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Towards turbine blade production with zero waste

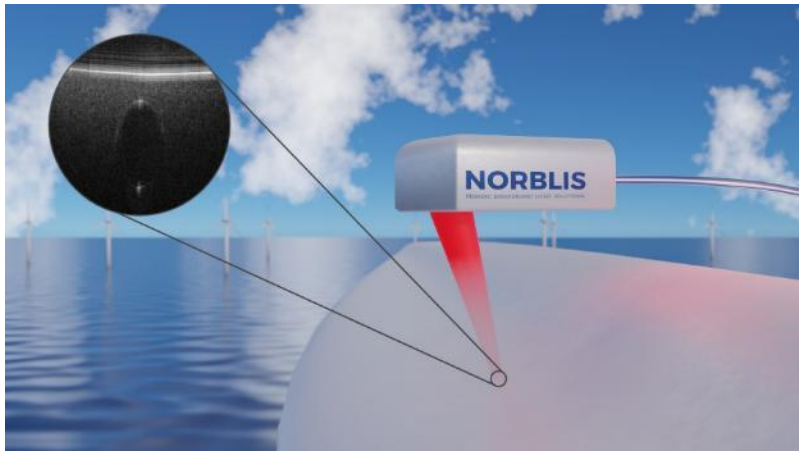
Horizon Europe 101058054

TURBO public presentation

https://turboproject.eu

Presentation outline

- **Overview**
  - Consortium
  - Key objectives
  - Partner contributions
- **Supporting technologies**
  - Simulation
  - In-line monitoring
  - NDT of blade coatings
- **Manufacturing technologies**
  - Digital twin
  - Improved composite manufacturing
  - Sustainability assessment
  - TURBO demo



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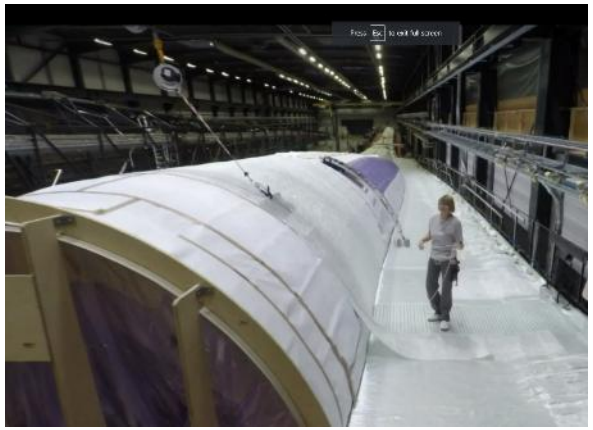
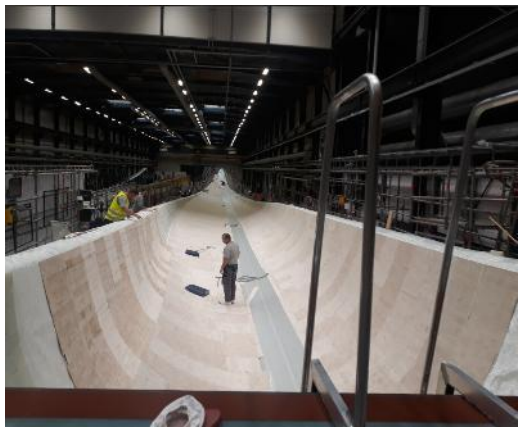
Consortium

No.	Short name	Name	Country
Beneficiaries			
1	DTU	DANMARKS TEKNISKE UNIVERSITET	DK
2	SGRE	SIEMENS GAMESA RENEWABLE ENERGY AS	DK
3	UPV	UNIVERSITAT POLITECNICA DE VALENCIA	ES
4	SYN	SYNTHESITES	BE
5	NORBLIS	NORBLIS APS	DK
6	VIV	VIVID COMPONENTS GERMANY UG	DE
7	ARDITEC	ARDITEC	FR
Associated partners			
8	NCC	NCC OPERATIONS LIMITED	UK
9	CPI	CENTRE FOR PROCESS INNOVATION LIMITED	UK

TURBO casting process– SGRE IntegralBlade®

- SiemensGamesa Offshore uses patented IntegralBlade® technology
- Manufactured in one piece using a closed process and based on vacuum-assisted resin transfer moulding (VARTM).
- The result is a complete, seamless blade with no glued joints that may become weak points
- The primary materials used in manufacturing are epoxy, fiberglass, balsa wood and paint.





