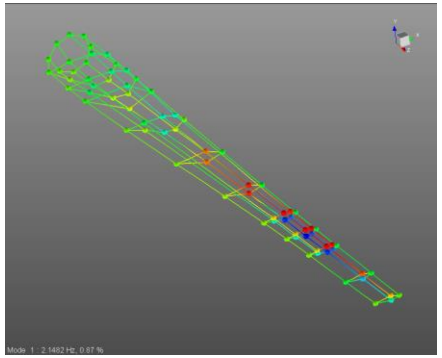
Mode No. 11: 6th Flapwise Bending (66.8 – 60.8 Hz), MAC=0.86

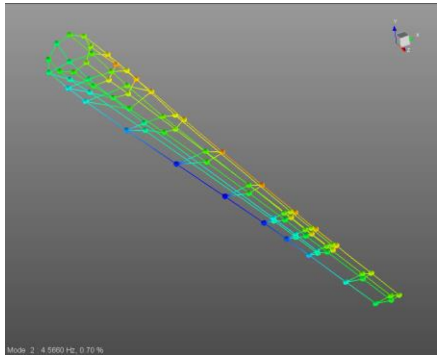
Mode No. 12: 2nd Torsion (80 – 71.75 Hz), MAC=0.87

Mode No. 14: Higher order mode (100.1 – 96.78 Hz), MAC=0.66

FE model provided by DTU Wind Energy

Strain-based Operational Modal Analysis
Pull & release test



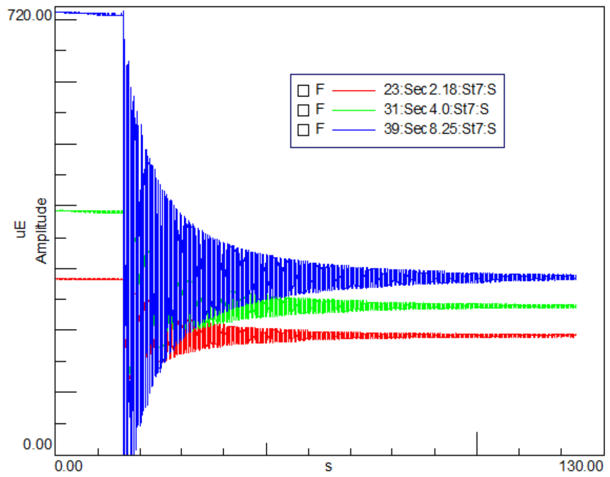


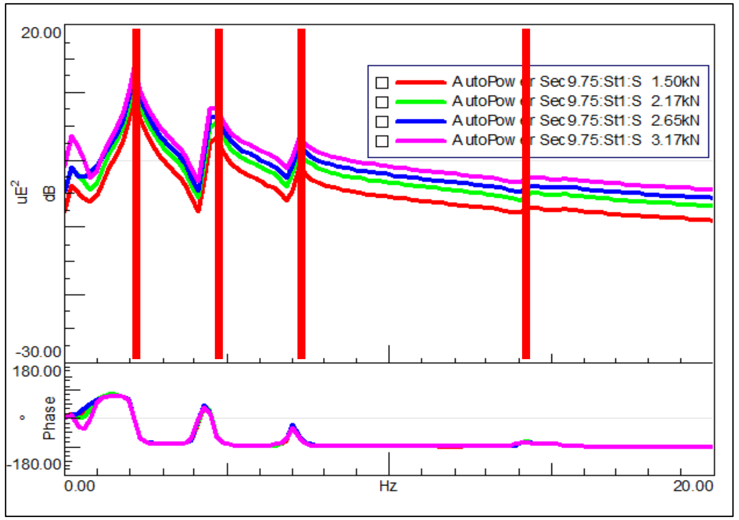
Pull & release test

- 4 different force levels (1.50kN, 2.17kN, 2.65kN, 3.17kN)
- 76 strain gauges along 12 sections

Data processing (no force, no accelerometers)

- Strain-based Operational Modal Analysis





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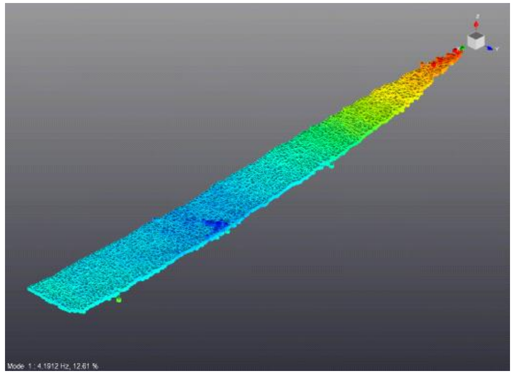
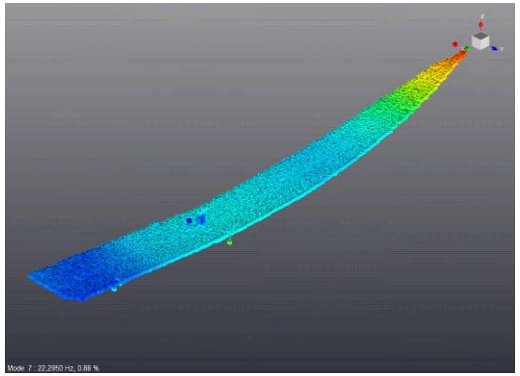
Digital Image Correlation for wind turbine blades testing

Off the shelf solution for full field 3D deformation measurements based on camera images

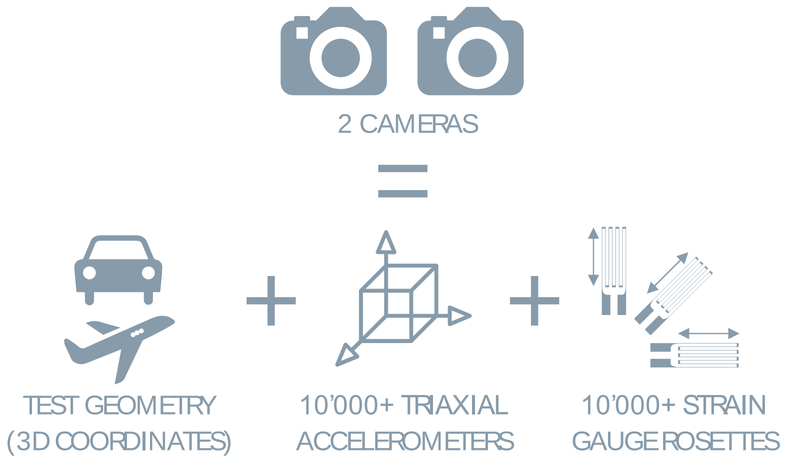
Complementary with Simcenter structural dynamics testing

Full field correlation with Simcenter 3D simulation results





Advanced image processing for measuring full-field 3D displacements, strains and vibrations (DIC)



DTU

MatchID
Metrology beyond colors

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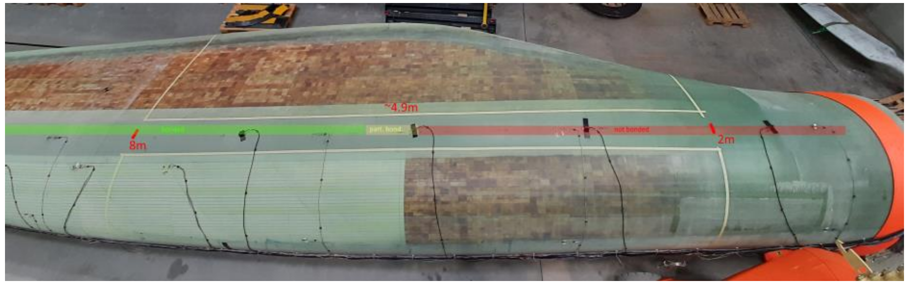
DIC activities on 31m IWES blade

