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SHM Technologies for Wind Turbine Blades

- **EOLIAN Webinar: A new generation of sustainable wind turbine blades**
- 11th December 2025, 10:00-11:30 CET

www.eolian-project.eu

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CONTENTS

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1. SHM Technologies for Wind Turbine Blades

- **Structural Health Monitoring (SHM)** in wind turbine blades is essential to maintain efficiency, safety, and reduce maintenance costs

LEADING EDGE

- High particle/rain/hail impact and ice accretion / adhesion
- v_r ↑↑ Energy impact
- Aerodynamic degradation and structural damage

Physical mechanisms

LEE: Repeated impacts remove material

LEI: Accretion of supercooled droplets (Atmospheric Icing → Rime and Glaze)

Key Impacts

Leading Edge Erosion (LEE)

- AEP loss 1–6 %
- Pitch control: Drag ↑ Lift ↓
- Structural lifetime ↓

Leading Edge Icing (LEI)

- Power loss 20–50 %
- Unbalanced mass / vibrations
- Risks: ice throw / shutdown

SHM → **DETECT** → **ACTUATION** → **OPTIMISATION**

Sensors: strain, acoustic emission, vibration, thermal sensors, cameras, UAVs.
Processing: filtering, time–frequency transforms, physics-based models.
ML/AI: CNN/YOLO for images, TCN/LSTM for SCADA, autoencoders.
Decision: damage detection, severity classification, prognosis.

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2. Erosion Detection Technologies - Classification

Technology	Detects	Advantages	Limitations	Maturity
Visual / Drone inspection	Surface erosion, pits, cracks, coating loss	Direct observation, well-established, high accuracy	Requires turbine shutdown or access; periodic only, not continuous	High
Image-based ML (drone or ground photos)	Surface damage patterns, severity classification	Scalable, automated assessment, good for fleet-level monitoring	Dependent on image quality; misses subsurface damage; needs labelled data	Medium
Far-field aeroacoustics (microphone arrays)	Noise changes caused by roughness or erosion	Non-contact, remote, no blade modification	Sensitivity reduced in turbulent farms; validated mainly in wind-tunnel	Medium
CFD + aeroacoustics simulation (predictive)	Expected erosion progression & acoustic signature	Useful for prediction, design, coating testing	Not real-time; depends on accurate environmental inputs	Medium
SCADA + Performance/Power Curve deviation	Aerodynamic degradation from roughness/erosion	No added hardware; scalable to entire fleet	Indirect, cannot locate damage; confounds with other losses	Low–Medium
Structural vibration response	Changes in dynamic response due to mass/shape loss	Uses existing sensors in some turbines; potential early indication	Erosion produces subtle changes → low sensitivity; noise masking	Low
Rain / impact erosion modelling (material & physics-based)	Predicted coating wear due to rain/particles	Supports maintenance planning + risk maps	Predictive only; requires validation; site-specific	Medium
Coating/erosion sensors (embedded or surface)	Coating degradation or thickness loss	Direct, continuous monitoring possible	Prototypes only; integration in blades complex; durability issues	Low

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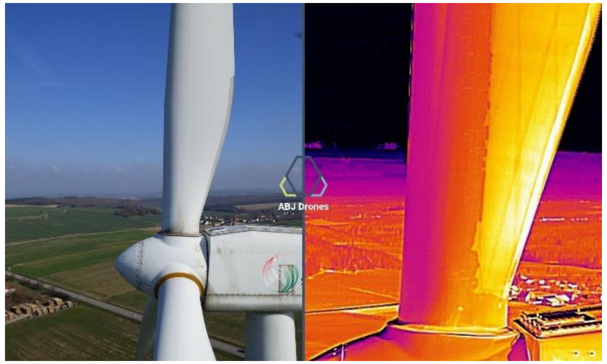
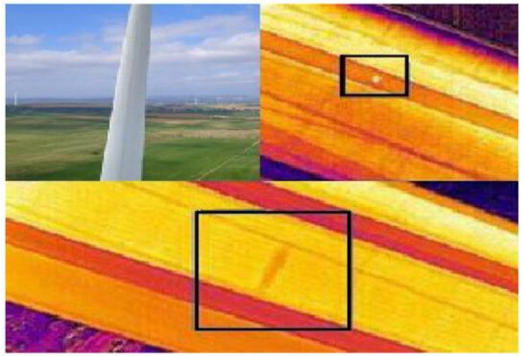
2. Erosion Detection Technologies – Examples