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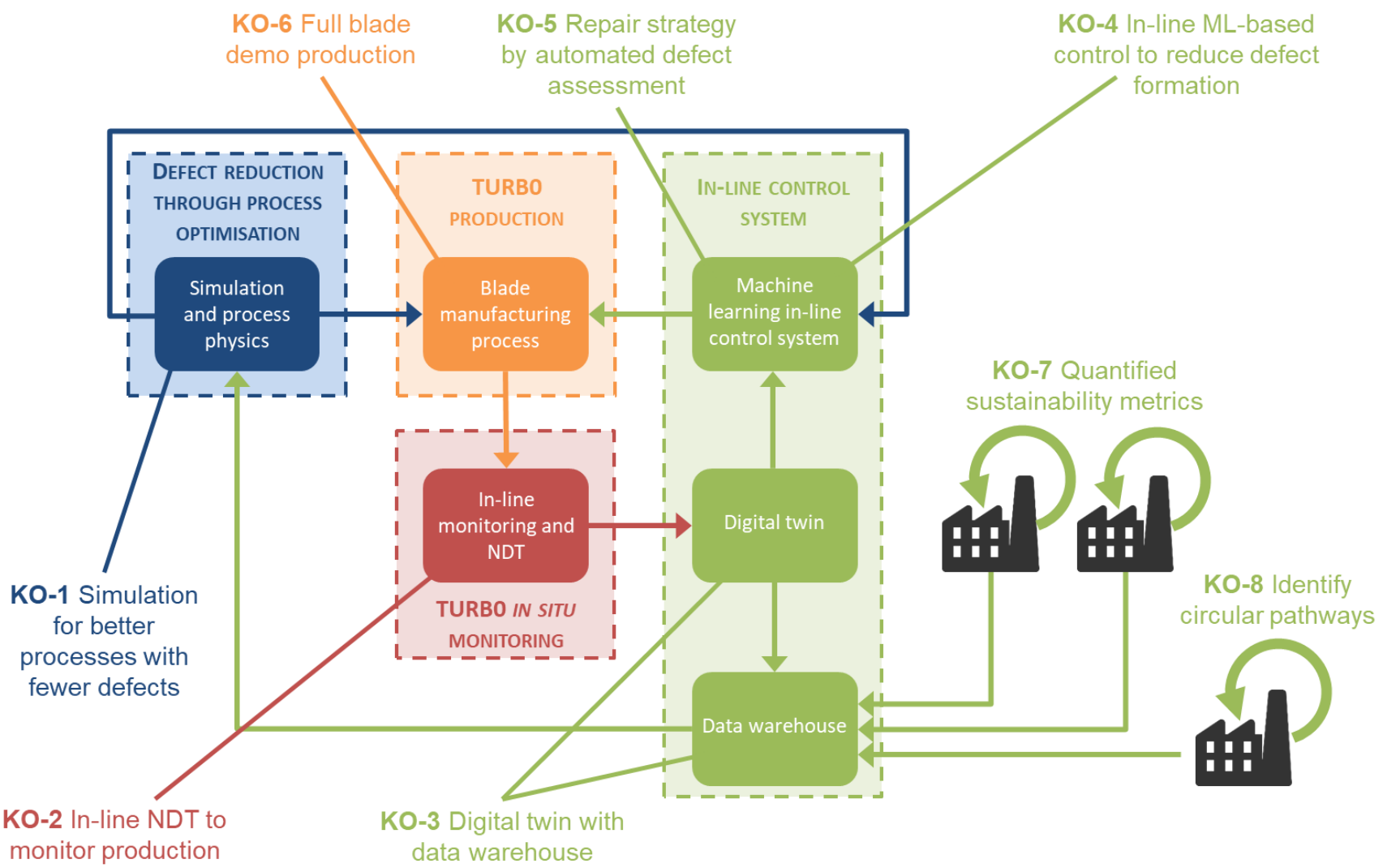
TURBO key objectives