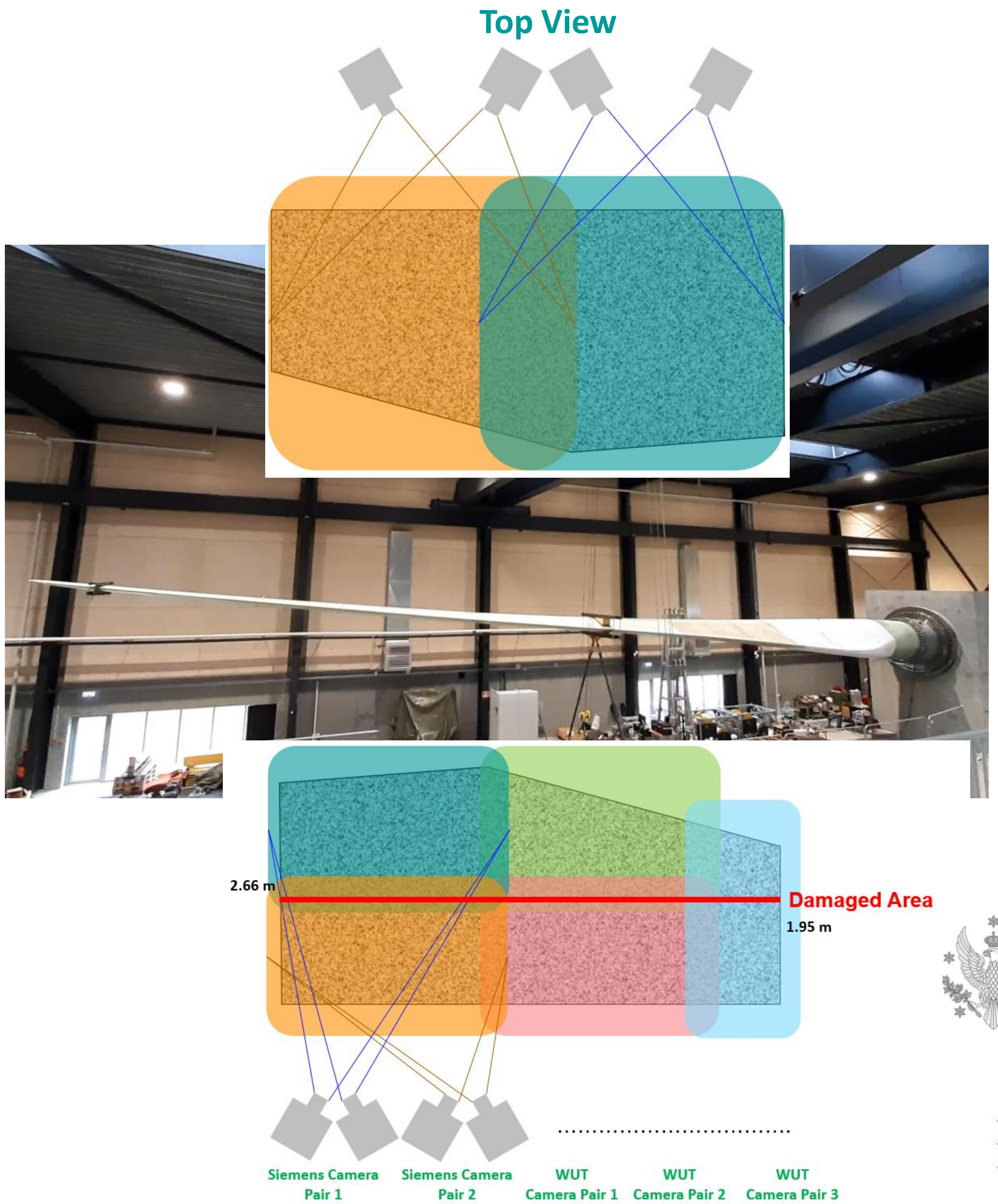
DTU:
- X4 4096x3000 (12 MPx) 10GigE 68FPS (3.45 µm)
- X4 16 mm lenses

WUT:
- X6 2448 x 2048 (5 Mpx) 15FPS (3.45 µm)
- X6 16 mm lenses
- X6 8 mm lenses

SIEMENS:
- X4 5 MPx USB3 Camera 75 fps (3.45 µm)
- X4 12.5 mm lenses
- X4 25 mm lenses

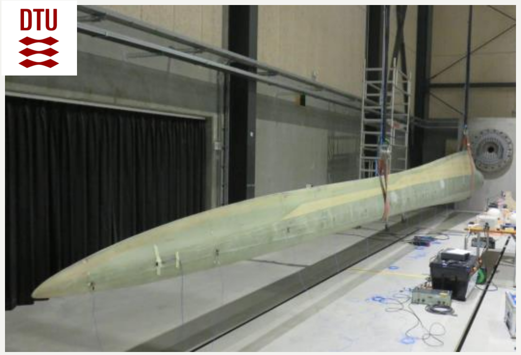


Bandwidth 0-10 Hz
Blade 31 m (Test on 2 to 8 meters)
DIC for Damage Detection and Crack Propagation Analysis



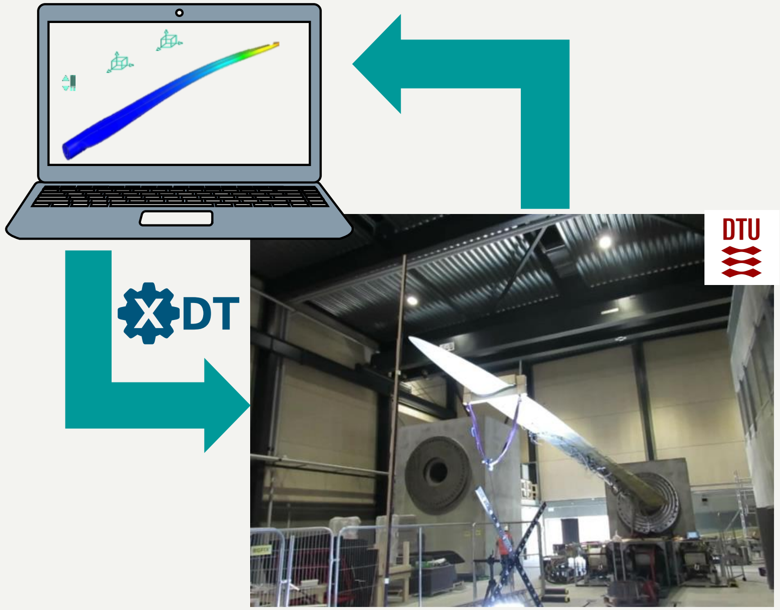
Executable Digital Twin
Measure the unmeasurable with smart virtual sensors

