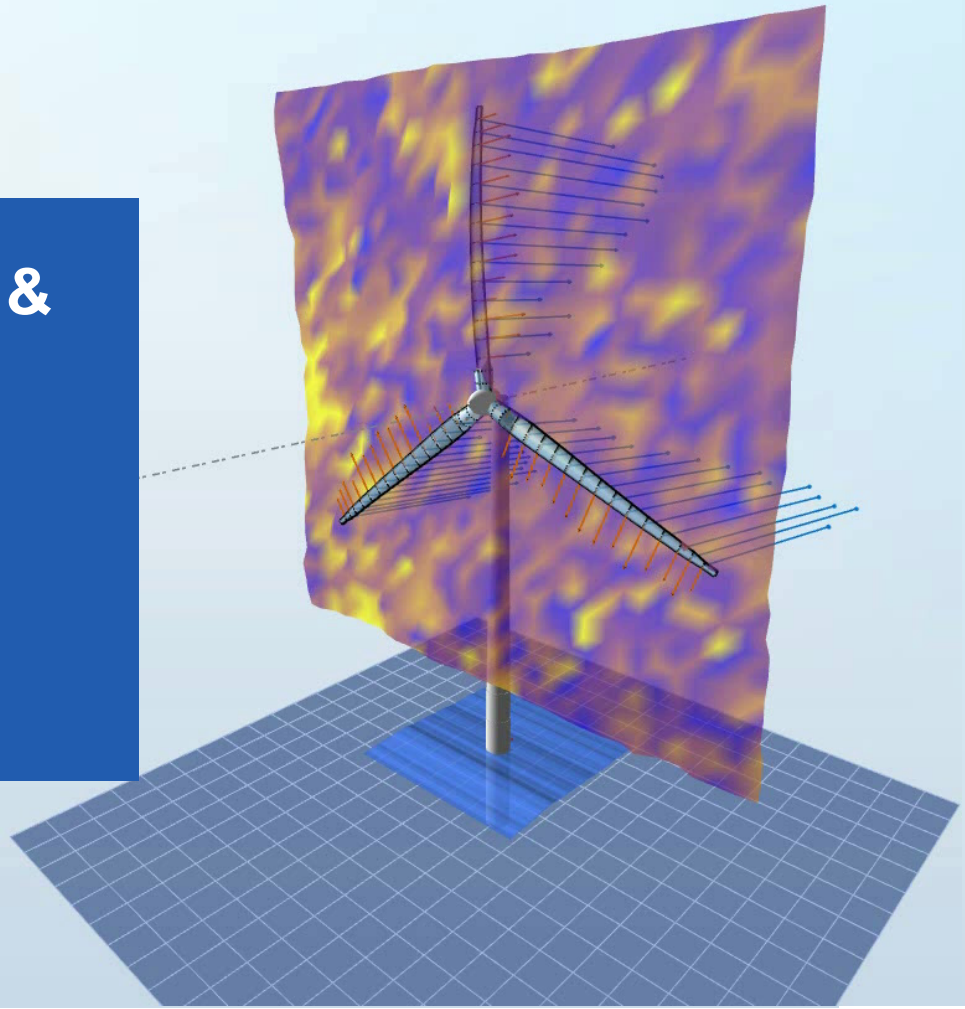
ETH zürich

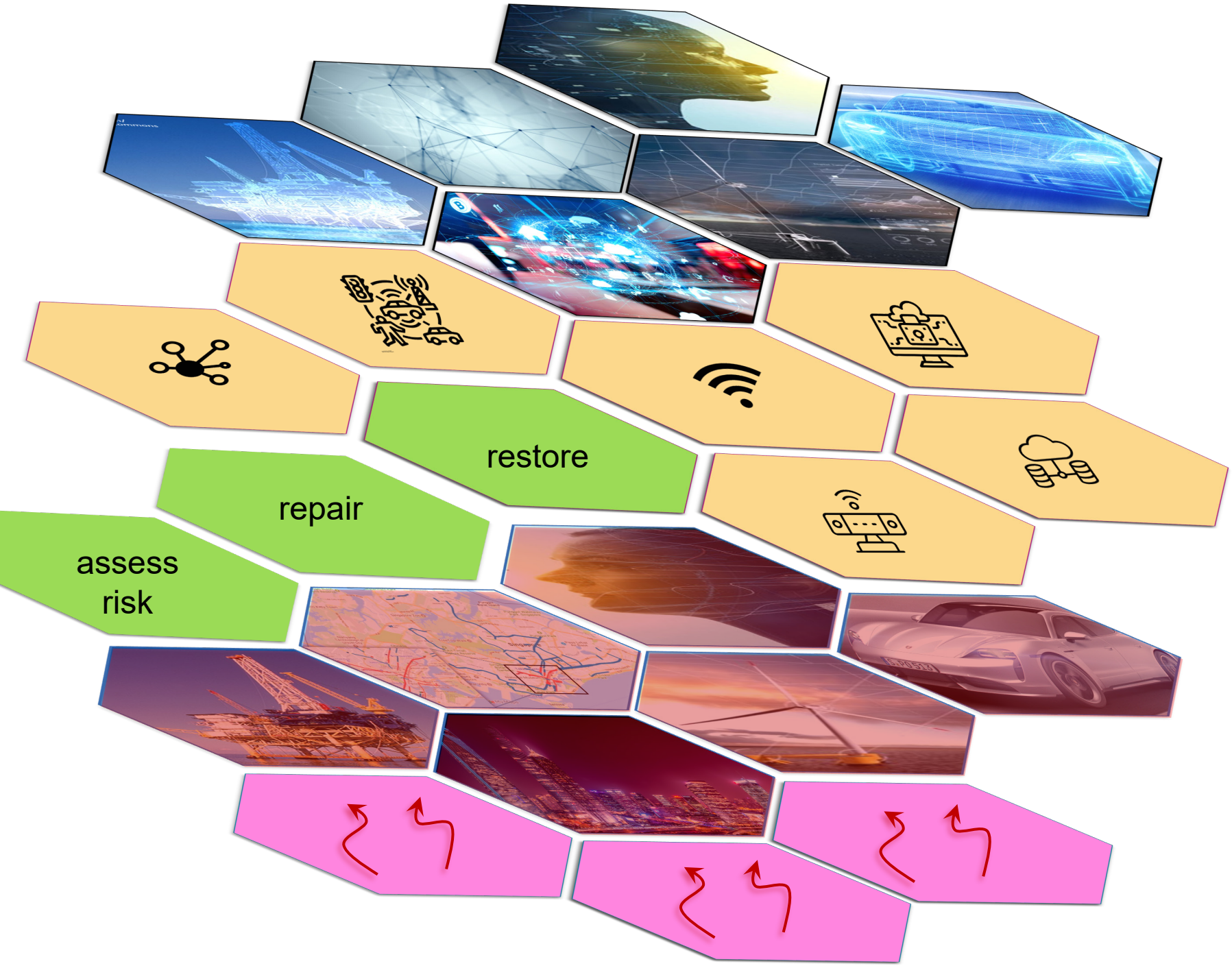
Chair of Structural
Mechanics & Monitoring

Dynamics Informed Monitoring & Twinning

Prof. Dr. Eleni Chatzi
ETH Zürich



D BAUG



Resilient cyber physical systems

digital system

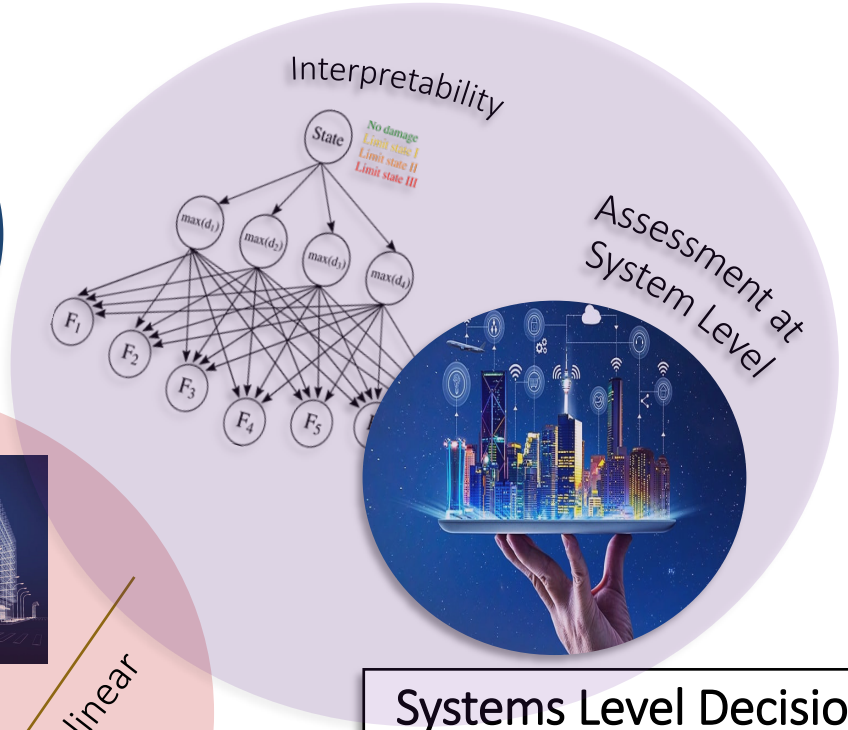
sensing, computation, control, networking