Visual RBG Inspection

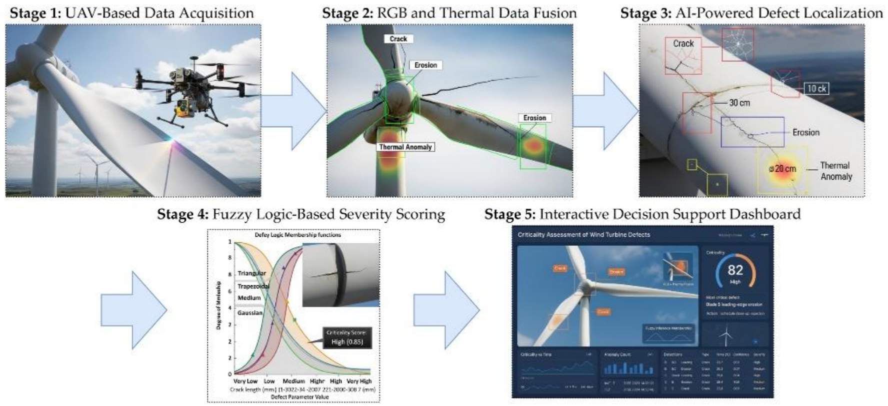


Visual IR Inspection

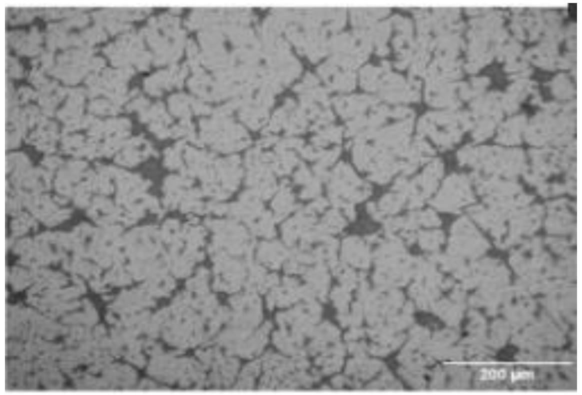
Acoustic emission sensor installed on a turbine blade



LiDAR-based drone inspection and modeling



Multi-sensor integration



Microscopy Inspection

Robotic crawler inspection

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2. Ice Detection Technologies - Classification

Technology	Detects	Advantages	Limitations	Maturity
SCADA + ML	Ice via operational changes	No extra hardware, scalable	Only detects when turbine operates, may confuse with faults	High
Rotor vibration	Blade mass changes	Sensitive, can retrofit, works during operation	Only estimates ice amount, not location	Medium-high
Vibration + ML	Early ice accumulation	Can distinguish subtle ice, early warning	Needs good training data, possible false alarms	Medium
On-blade sensors (capacitive/impedance)	Ice on blade surface	Direct detection, independent of operation	Hardware installation, maintenance, cost	Medium
Acoustic emission	Ice-induced stress/acoustic signals	Early detection, non-intrusive	Sensitive to noise, complex installation	Low-medium
Cameras (RGB/Thermal)	Visual/thermal ice	Direct detection	Weather/visibility limitations	Medium
FBG / temperature sensors	Load/temperature changes	Embedded, continuous monitoring	Expensive, complex installation	Medium
Aeroacoustics	Ice-induced noise	Potentially early detection	Requires modeling, experimental	Low-medium

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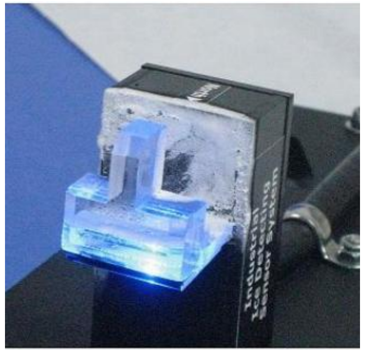
2. Ice Detection Technologies – Examples