Challenge
Improve accuracy of durability testing for composite blades

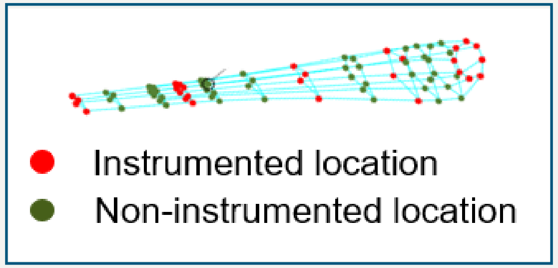


- Currently relies on a few physical sensors
- Suboptimal sensor positioning decreases accuracy of durability results
- Model updating can be lengthy and complex

Solution
Estimate full field stress and strain response with smart virtual sensor



Benefits
Detect critical locations on the full blade



Expand strain data from 10’s of data points to 100’s

Accuracy of durability testing

Up to
50% Time reduction for model updating and instrumentation

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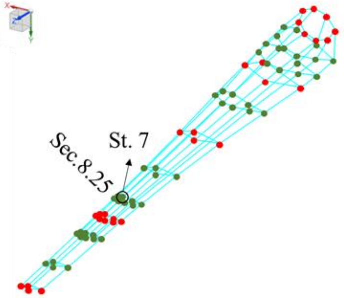
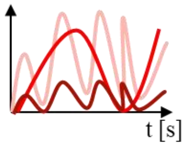
What is Smart Virtual Sensing?

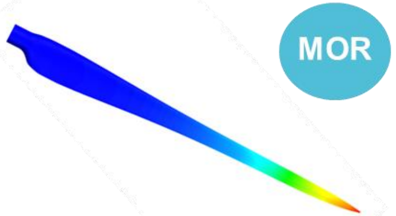


- Instrumented location
- Non-instrumented location

Observations set



FE model

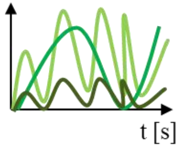


Input models

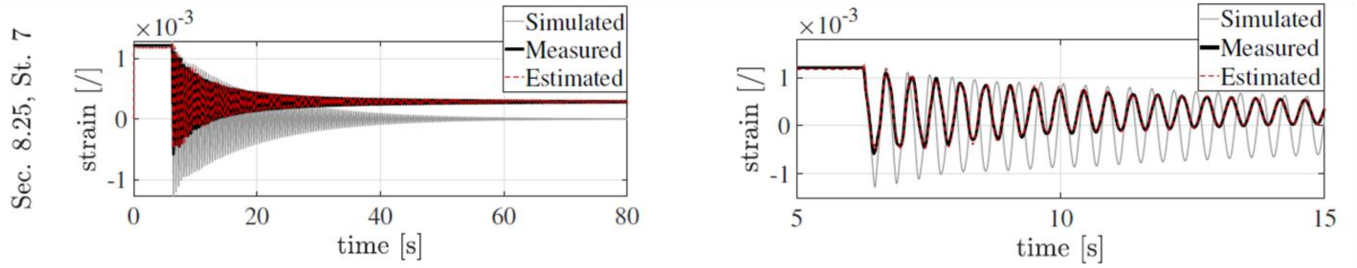
Noise statistics

Smart Virtual Sensing

Predicted responses at unmeasured locations



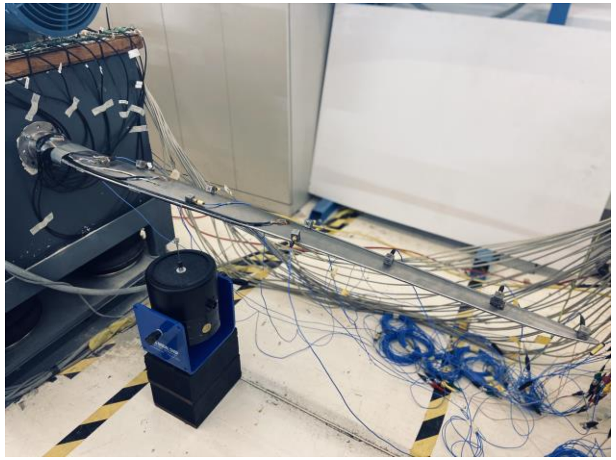
Full field response estimation



xDT Smart Virtual Sensing – Wind Turbines
Demonstrators

GOAL #1:

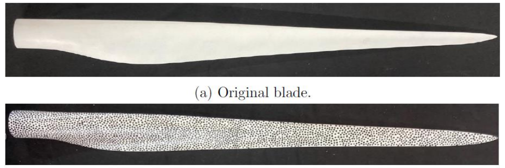
Physical demonstrator on 3D printed scaled wind turbine blade



3D SYSTEMS

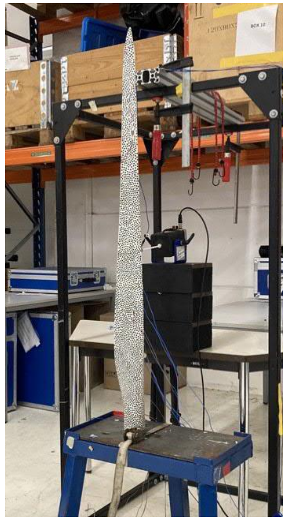
GOAL #2:

Physical demonstrator on composite scaled wind turbine



(a) Original blade.

(b) Speckled blade.



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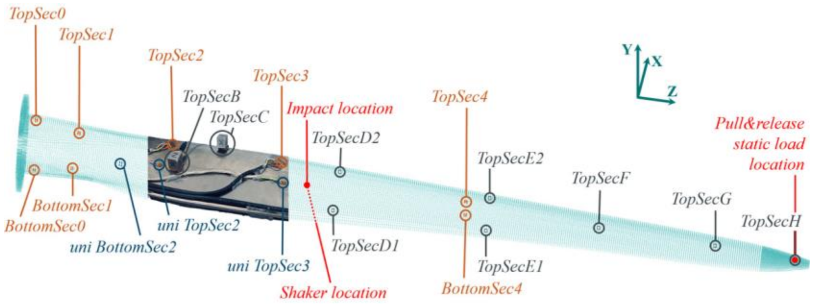
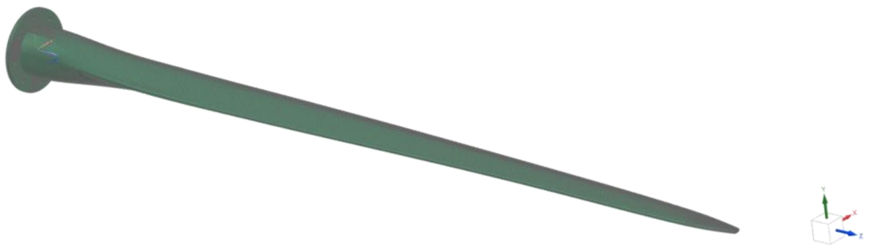
xDT Smart Virtual Sensing – Wind Turbines
Demonstrator #1



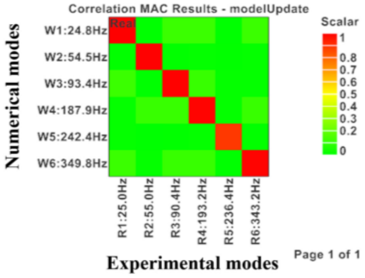


Boundary Condition:

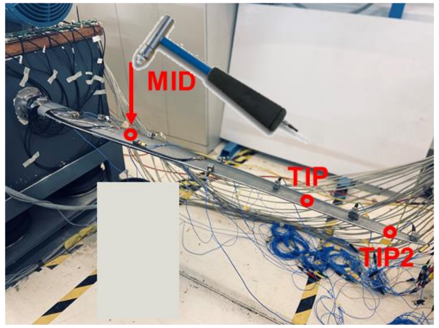
- Blade-on-block configuration;

Installed sensors:

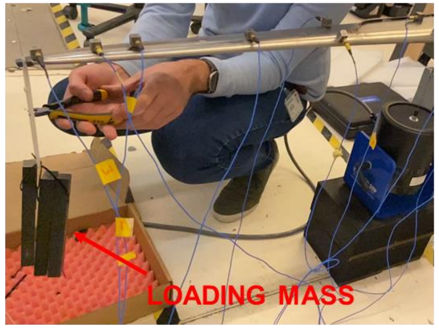
- 4 uniaxial strain gages;
- 10 rosettes;
- 10 triaxial accelerometers.