physical system

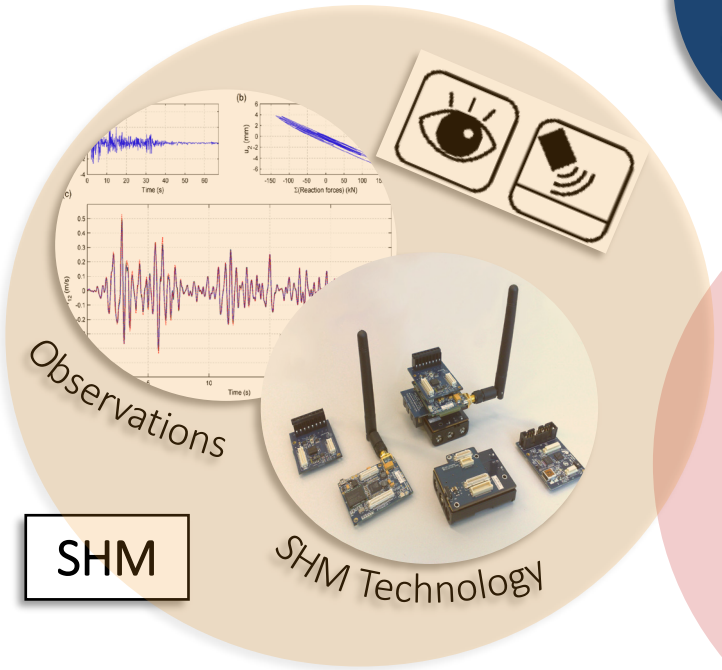
disruptive agents

The SHM approach

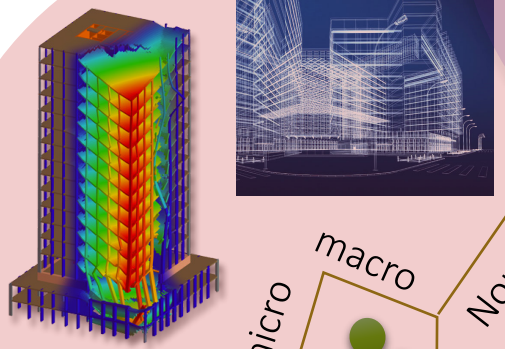




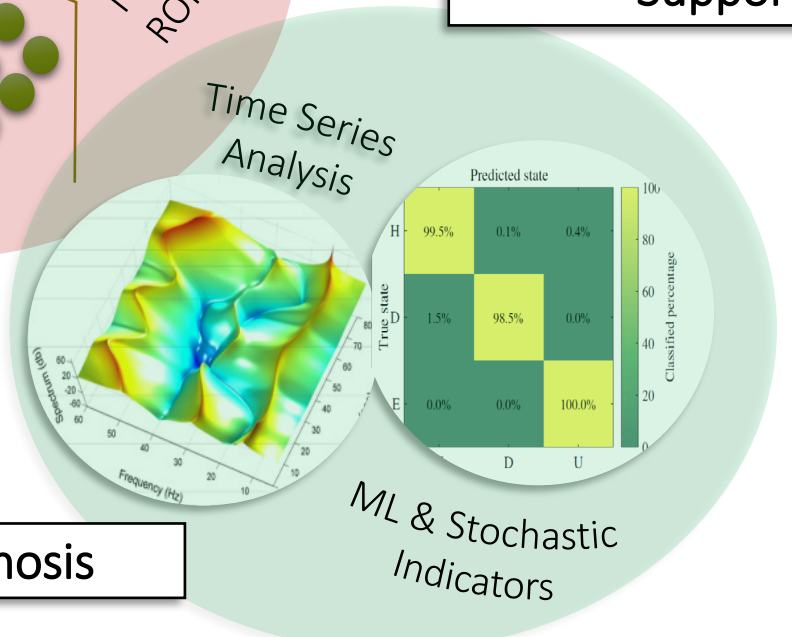
Systems Level Decision Support



SHM



Simulation



Diagnosis & Prognosis

Scope:

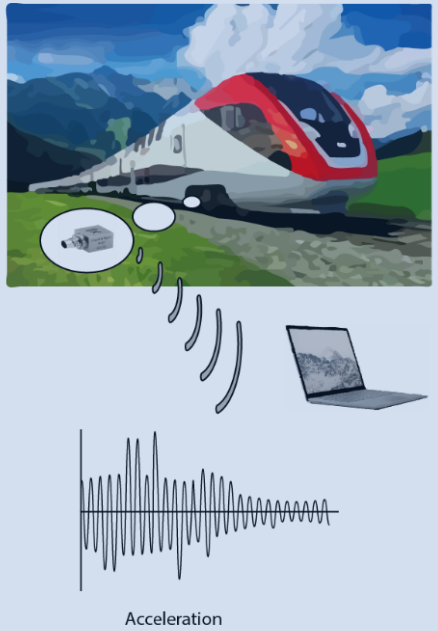
embodied, data-driven and intelligent assessment of engineered systems

Level 1: Data Augmentation



Bing Image Creator|

Data gathering - Domains of Activity of the SMM Chair



on board monitoring for roadway/railway

Transport infrastructure



PTOON, Wind Farm Greece



SMM owned Aventa Turbine

Wind Energy Infrast.