Ultrasonic vibrating finger

Vertical rotating cylindric load cell

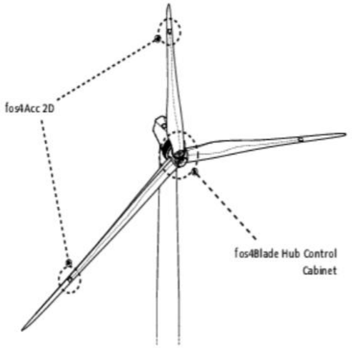


Change of opacity and reflection detector

IR camera to for IR reflection change

Impedance/resistive probe

Impedance sensors



Fiber optic sensors

Piezo electric sensors

Structural acoustic sensors

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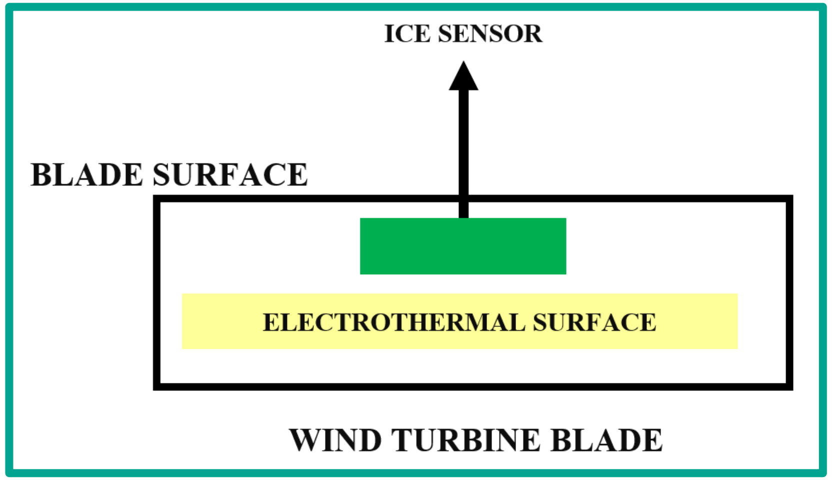
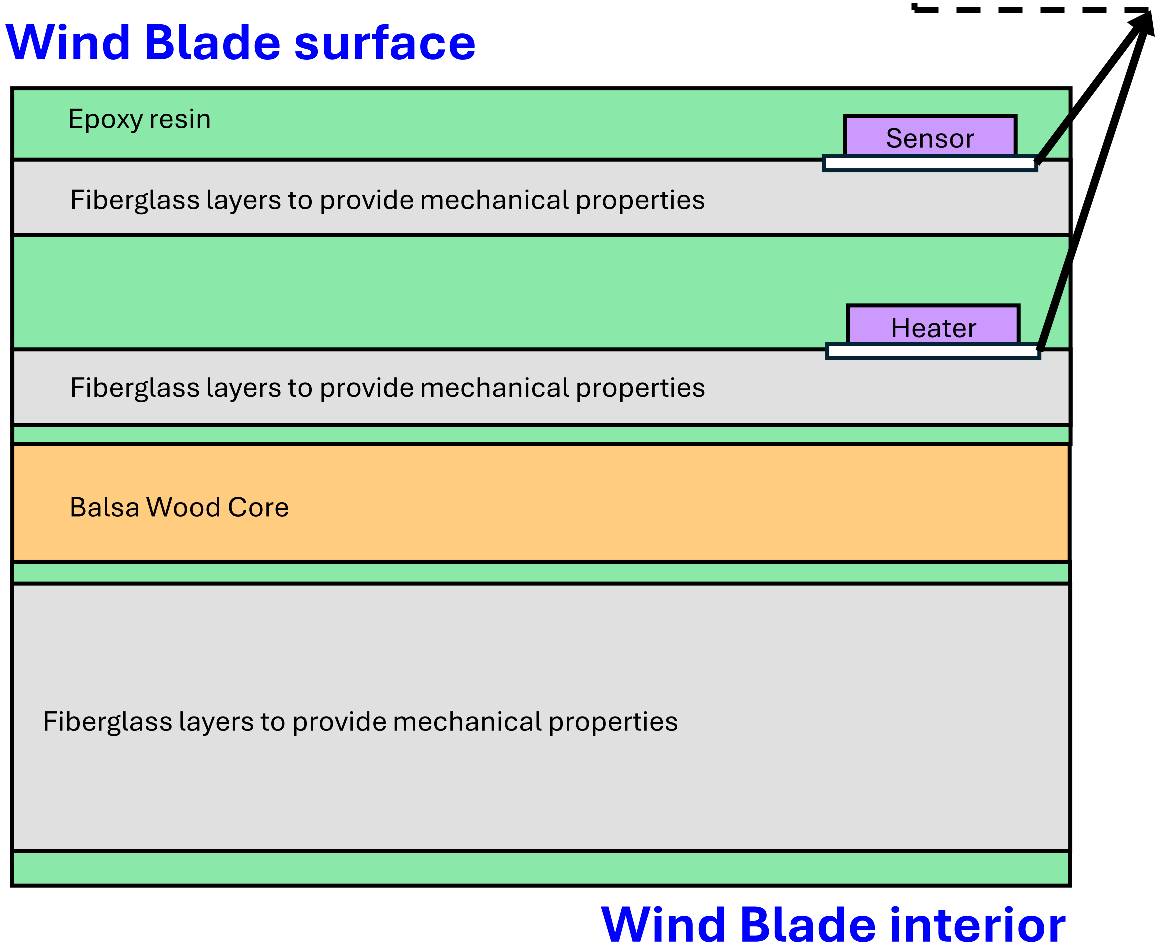
3. EOLIAN PROJECT APPROACH

CONCEPT



DEMONSTRATORS DESIGN (Cross section)

The sensor and heater are printed on a fiberglass fabric (thinner layer)



WIND BLADE STACK

(Near Leading Edge and the tip)