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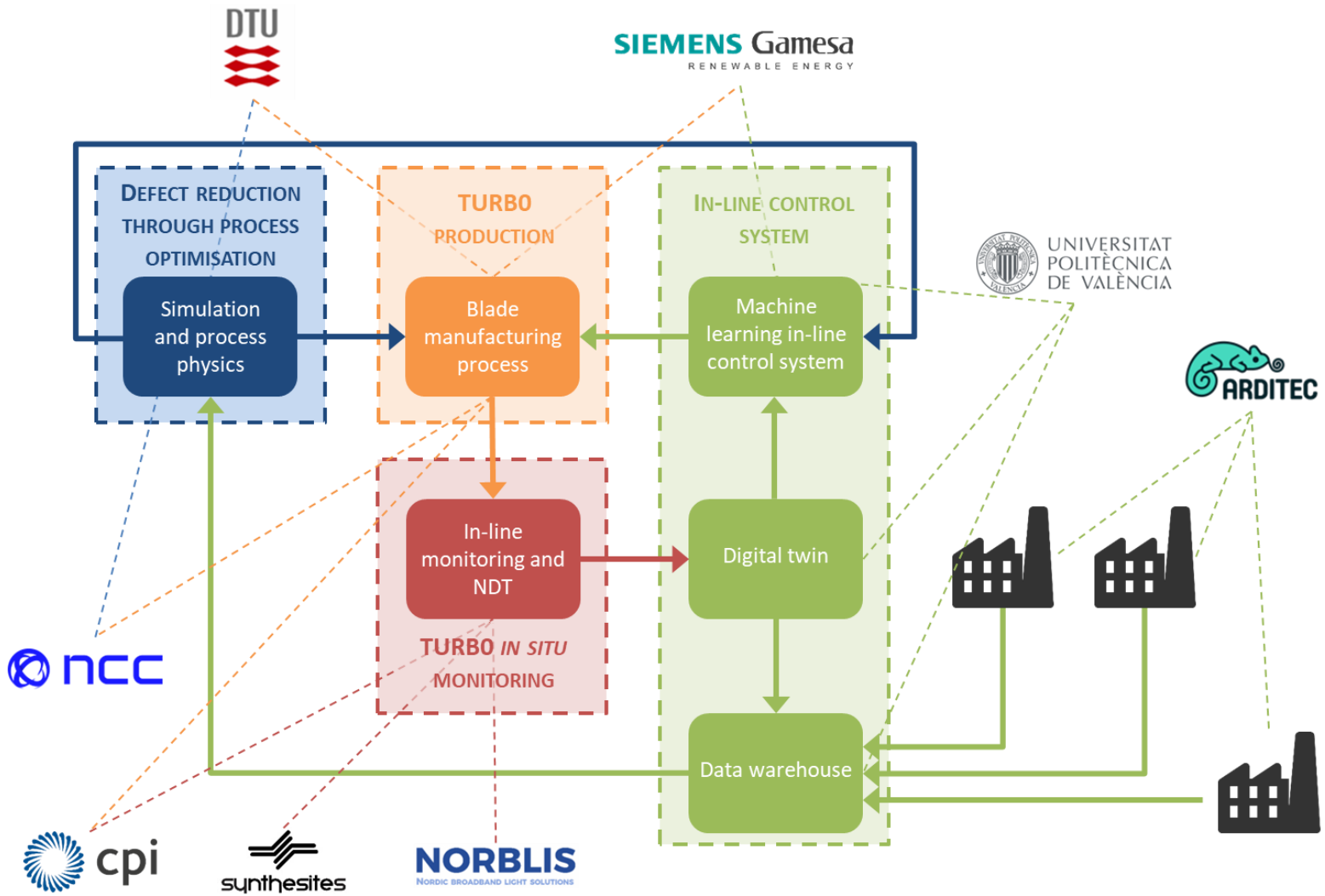
TURBO partner key contributions



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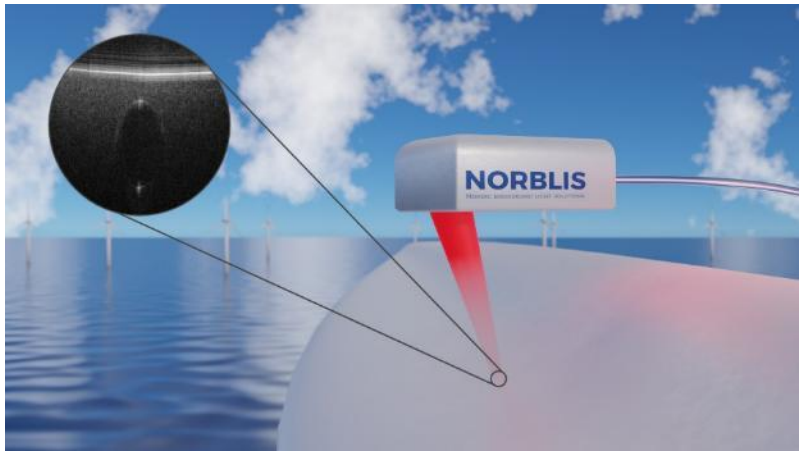

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Simulation

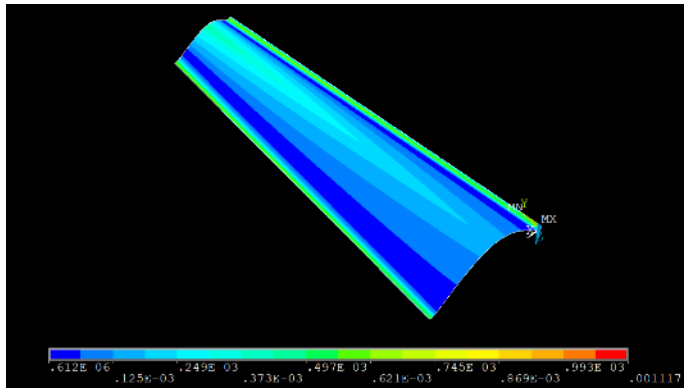
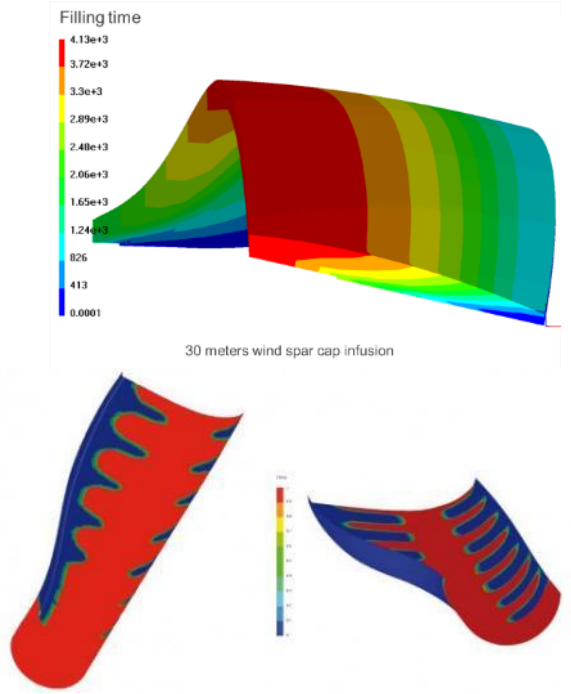