Monitoring under Demolition



Haus Du Pont, Zürich

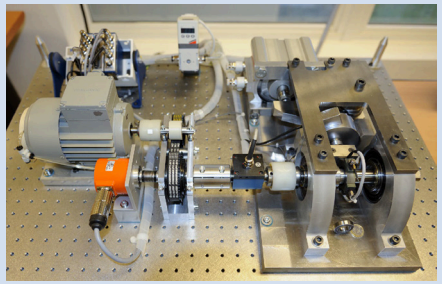


SBB Bridge, Sempach

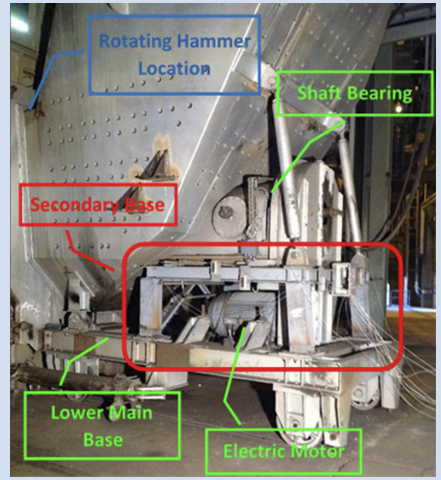


Steinavötn Bridge, Iceland

Built Environment



PRONOSTIA ball bearings

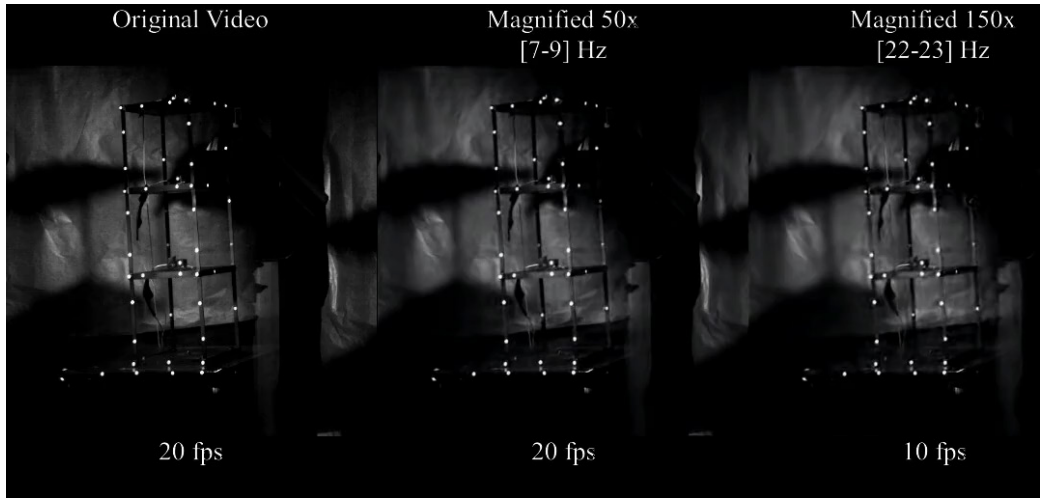


lignite grinder facility

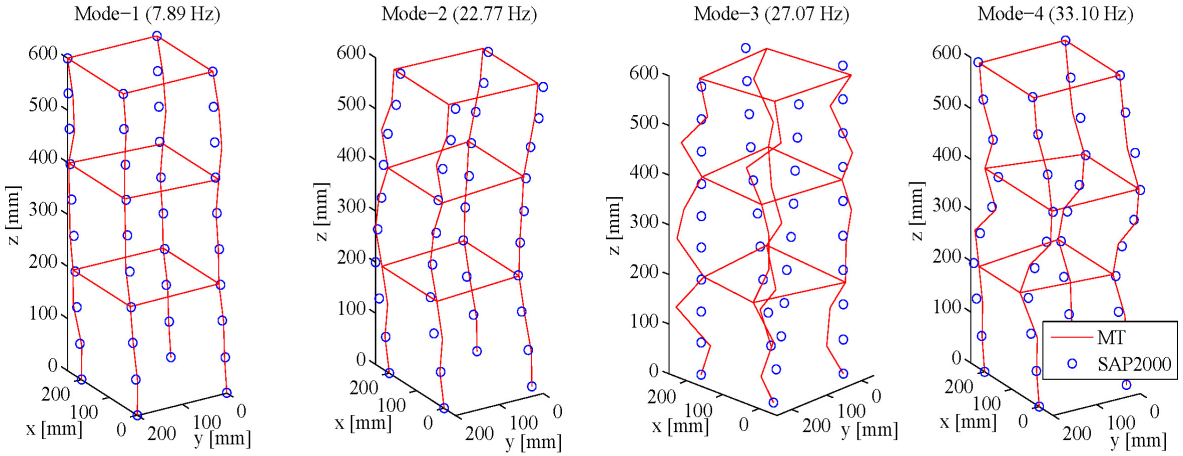
Industrial Assets

Learning from Data

Vision-based Monitoring

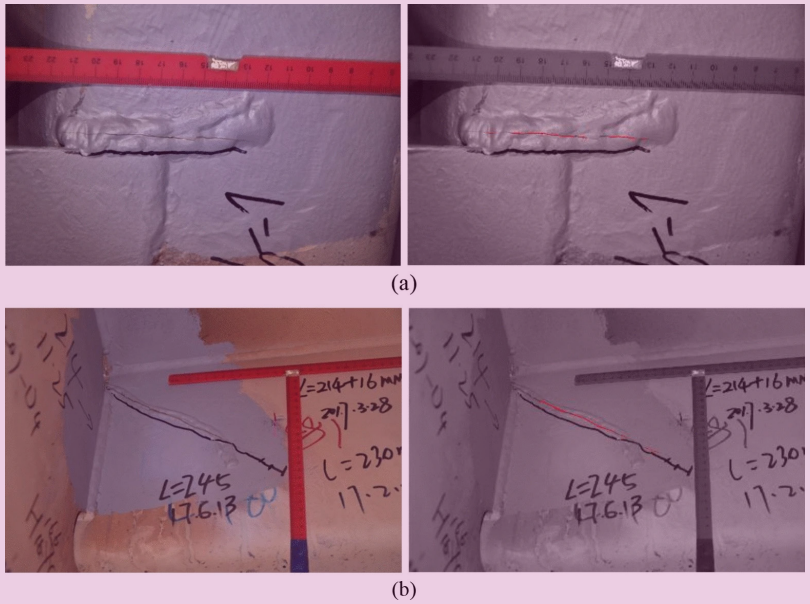


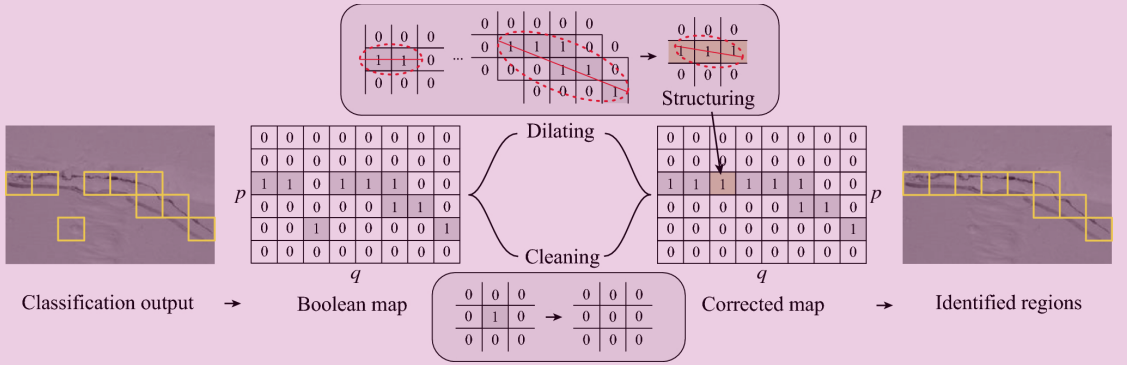
Identified natural frequencies and mode shapes
(imperceptible motion)



Harmanci, Y.E.; Gülan, U.; Holzner, M.; Chatzi, E. A Novel Approach for 3D-Structural Identification through Video Recording: Magnified Tracking. Sensors 2019, 19, 1229.

Crack Detection on bridges via imagery (UAV/inspections)

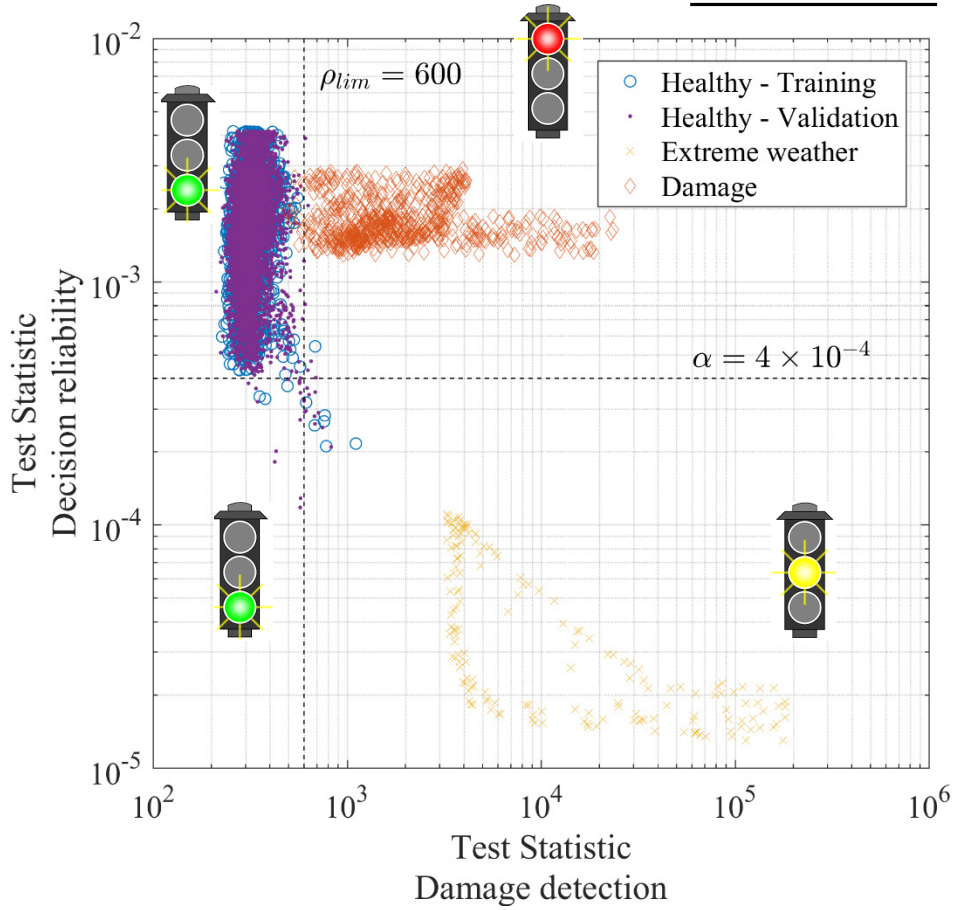




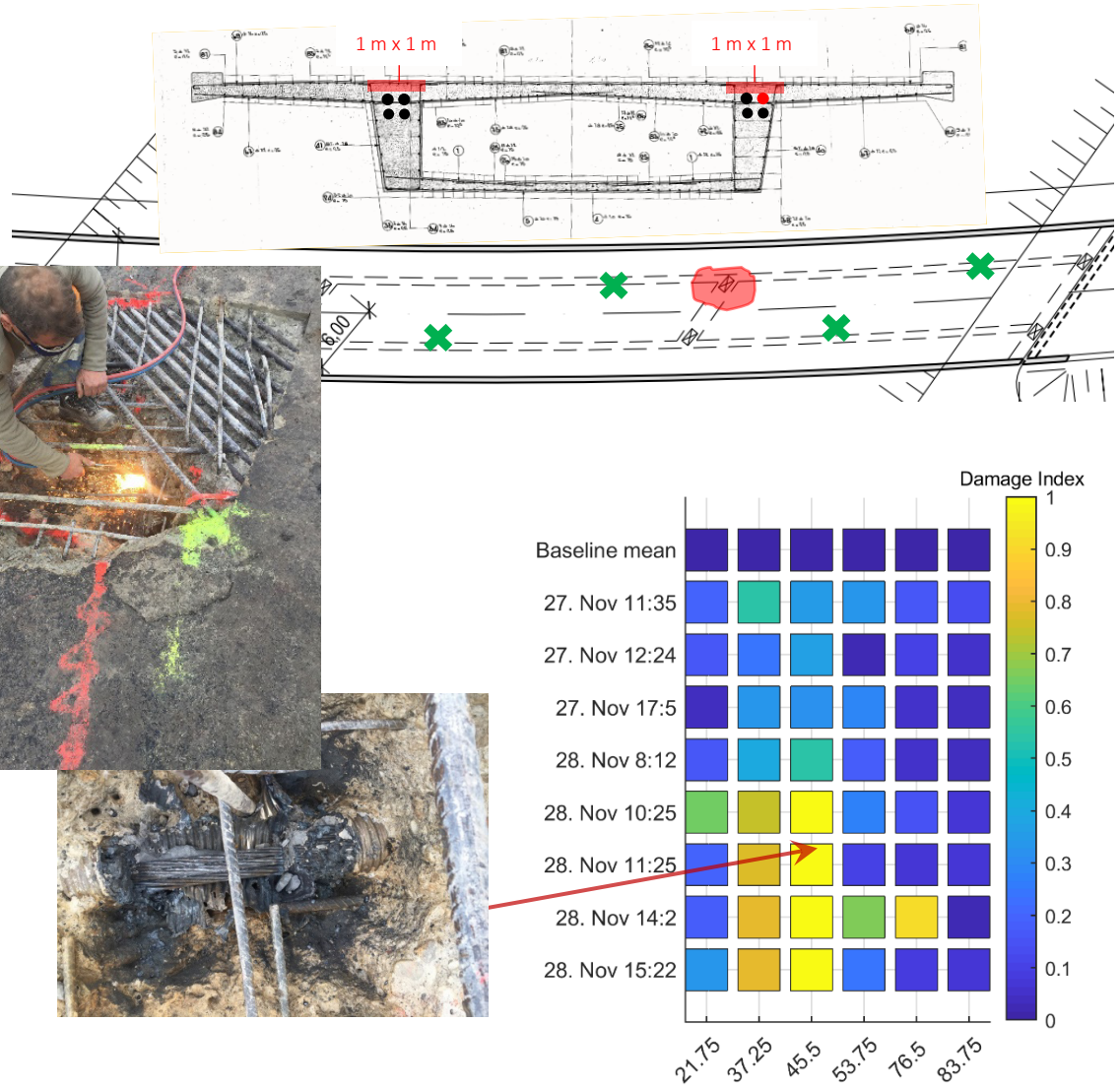
Quqa, S., Martakis, P., Movsessian, A. et al. Two-step approach for fatigue crack detection in steel bridges using convolutional neural networks. J Civil Struct Health Monit 12, 127–140

What can Data Driven analysis deliver?