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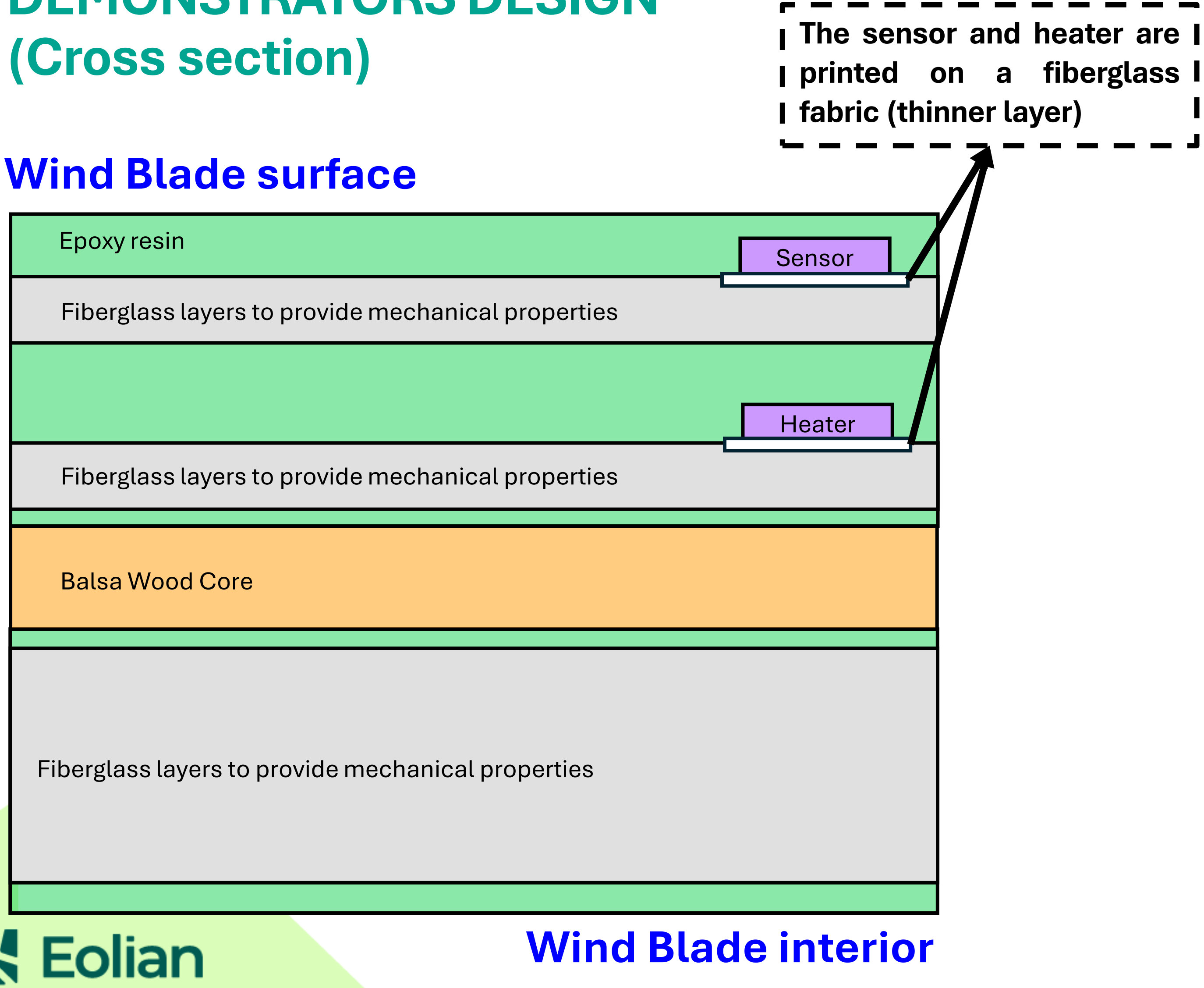
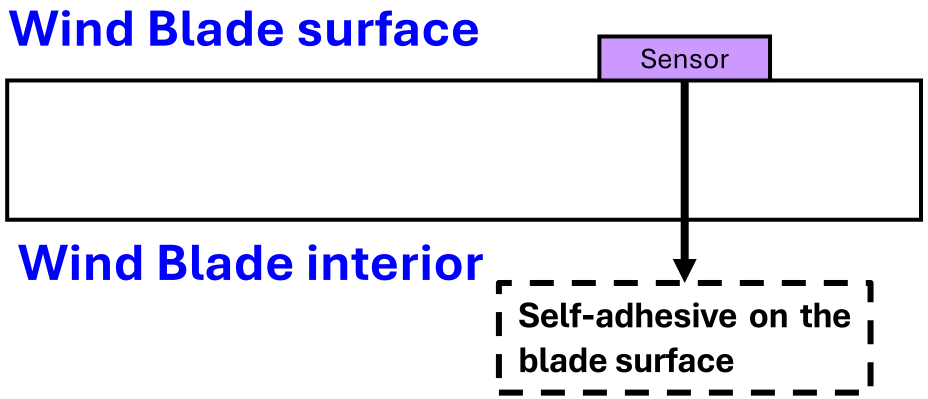
3. EOLIAN PROJECT APPROACH vs EOLOGIX