Image courtesy of DTU Construct

- What ?
  - Numerical simulation combined with sensor data
  - Used to minimise defect formation by:
    - Defining the manufacturing processes
    - Understanding how the process should be modified in real-time in response to *in situ* monitoring data

- How ?
  - Multi-scale modelling of the manufacturing process
    - From virtual characterisation of the local material properties to high fidelity analysis of the manufacturing of the blade
  - Exploring the field of possibilities in real time
    - By the combination of advanced AI techniques (model order reduction, machine learning *etc*.)
  - Generating physical-based prediction in a decision support system for the production hybrid sensor



Images courtesy of ESI Group

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Infusion simulation

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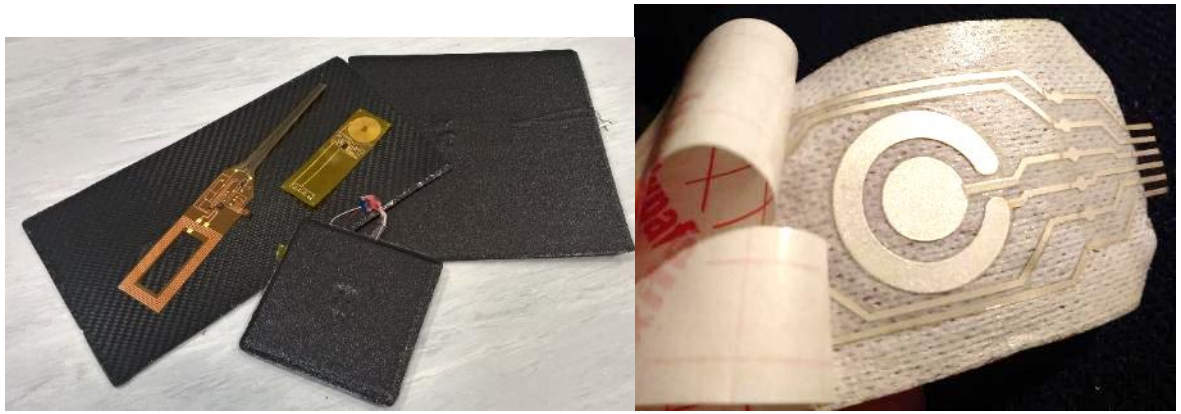
In-line process monitoring

- Synthesites TURBO system will
  - Measure resin arrival during infusion and temperature measurement (≤ 56 points)
  - Calculate online resin viscosity and gelation time
  - Track the evolution of glass transition temperature (T_g) at several locations
  - Broadcast all data in real-time to help define system control signals

Images courtesy of Synthesites

- CPI will develop a TURBO embedded wireless sensor system
  - Measures resin arrival and temperature
  - Fabricated on flexible substrate
  - Wireless communications will send data from inside the mould (*i.e.* LoRaWAN)



Images courtesy of CPI

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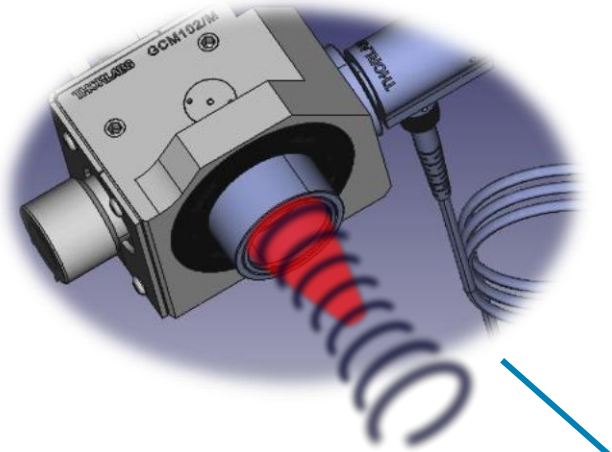
NDT of blade coatings