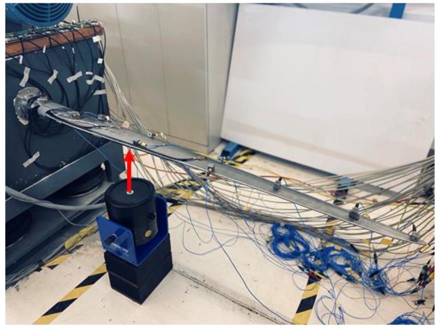
Types of excitation



Impact testing:
- Mid
- Tip
- Tip 2

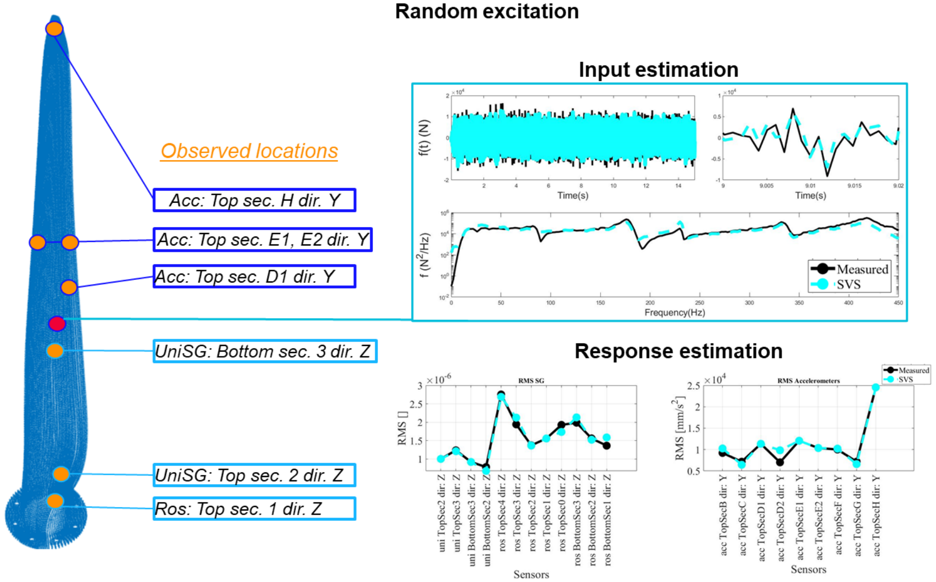


Pull & Release testing:
- 1.5 Kg
- 3 Kg
- 4.5 Kg



Shaker testing:
- Sine (20 Hz, 86 Hz);
- Chirp;
- Continuous random;
- Burst random;
- Sine sweep (linear, logarithmic).

Random excitation



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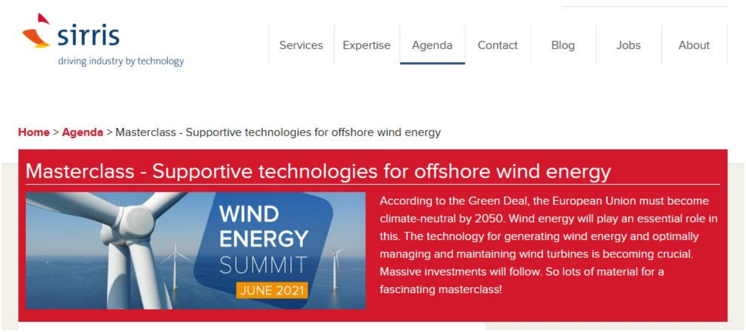
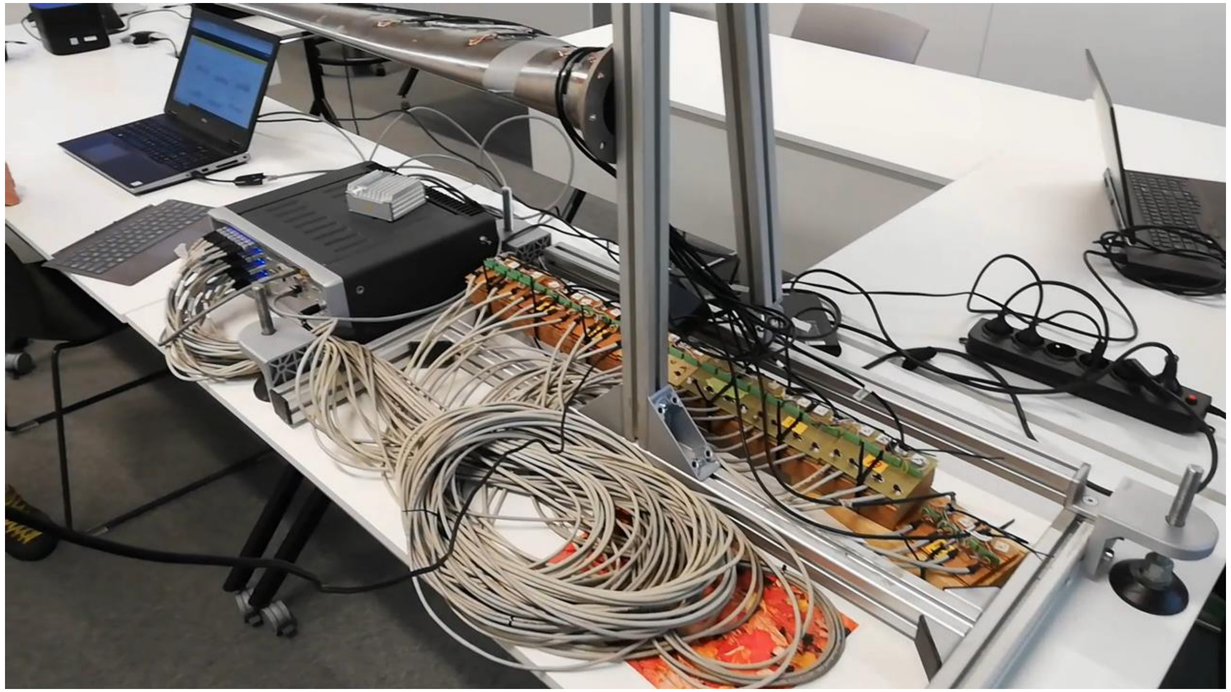
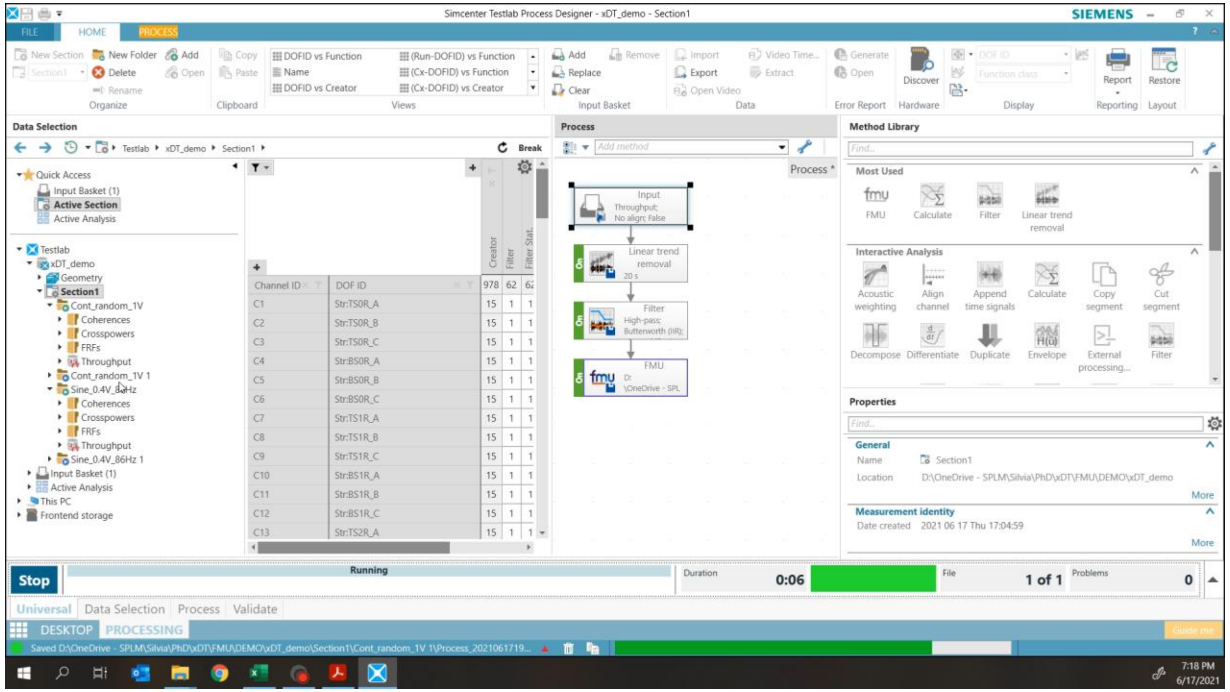
xDT Smart Virtual Sensing – Wind Turbines
Demonstrator #1