Detection



Localization



Diagnosis

But not prognosis

Data is not enough

Prognosis

Physics-based representations

Hybrid Models

- Used for advanced SHM tasks or as Digital Twins
  - Detection, localization, quantification, prognosis
- Used on the fly for diagnostics & control
- Are eXplainable/Interpreatable

Computational toll should be low

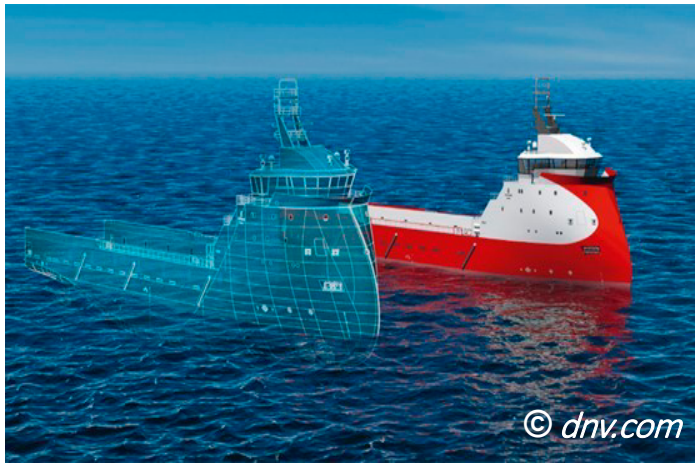
Purely data-driven representations

Diagnosis

Hybrid

Simulation Paths





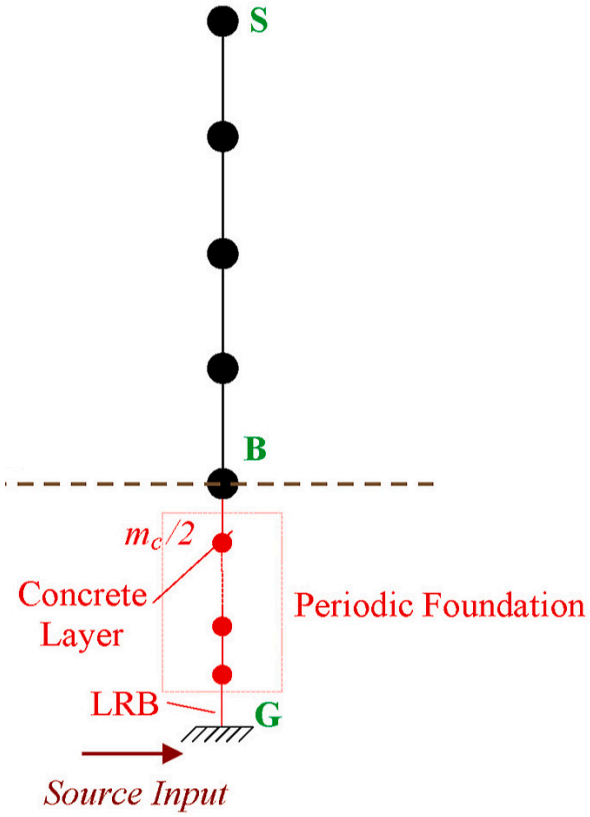
Level 2: Physics Augmentation

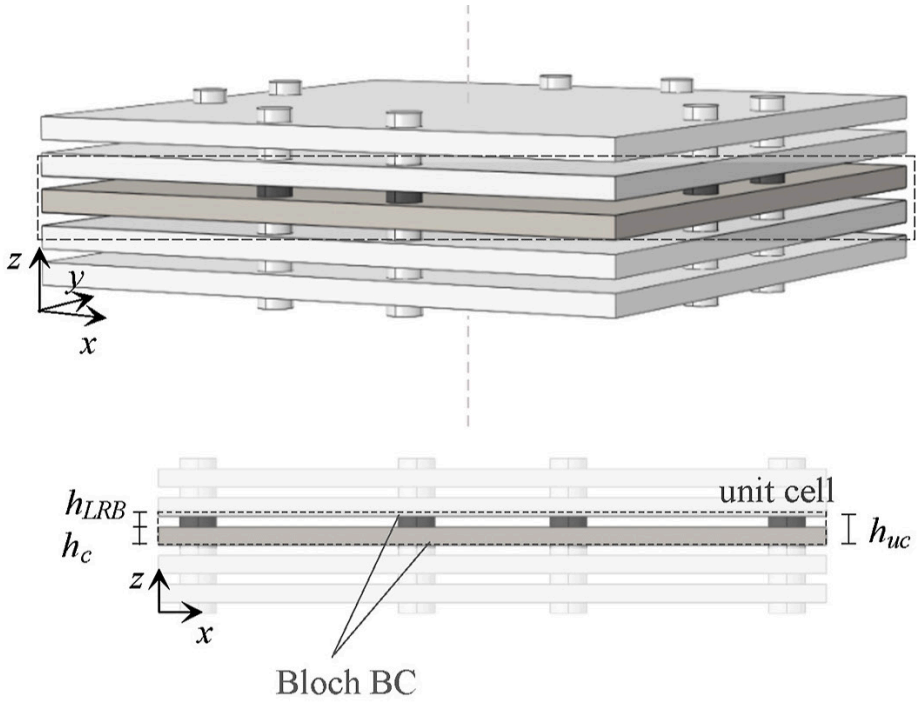


Bing Image Creator|

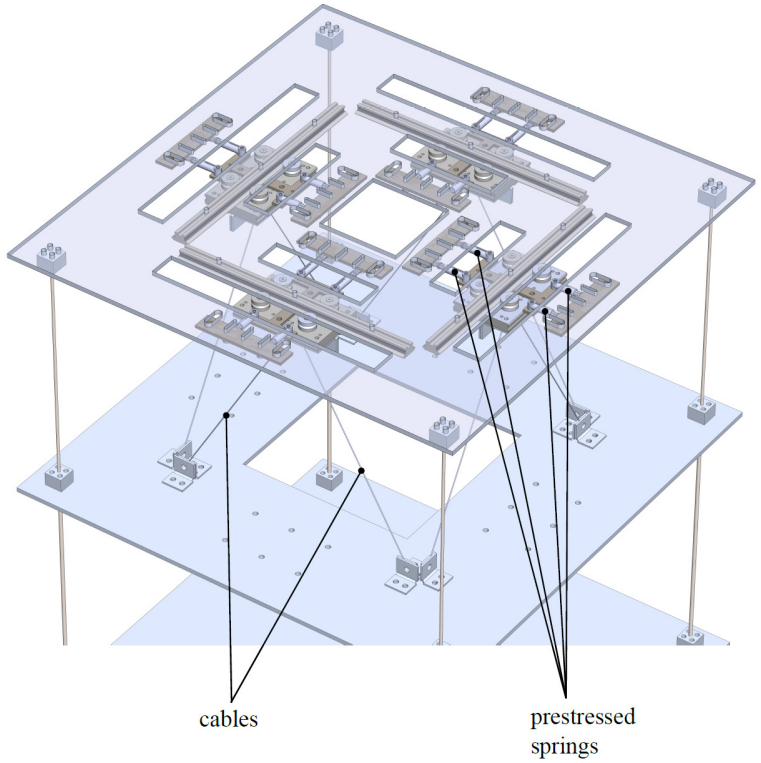
Modeling for Resilient Design

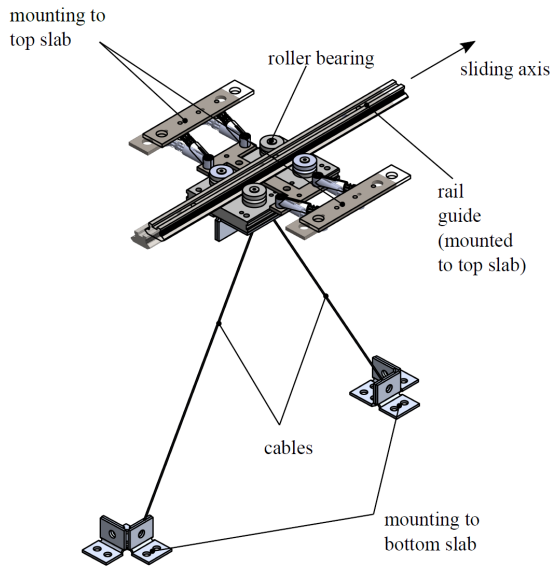
Metamaterials Solutions