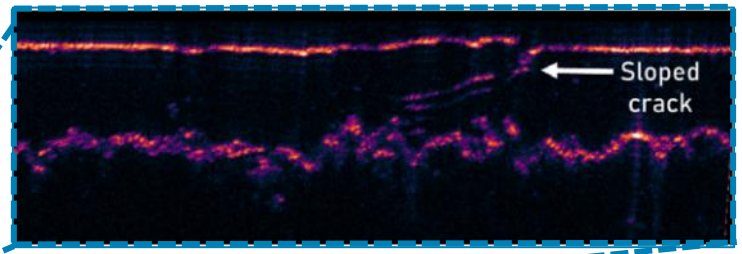
- First industrial-scale combined thermography and mid-IR optical coherence tomography (OCT) scanner

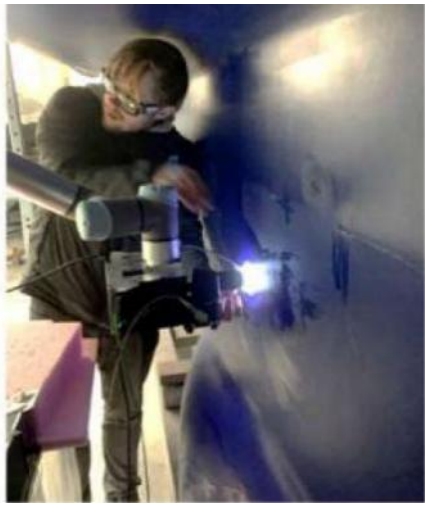


- Deep penetration of thermography combined with new technology of mid-IR OCT

- For *sub-surface* defect detection

- High resolution images of the critical upper layers





- Demonstrated on ship hulls

Petersen, Christian R., *et al*. "Non-destructive subsurface inspection of marine and protective coatings using near-and mid-infrared optical coherence tomography." Coatings **11**: 877 (2021).

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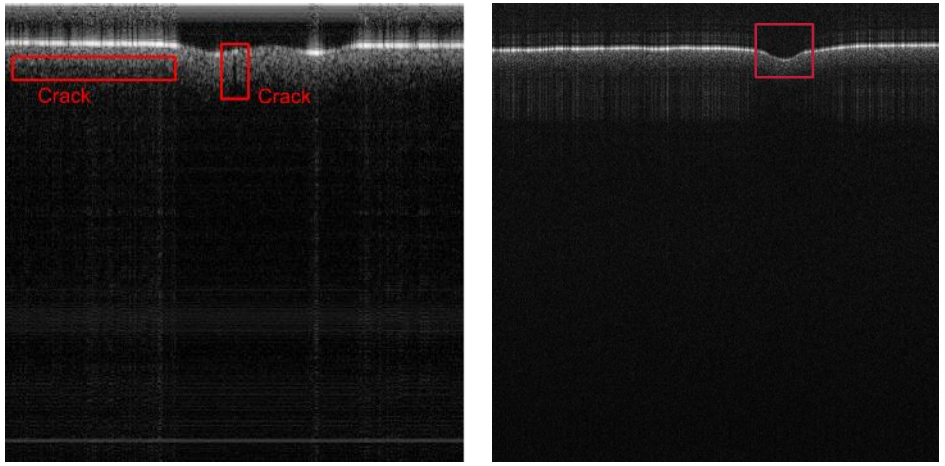
Machine learning analysis for NDT of blade coatings

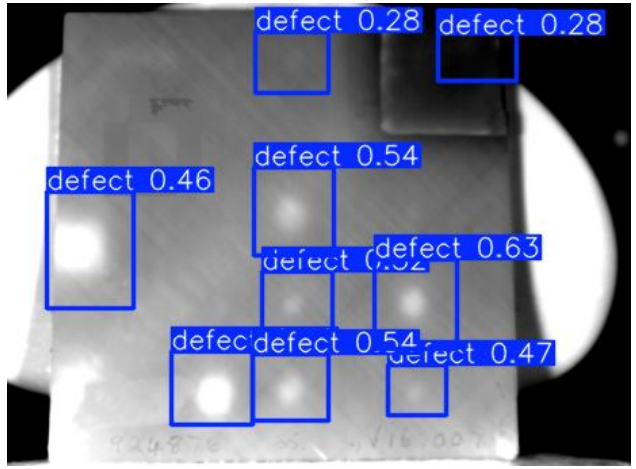
- DTU has developed a supercontinuum extending to longer mid-IR wavelengths (*e.g.* 4 μm)
  - These wavelengths penetrate deeper than traditional near-IR OCT systems (typically 1.3 μm)
  - Source is based on a 2 μm laser to pump ZBLAN fibre

- UPV has developed machine learning-based algorithms for defect detection using object detection techniques (YOLO) applied to OCT and thermographic images