<u>Combined SIM3D (Smart Virtual Sensing) / Testlab NEO capabilities:</u>

<u>Successful demonstration at Sirris Master Class</u>





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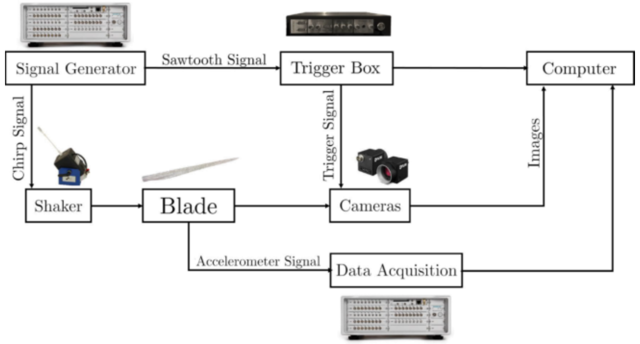
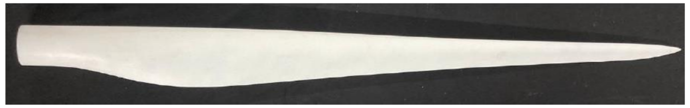
xDT Smart Virtual Sensing – Wind Turbines
Demonstrator #2

Demonstrator #2:

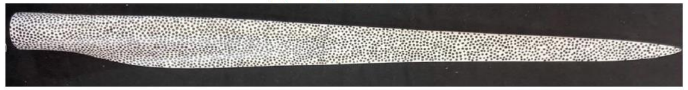
Several parallel activities on Demonstrator #2:

- **Digital Image Correlation**
  - MSc thesis on:
    - Static tests (clamped-free)
    - Modal tests (free-free)
    - Fatigue tests (shaker)
    - …to be extended to rotational conditions
- **Damage Detection algorithms**
  - MSc thesis work on the use of Automated Modal Analysis and Anomaly Detection Autoencoders to identifying damages (e.g. added masses)

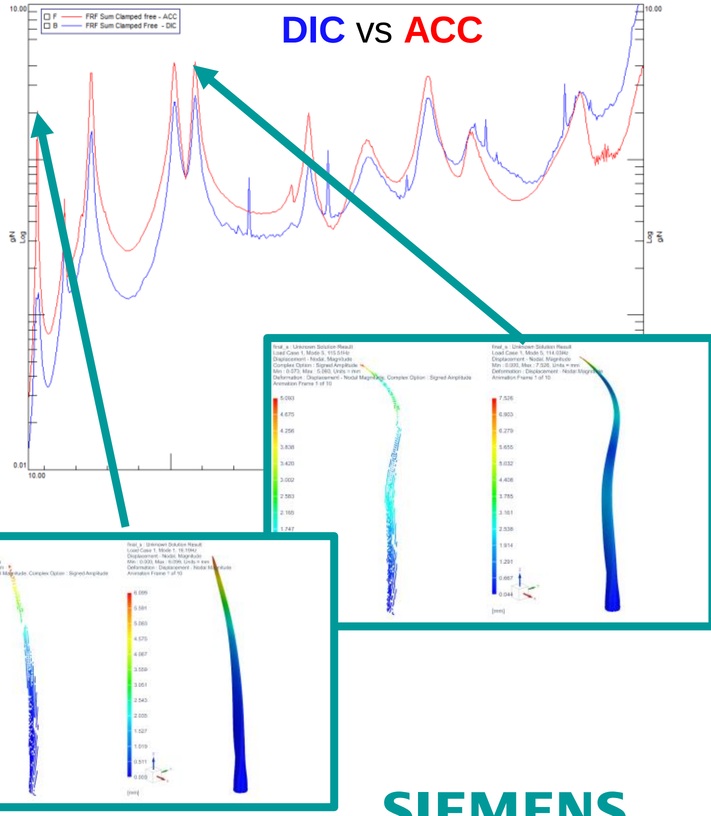


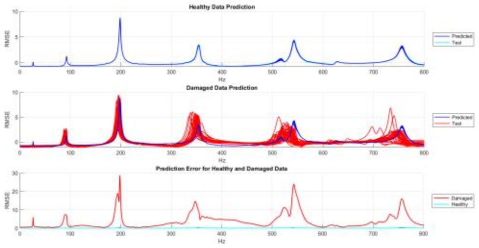


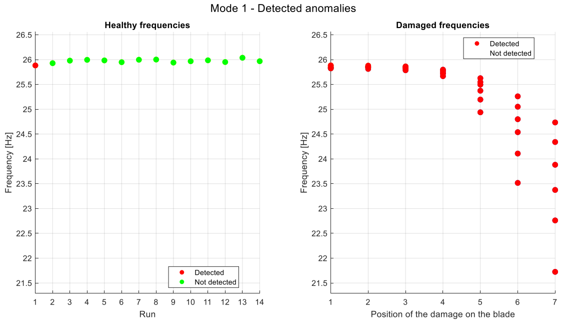
(a) Original blade.