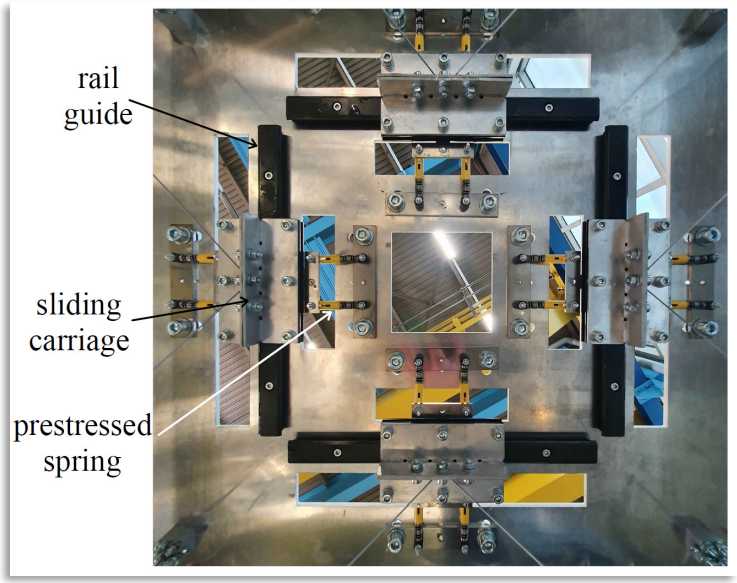
Nonlinear Solutions



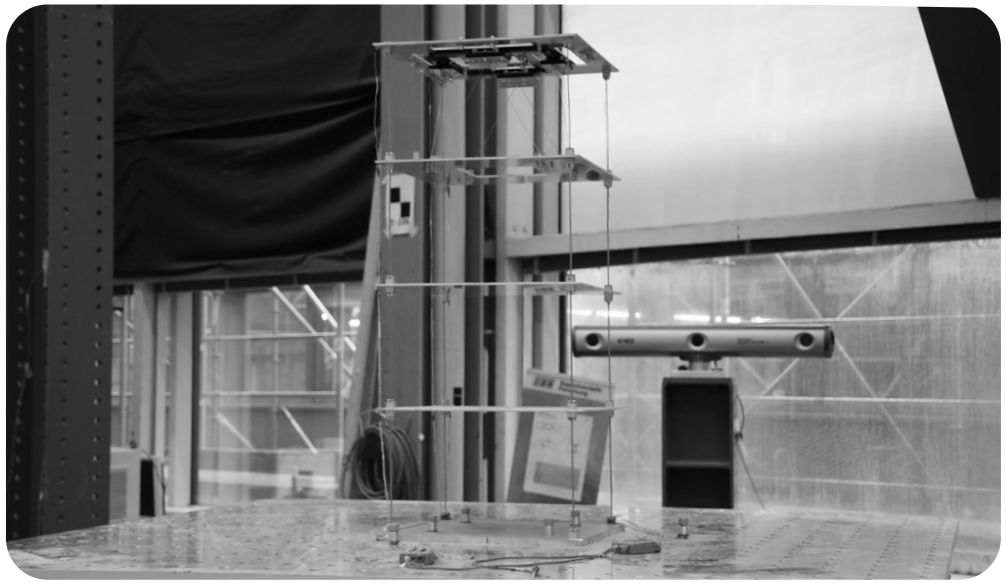


Modeling for Resilient Design

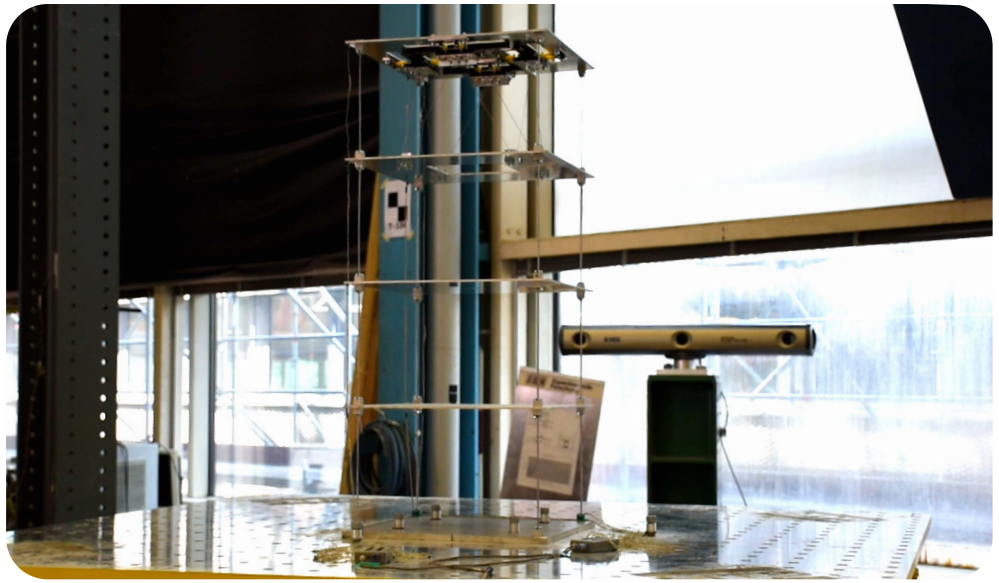
The NegSV damper



Small scale experiment



unprotected



NegSV protected

Hybrid Modeling for Digital Twins
Fusing Physics with Data, feasibly in Real-Time

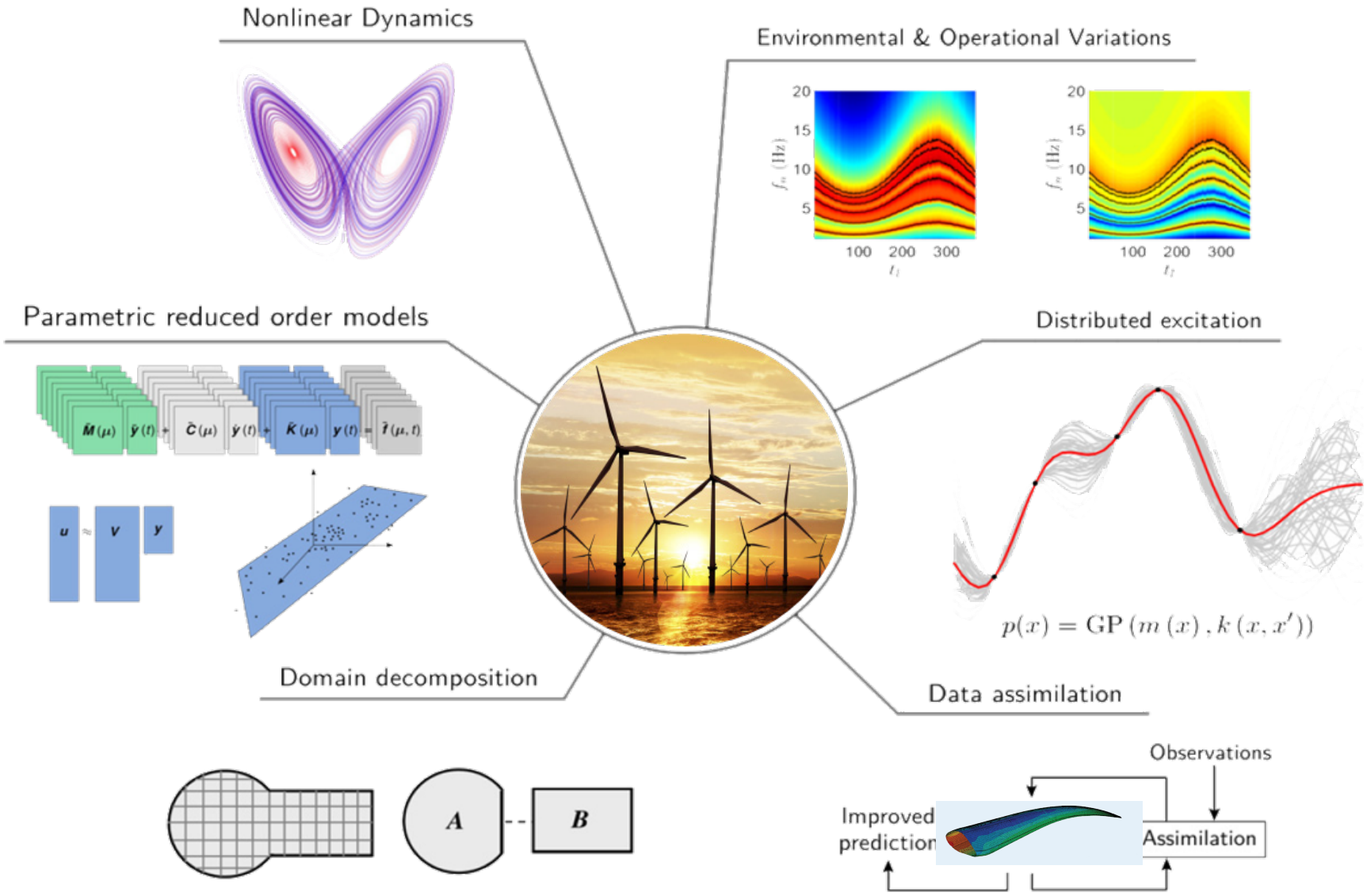
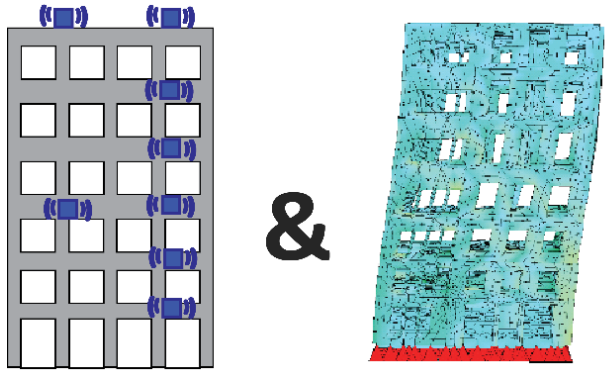


Photo Credit: Dr. K. Tatsis

Hybrid Models
Data-Driven Seismic Assessment

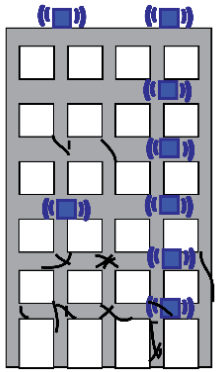


Initial state

Combining **sensor data** and **structural models** can help to assess the influence of ageing materials and temperature effects on dynamic properties and the structural state.