DEMONSTRATORS DESIGN (Cross section)



Impedance sensor



EOLOGIX-PING ON-BLADE

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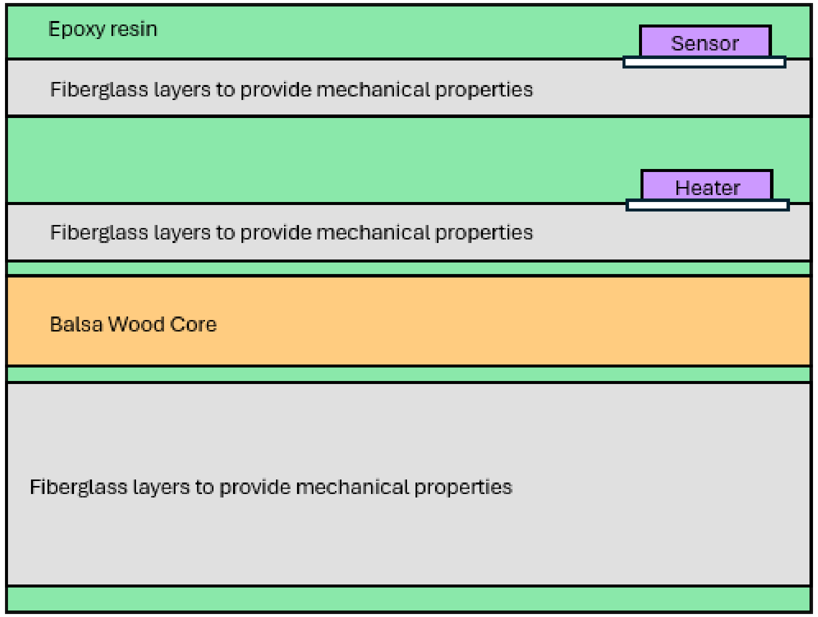
3. Manufactured Demonstrators → Sensor and heater approach