OCT defect detection



Thermographic defect detection



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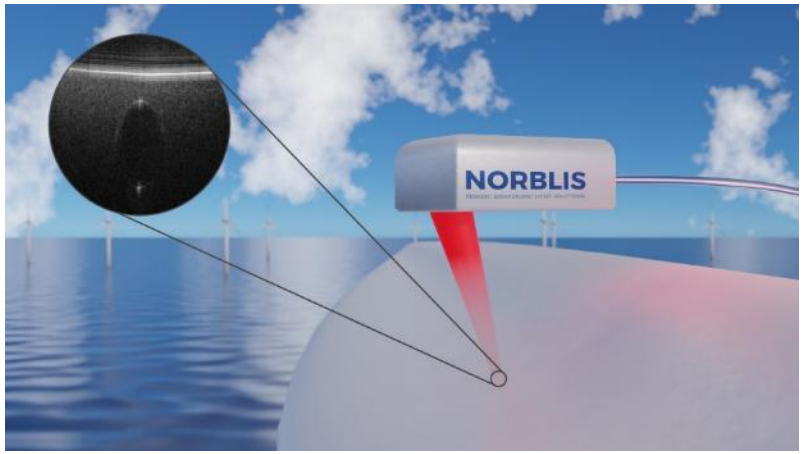

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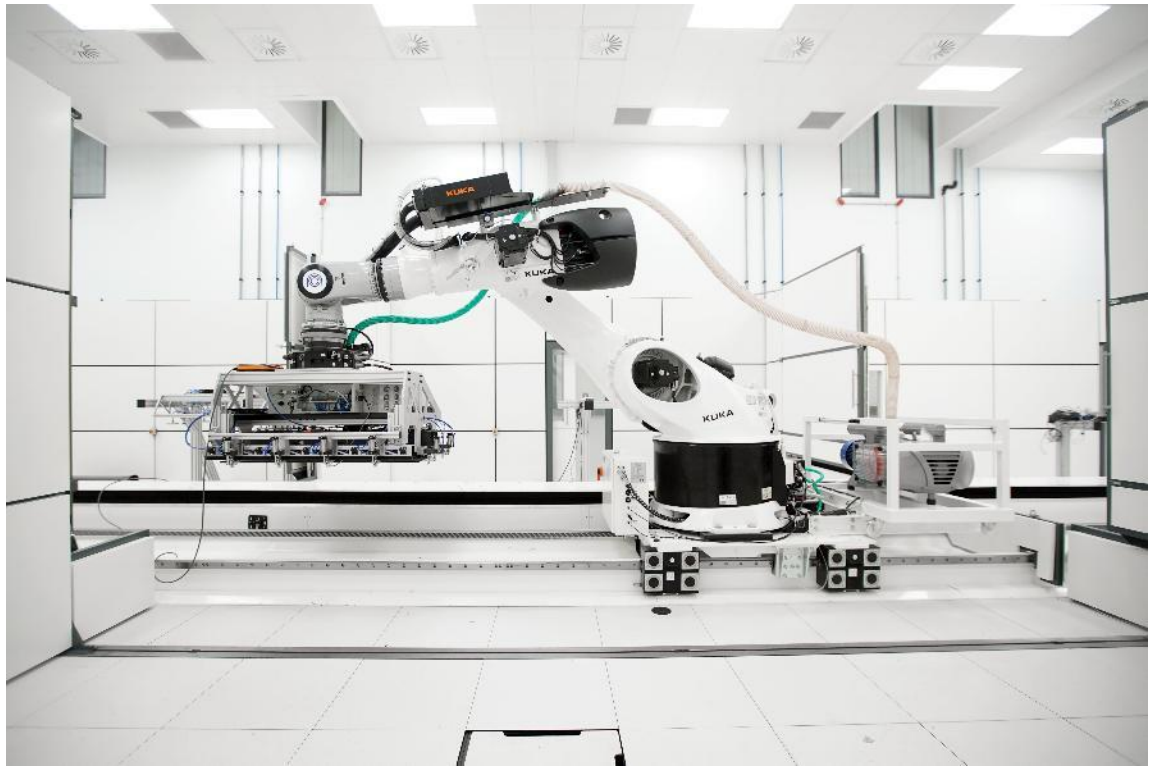
TURBO digital twin framework

- NCC is developing a self-adaptive manufacturing process
  - Digital framework for zero waste wind turbine blade manufacturing
- Key steps:
  - Scale-up of manufacturing and simulation to a full-scale blade demonstrator
  - Combine process and sensor data with machine learning and physics-based simulations
  - Provide live manufacturing quality insights and corrective feedback loop control
  - Development of a secure digital twin architecture scalable for industrial production environments



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TURBO digital twin framework

- UPV is developing deep learning algorithms based on reinforcement learning strategies to:
  - Control the resin flow front during the infusion
  - Avoid the formation of defects

BEFORE TURBO

Uncontrolled turbine blade infusion caused defects and quality issues.

AFTER TURBO

Achieve first-time-right production with an adaptive infusion ML model.

Model adjusts to varying boundary conditions for consistent quality.