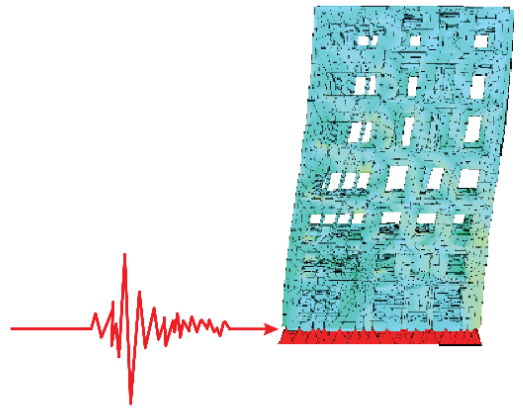


Earthquake



Post-seismic state

Sensor data can help to assess the building state after an earthquake through providing estimates of **presence and extent of damage**.



Informed predictions

With the help of updated **structrual models** vulnerability to subsequent aftershocks can be assessed thus enabling **smart tagging** of buildings as safe or unsafe for occupants.

Data-Driven Seismic Assessment



Real building

Monitor building response during earthquake

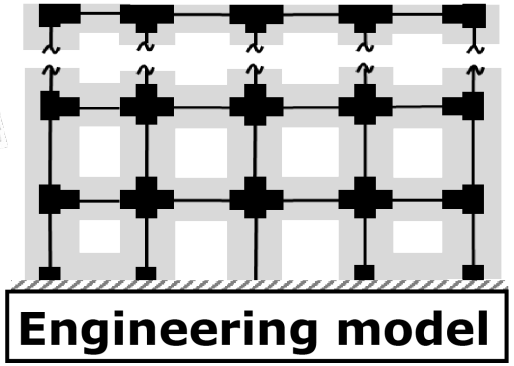
DSF derived in time domain and frequency domain