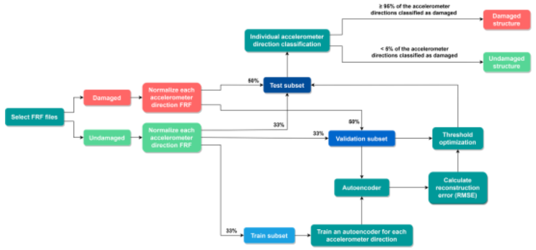


(b) Speckled blade.









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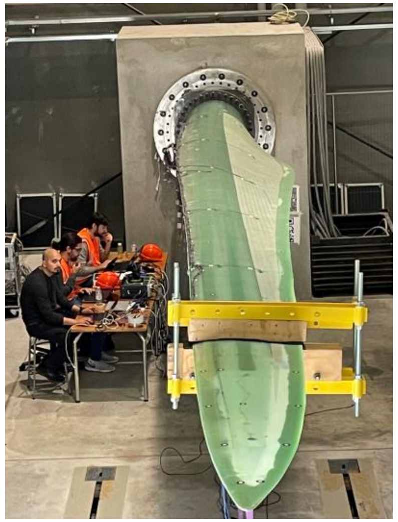
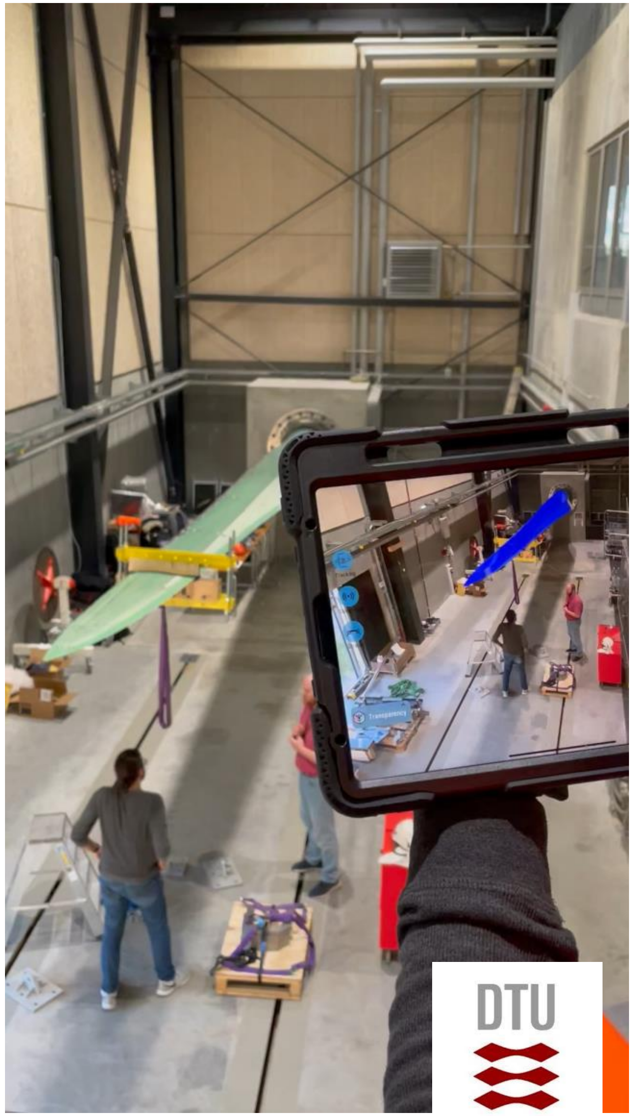
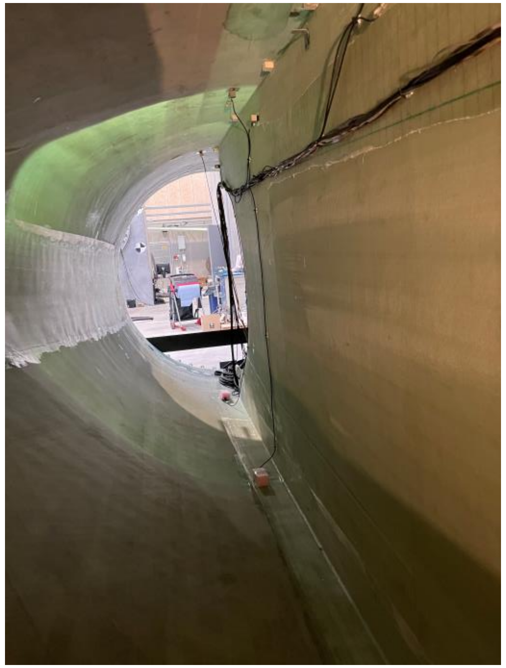
xDT Smart Virtual Sensing – Wind Turbines
Demo preparation: 12.6m wind turbine blade setup



- 64 Installed strain gauges
- 13 Strain gauges measured with the Scadas
  (handmade cables to connect HBM strain gauges to LEMO)
- 4 Strain gauges used for estimation (Augmented Kalman filter)
- 6 Accelerometers to check modal behavior

Operational tests: pull-release





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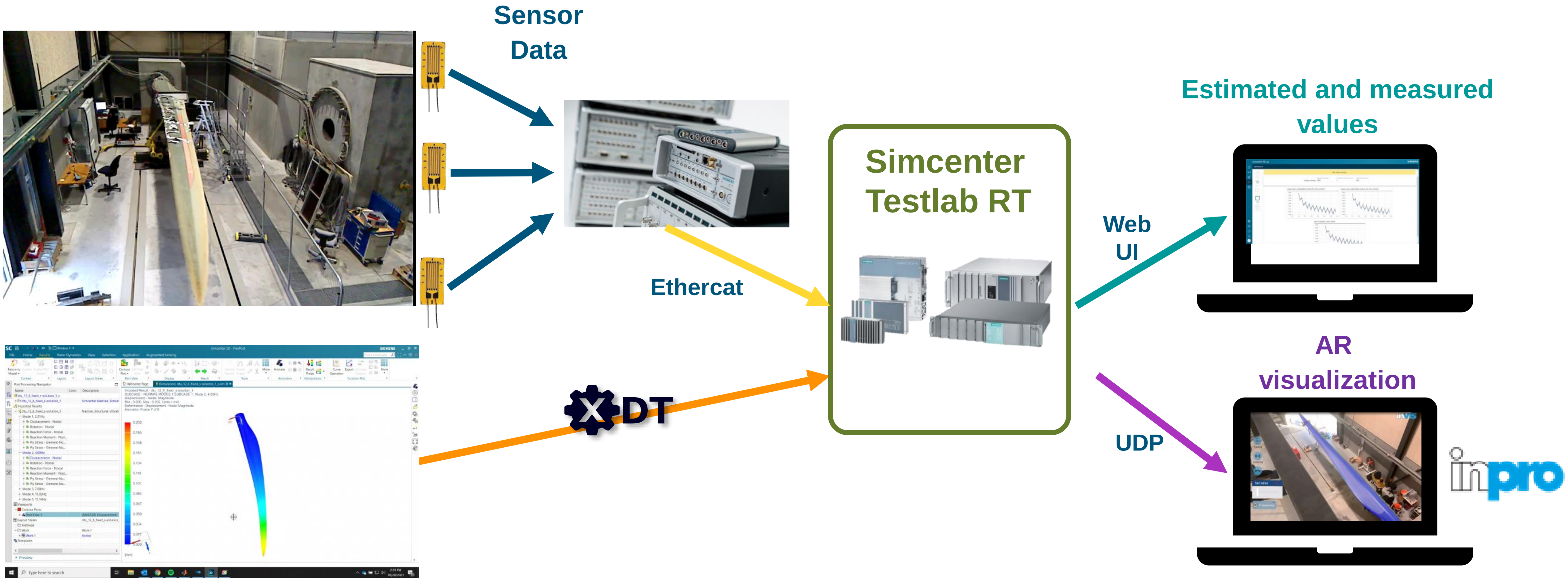
xDT toolchain