No defect

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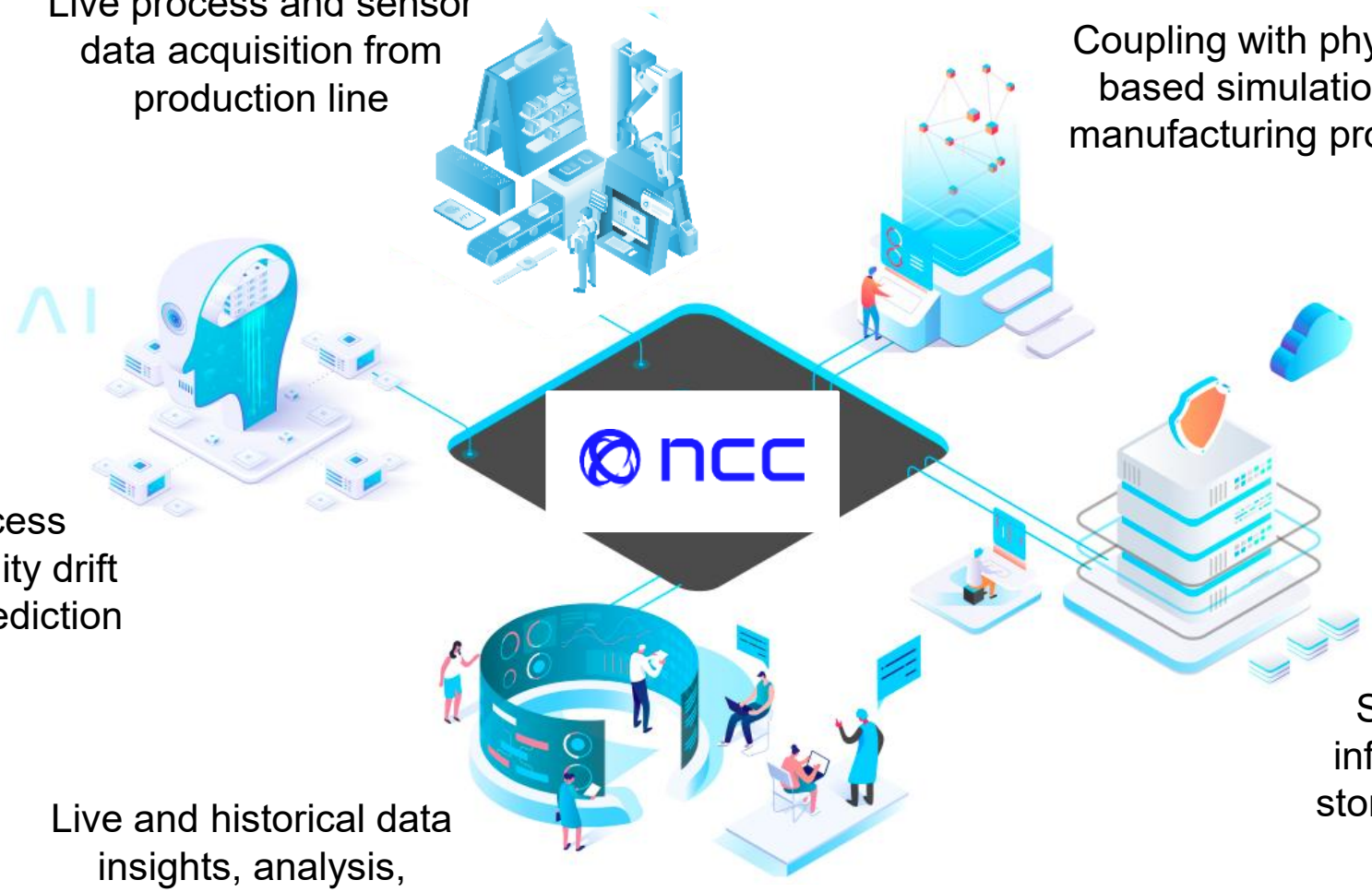
TURBO digital overview

Live process and sensor data acquisition from production line

Coupling with physics-based simulation of manufacturing process



ML-based process anomaly and quality drift evaluation and prediction

Secure hybrid data infrastructure for data storage and processing

Live and historical data insights, analysis, notifications and alarms

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Improved composite manufacturing

- TURBO objective and tasks
  - SGRE will integrate the TURBO advances into infusion and control systems, particularly
    - Lessons from process simulation
    - Machine-learning based analysis of the digital twin based on in-line process monitoring and NDT
  - These objectives require a:
    - Manufacturing system interface to interpret and process the data from simulation and digital twin
    - Real-time infusion control system (hardware and software) based on data from the in-line sensors and NDT devices during infusion