IM

Compare measured values with thresholds

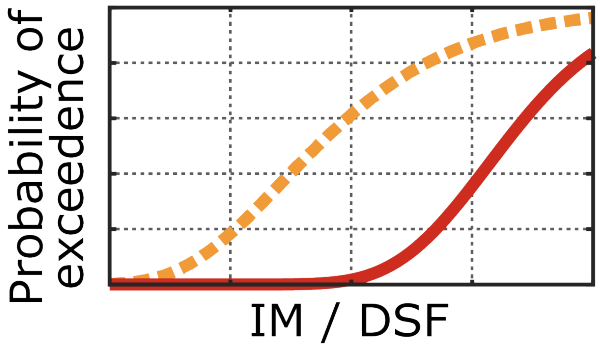
Modelling





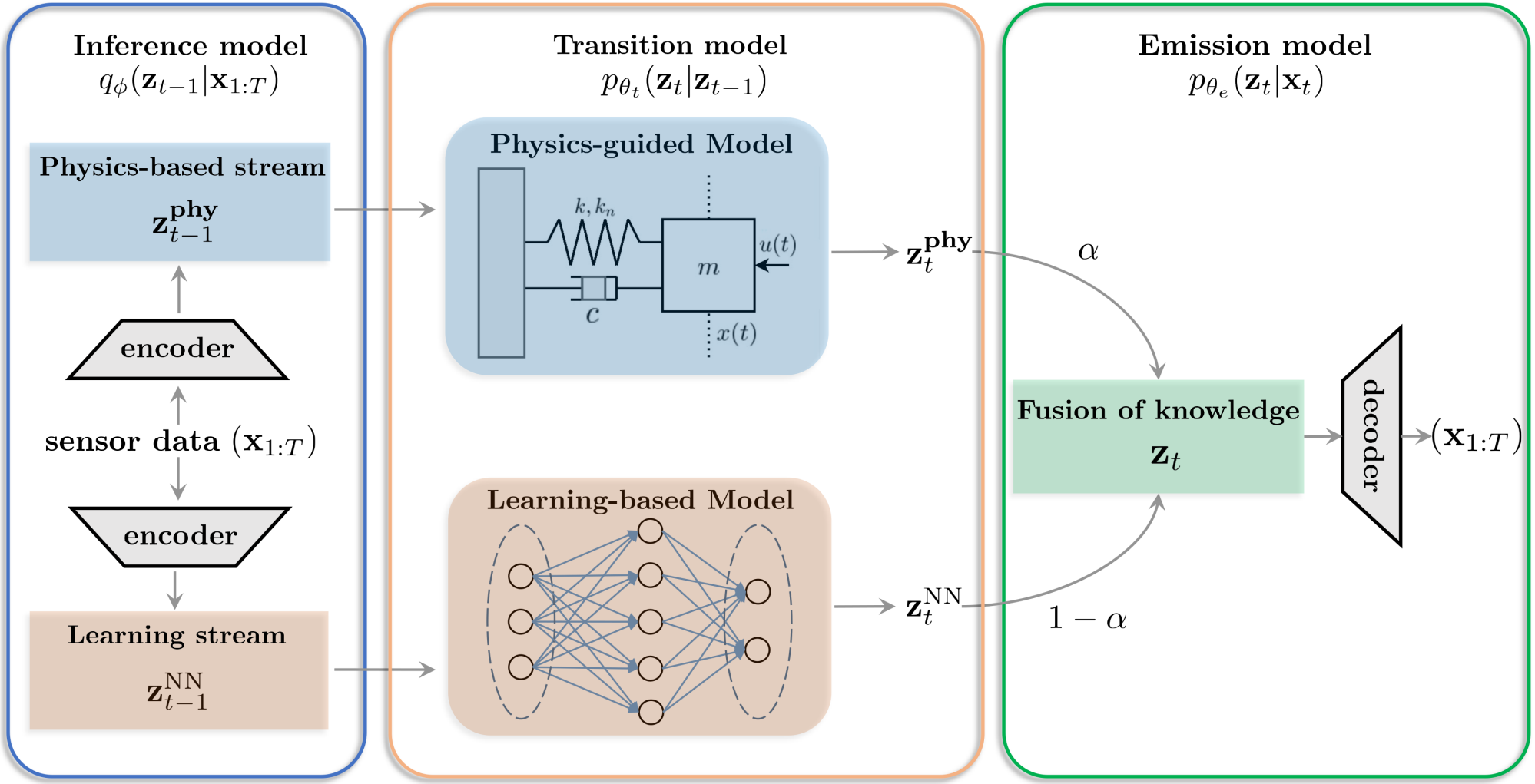
Engineering model

Nonlinear time-history analysis



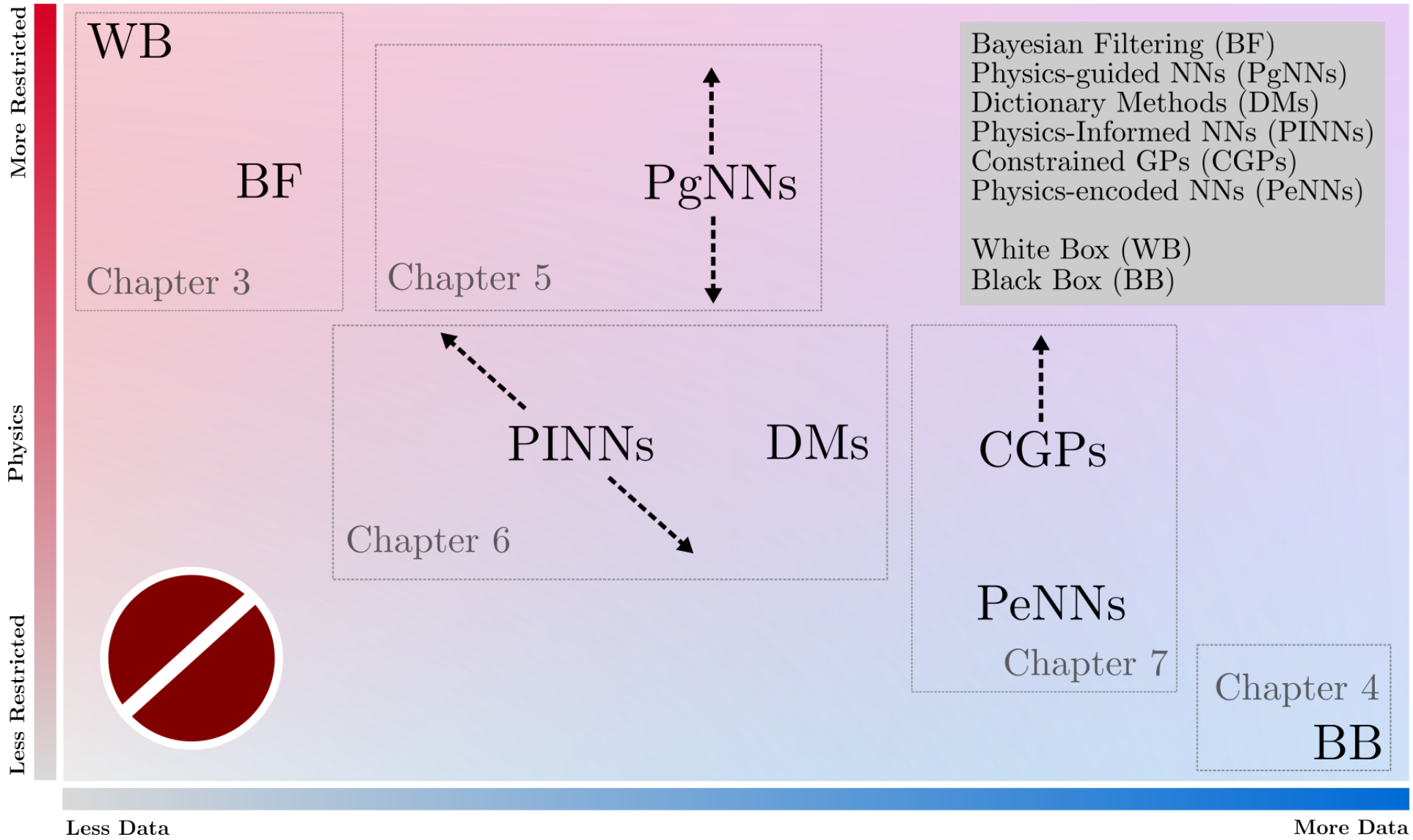


At the Nexus of Models & Data → Physics - enhanced Learning



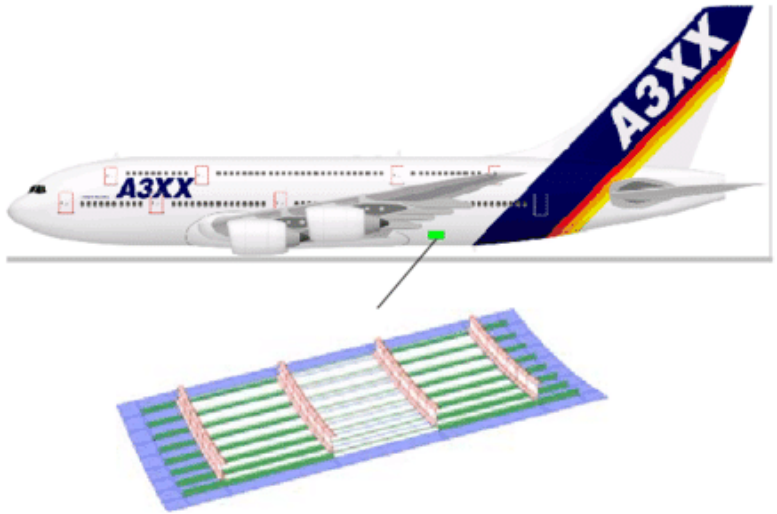
Haywood-Alexander, Liu, Bacsa, Lai & Chatzi, ArXiv

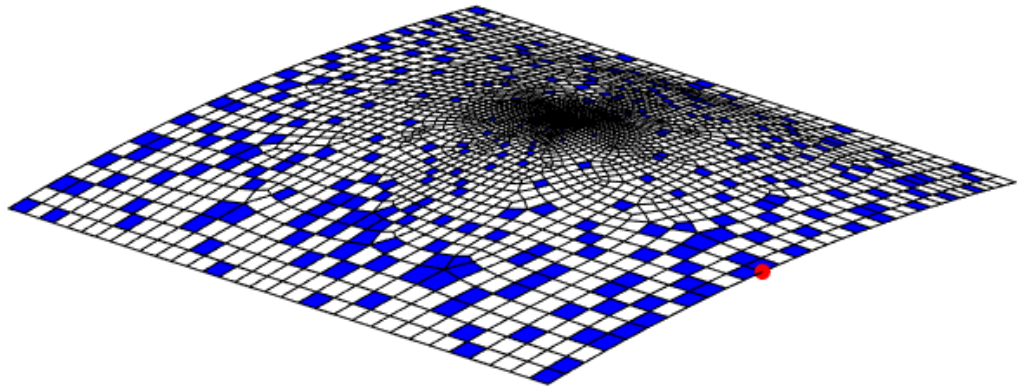
At the Nexus of Models & Data → Physics - enhanced Learning



Haywood-Alexander, Liu, Bacsa, Lai & Chatzi, ArXiv

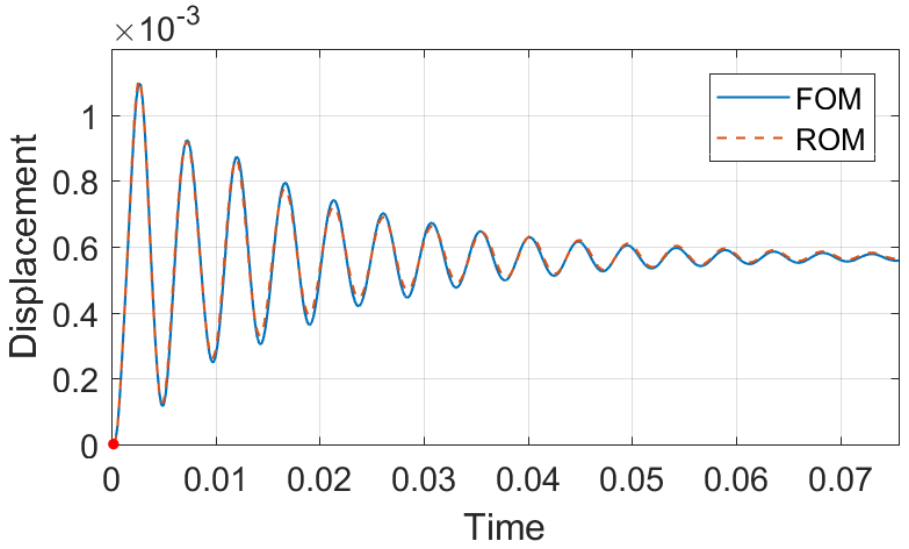
At the Nexus of Models & Data





Applications

- Real-time Digital Twinning
- Damage Detection
- Deterioration prediction
- Design Improvement



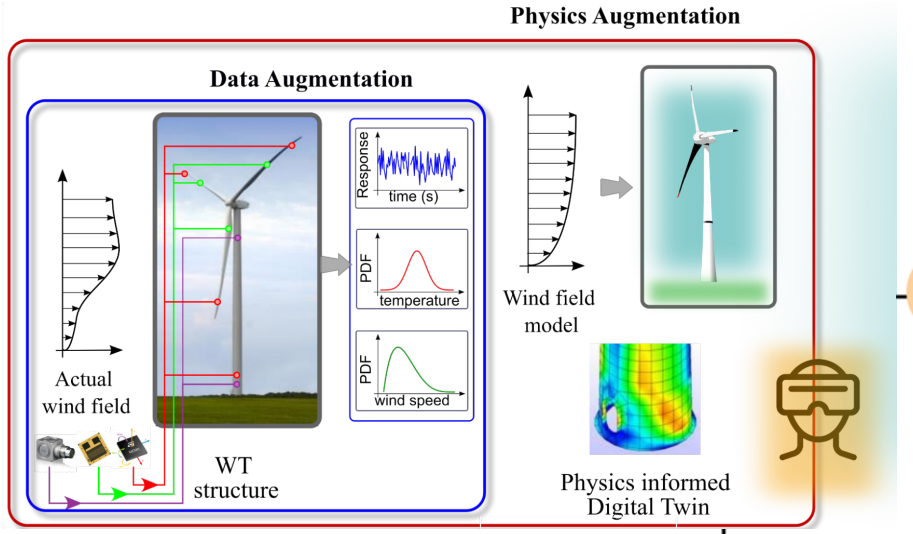
Agathos, Tatsis, Chatzi et al. (2021)

Expert & Ecosystems Augmentation



Bing Image Creator|

Validated Real-Time Digital Twins @ETHZ

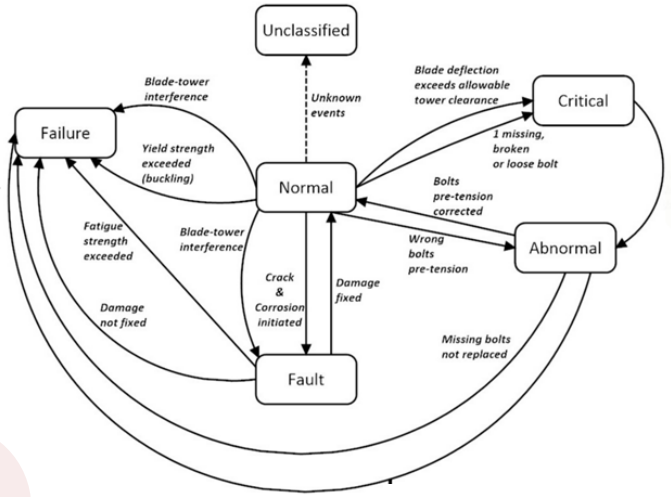


API



Courtesy of Dr. Silvia Vettori – ETHZ/Siemens DIS

Object-Oriented Real-Time Decision-Tree





Courtesy of Dr. Silvia Vettori – ETHZ/Siemens DIS & SMM Chair

API

Cloud computing, storage & analytics



Spotlight: Data Gathering via Mobile Sensing

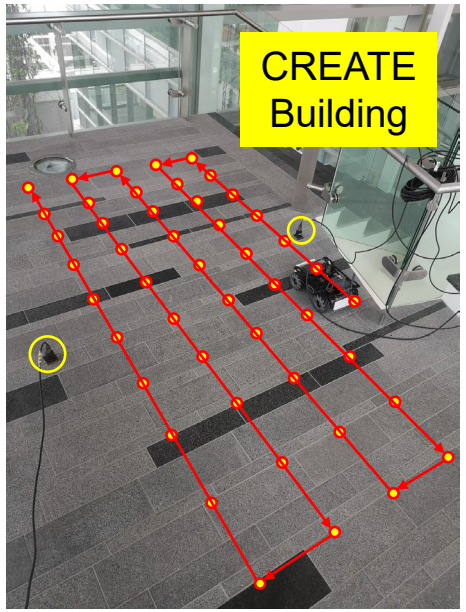
Mobility Projects OMISM, REASSESS (SBB) & Future Resilient Systems (Singapore)



Mobile Sensing for Infrastructure Resilience

Robot-assisted Drive-by Bridge Monitoring

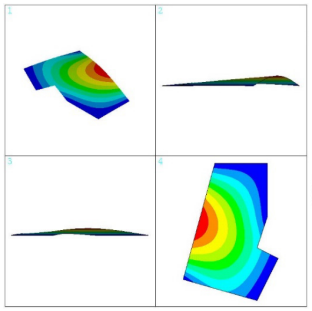
Land Transport Authority
We Keep Your World Moving