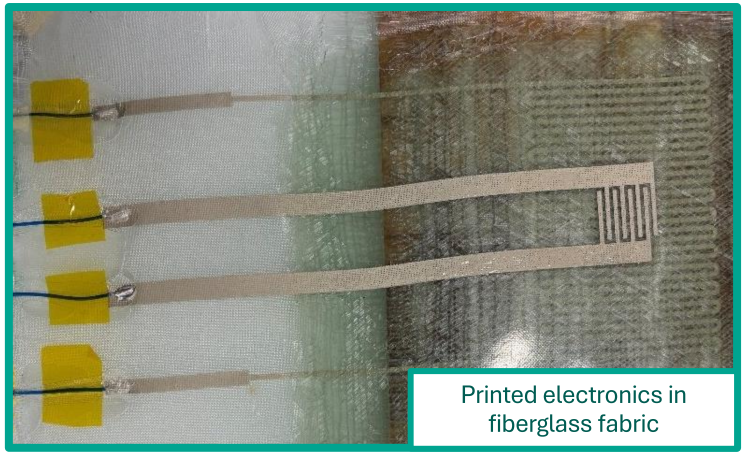
Composite → Vacuum Infusion Process

Wind Blade surface



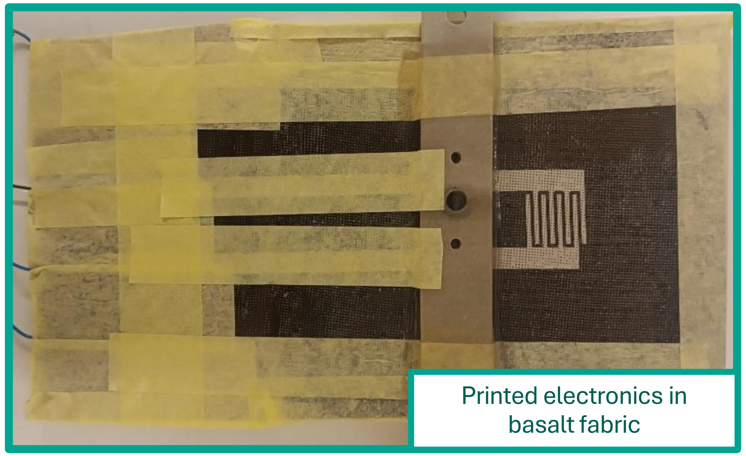
Wind Blade interior

Blade_wood_demo_ID



Printed electronics in fiberglass fabric

Blade_wood_demo_basalt_ID

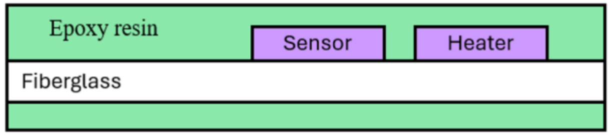


Printed electronics in basalt fabric

Idea3_demo

NOT EOLIAN STACK

Printed electronics in fiberglass fabric



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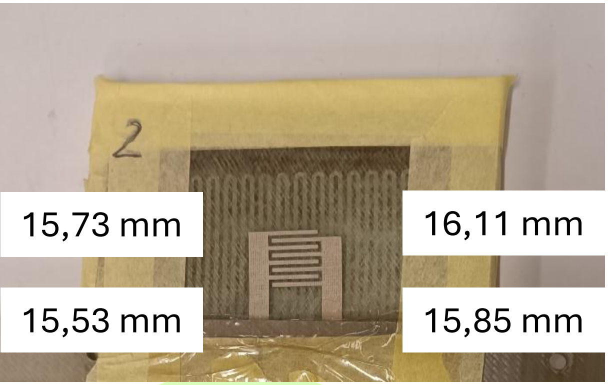
4. Ice detection approach → EIS measurements

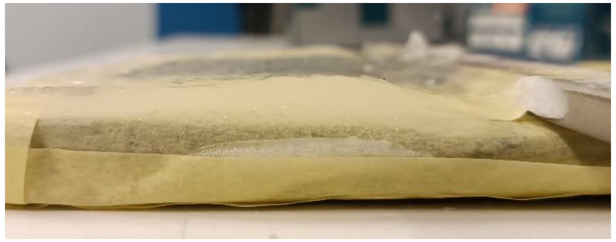
Test conditions:
- Temperature = -10°C
- Humidity = 80 %RH

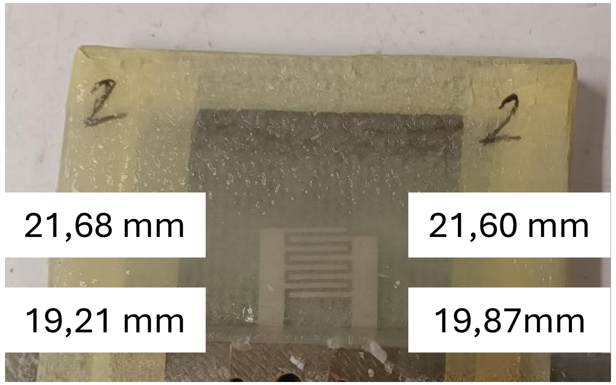
WIND TUNNEL ICE ACCRETION (water droplet speed 25 m/s)