Operate in real-time the xDT of a wind turbine blade and stream the estimated results to Simcenter Testlab RT



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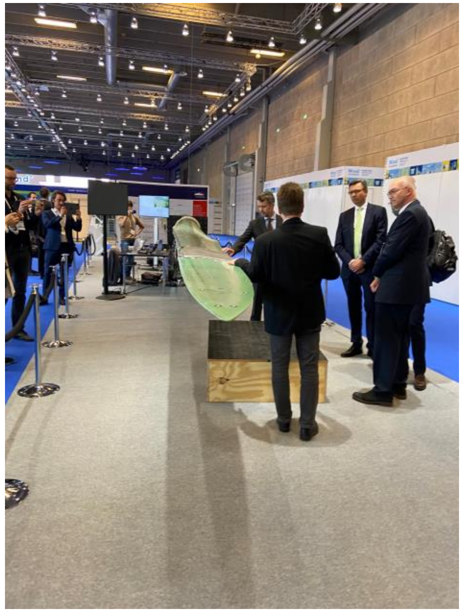
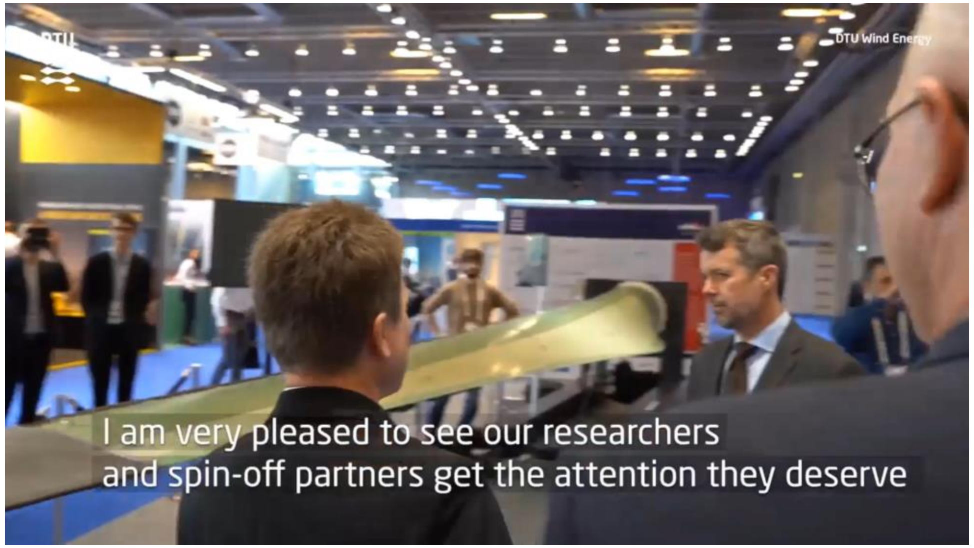
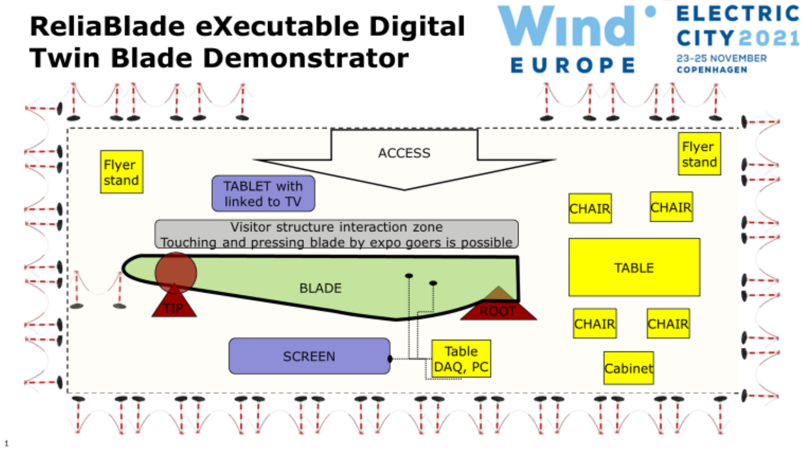
Wind Europe Electric City conference (23-25 November 2021)

Demonstration on **12.6m long blade**







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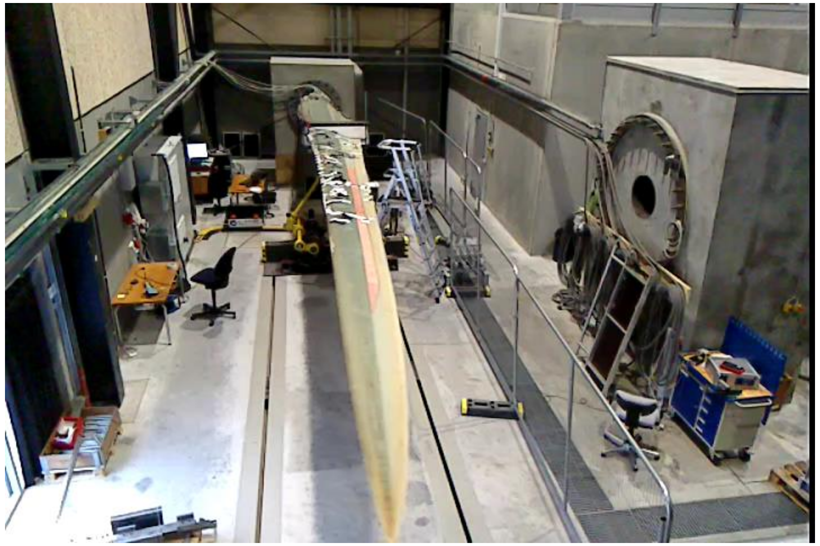
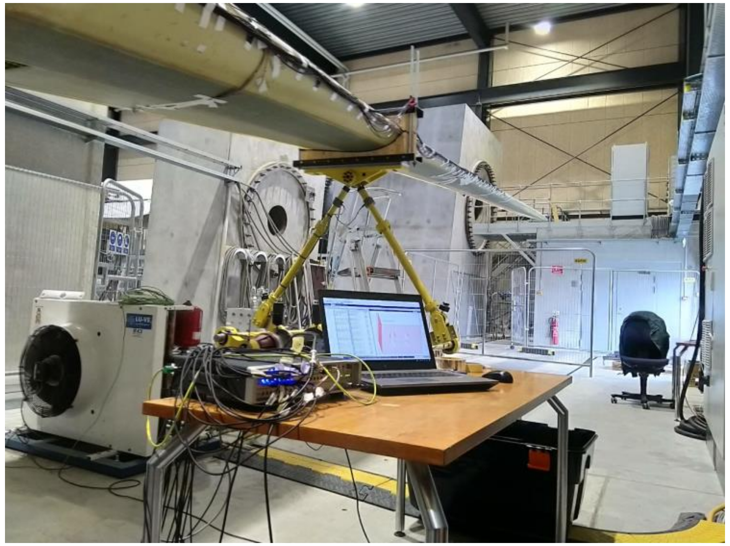
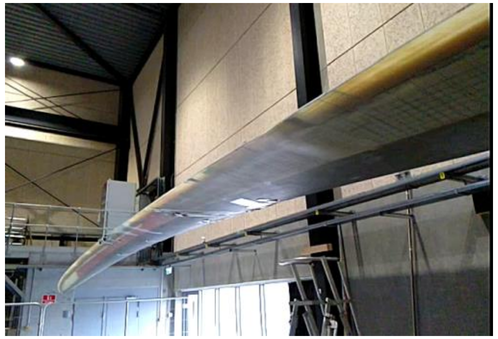
Future outlook