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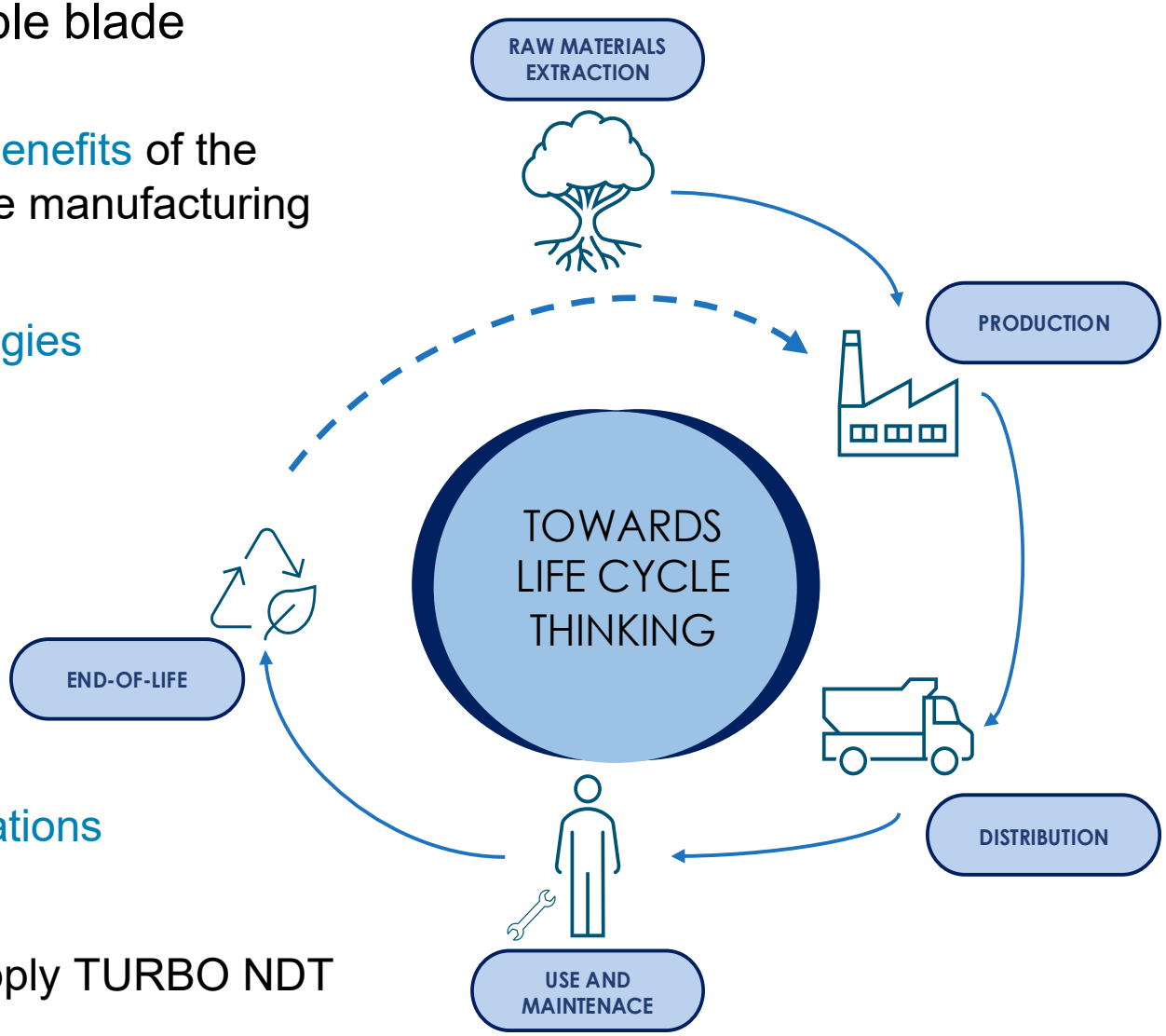
Sustainability assessments

- Arditec will help to develop circular and sustainable blade manufacturing by:
  - Assessing the environmental, economic and social benefits of the innovative value chain in comparison to current blade manufacturing processes
  - Using standardised life cycle assessment methodologies
    - LCA (ISO 14040/14044)
    - Life Cycle Costing (LCC, ISO, 2006)
    - Social LCA (UNEP/SETAC)
  - Developing circular pathways for production waste
    - Material Circularity Indicator (MCI) methodology developed by the Ellen MacArthur Foundation
  - Contributing to current relevant standards and regulations
    - IEC 61400-5/IEC 61400-28-2/REACH
  - Training SGRE personnel to operate the sensors, apply TURBO NDT methods and interpret the results



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TURBO demo

- SGRE has a dedicated space in its Aalborg factory for the TURBO demos
- A large section of a >80 m blade will be used to demonstrate TURBO advances
  - Allows analysis of large blade aspects not possible on a smaller scale blade
  - Assess how TURBO technology can be integrated into a real production line
  - Quantify benefits in terms of improved quality and reduced scrap

Images courtesy of Siemens Gamesa Renewable Energy A/S.

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Thank you for your attention!

TURBO project website

https://turboproject.eu

Bruce Napier

Vivid Components Germany UG

bruce@vividcomponents.co.uk

TURBO LinkedIn group

www.linkedin.com/company/turbo-project

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