WITHOUT ICE

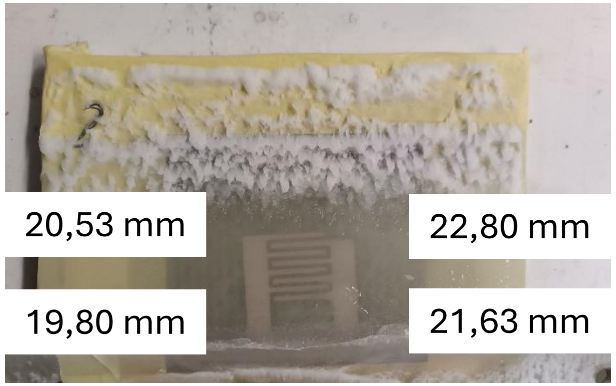


GLAZE ICE ≈ 5 mm

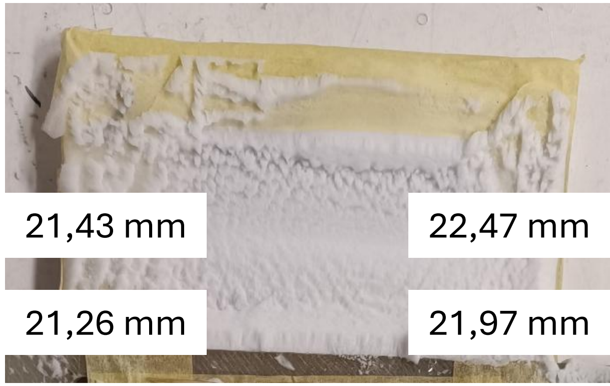




MIXED ICE ≈ 5 mm



RIME ICE ≈ 5 mm



Sensing different types of ice with interdigitated transducers

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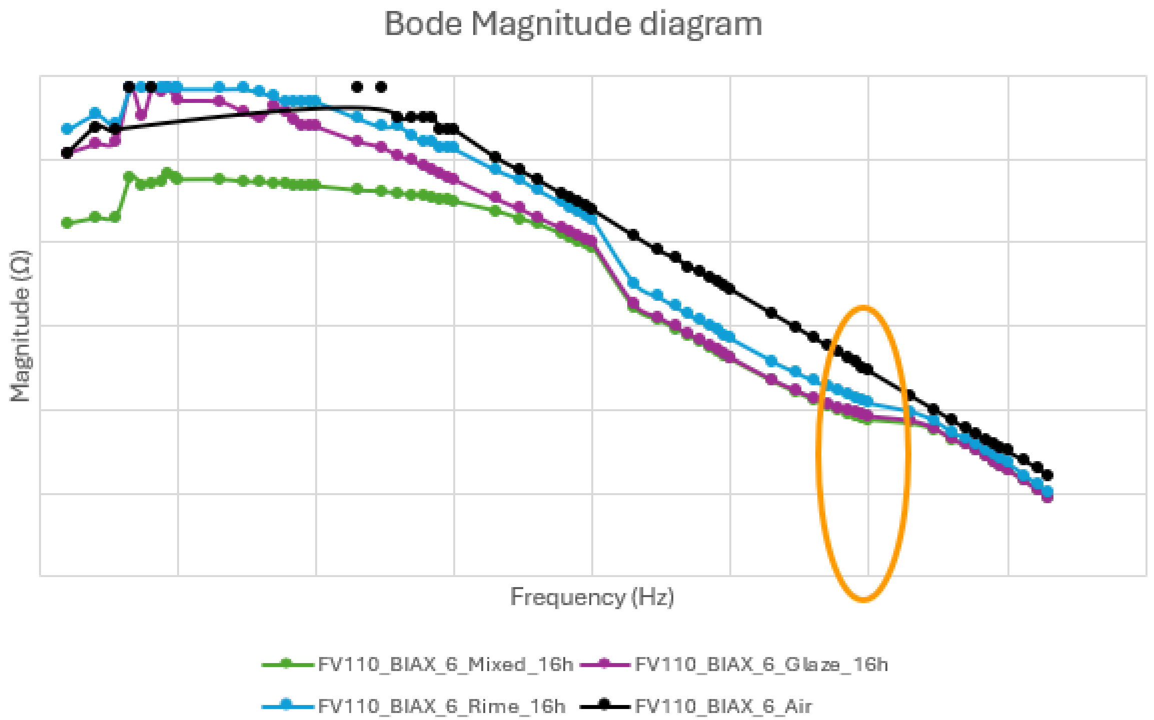
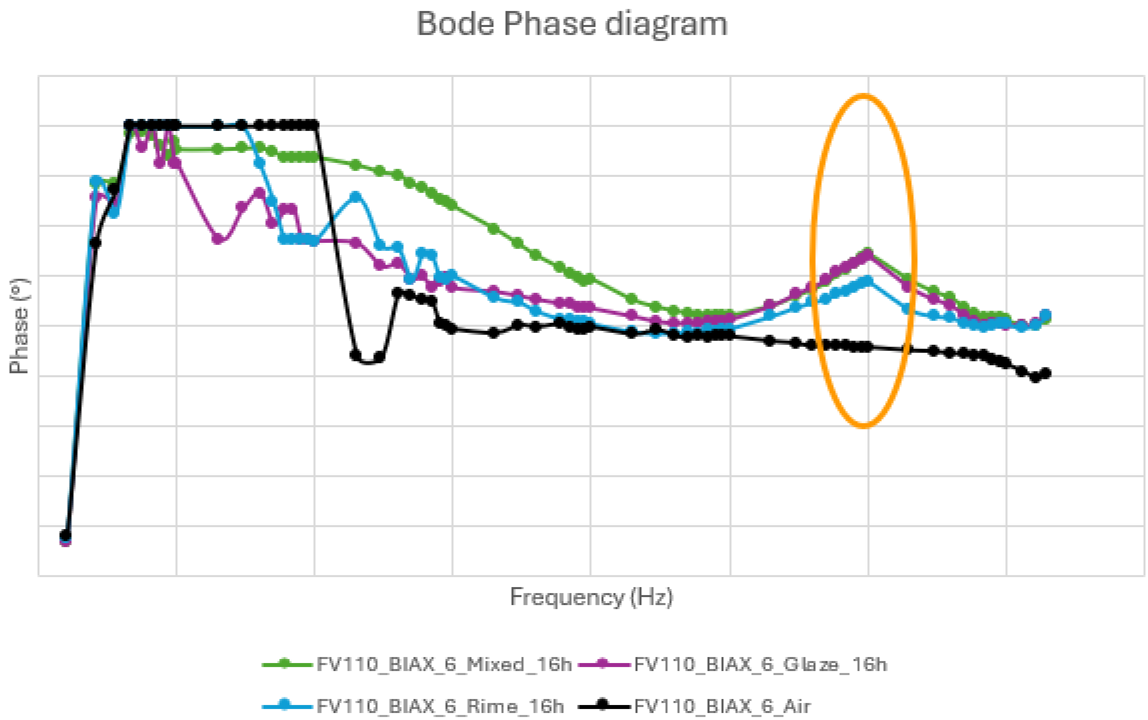
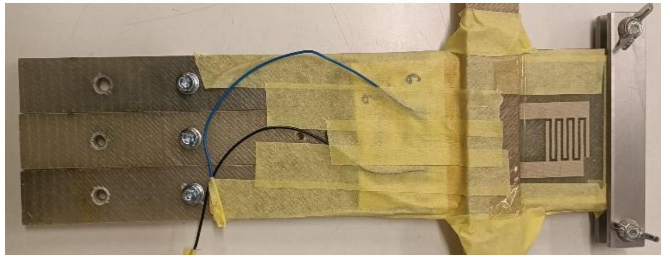
4. Ice detection approach: Impedance measurements