- Apply developed Digital Twin architecture from full scale blade laboratory tests to operational environment
- Embed Machine Learning methods for the automated model updating
- Vibration based Structural Health Monitoring



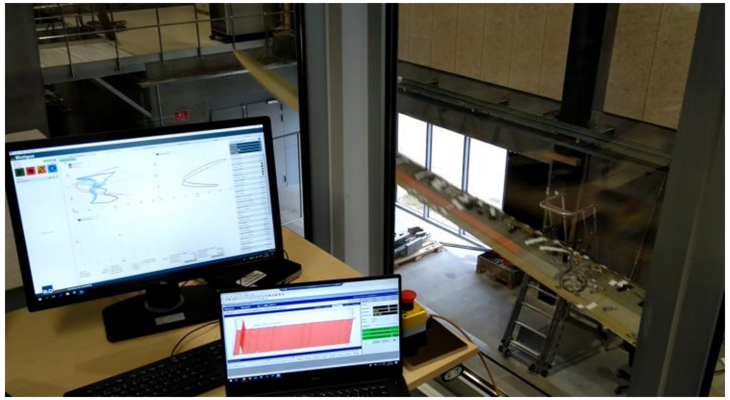




TE Debonding

Delamination

- Full Scale Fatigue Test
- Data Collection
  - SHM
  - Machine Learning Training
- Damages Induced
- Digital Twin Creation



Wrinkles

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Acknowledgements

- A special acknowledgment goes to all involved colleagues from both Siemens Digital Industries Software and DTU Wind Energy:

  - Peter Berring (DTU Wind Energy)
  - Kim Branner (DTU Wind Energy)
  - Philipp Ulrich Haselbach (DTU Wind Energy)
  - Cem Yeniceli (DTU Wind Energy)
  - Marcin Luczak (DTU Wind Energy)
  - Steen Hjelm Madsen (DTU Wind Energy)
  - Sergei Semenov (DTU Wind Energy)

  - Filippo Capurso (Siemens Digital Industries Software)
  - Roberta Cumbo (Siemens Digital Industries Software)
  - Emilio Di Lorenzo (Siemens Digital Industries Software)
  - Simone Manzato (Siemens Digital Industries Software)
  - Davide Mastrodicasa (Siemens Digital Industries Software)
  - Bart Peeters (Siemens Digital Industries Software)
  - Tommaso Tamarozzi (Siemens Digital Industries Software)
  - Andre Tavares (Siemens Digital Industries Software)
  - Brecht Van Baelen (Siemens Digital Industries Software)
  - Silvia Vettori (Siemens Digital Industries Software)

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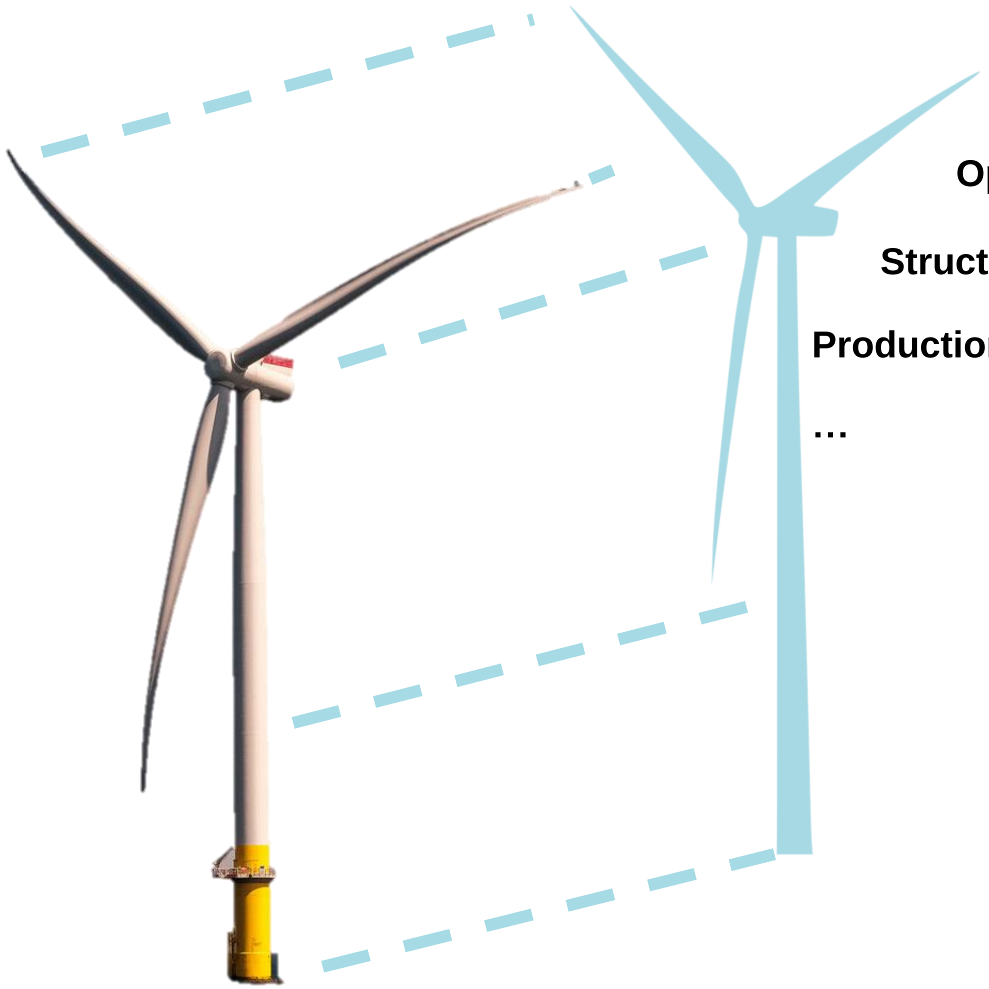
Conclusions
Digital twin: final considerations

- Collection of **different information**
- Exploitable in **several domains**
- Living concept **evolving** throughout the life-cycle
- Fluid representation of the **individual specimen** rather than a generic model
- Integrating **simulation** and **test** data, e.g., via Smart Virtual Sensing



Models

Operational data

Structural data

Production process data

...

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Thank you!

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Siemens Industry Software NV