PRELIMINAR SELECCTION OF THE FREQUENCY RANGE: Air measurement





Frequency, Magnitude (Ω) and Phase (°) range values deleted for being private information



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Sensor characterization for air conditions at -10 °C is REQUIRED (for comparison of icing and no icing conditions)

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Conclusions

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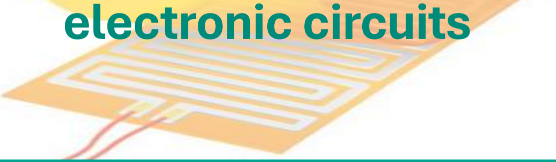
Extended operational time

Cost savings → Integration of electronic circuits



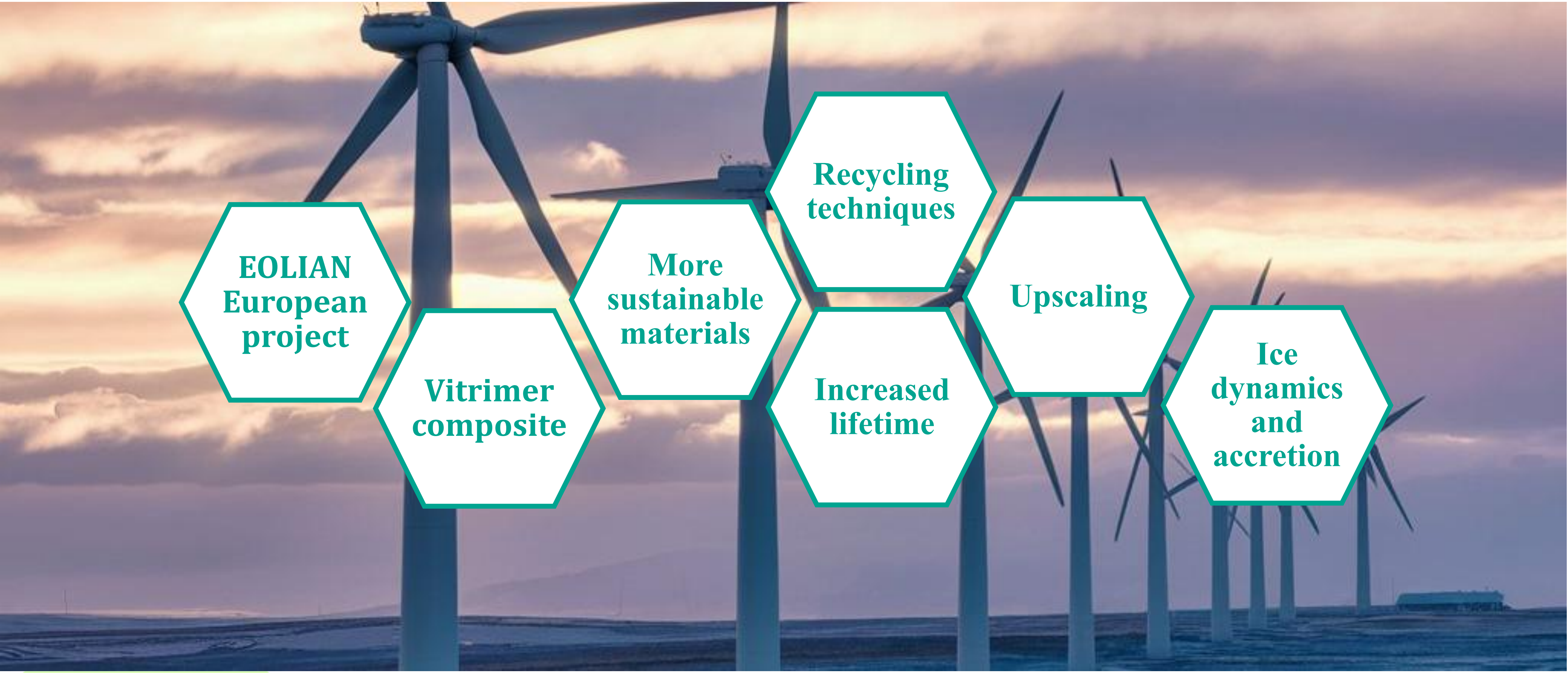
Development of intelligent systems

Remote monitoring and control

In situ detection

Multidisciplinary approach

Future work: Next steps



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Thank you for your attention!

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