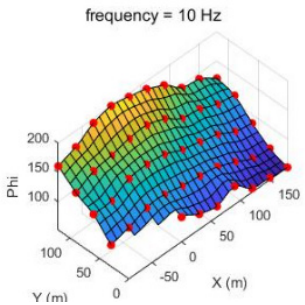


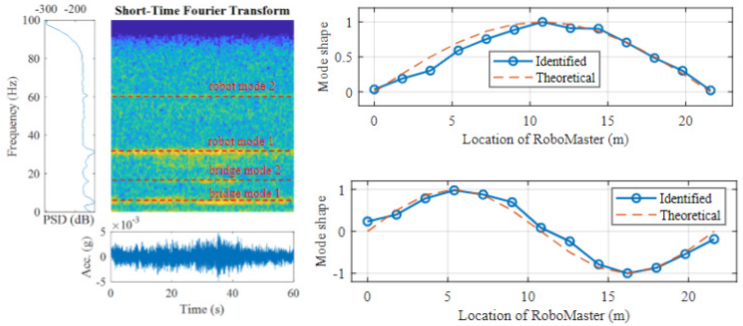


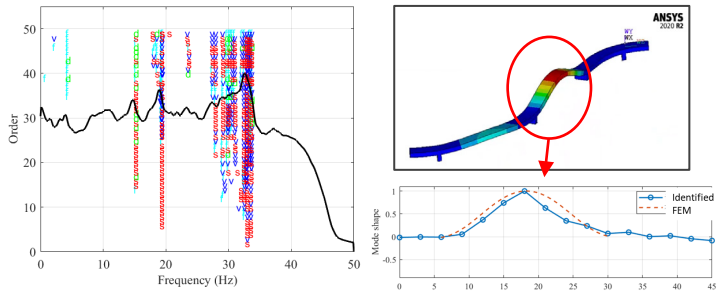












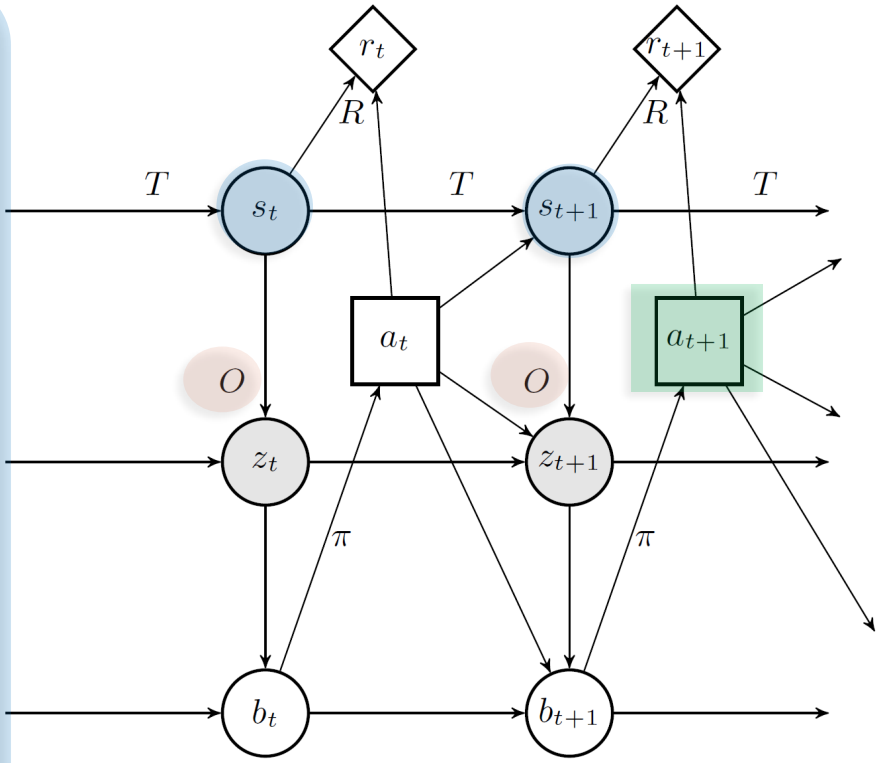


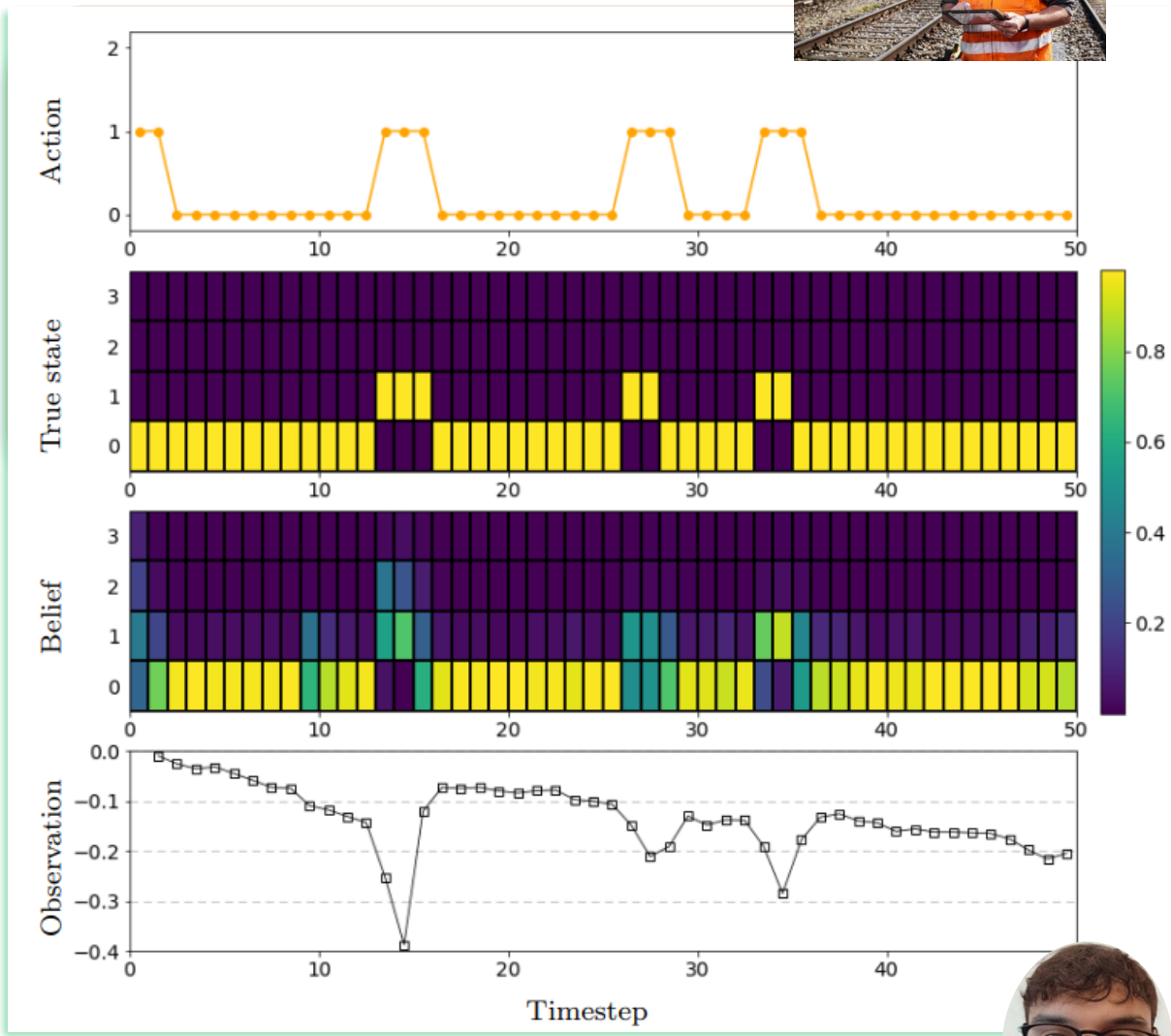
Decision Support for Railway Assets

Optimizing Operation & Maintenance of critical assets











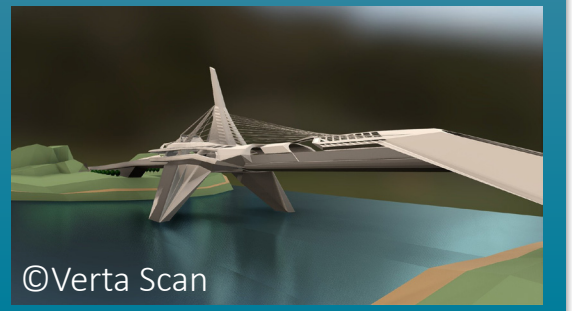
ETH zürich

SBB CFF FFS

Arcieri, Hoelzl, Papakonstantinou, Straub, Chatzi, et al., Bridging POMDPs and Bayesian decision making for robust maintenance planning under model uncertainty: An application to railway systems, LINK

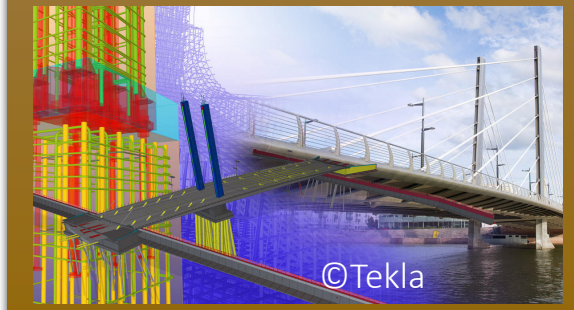
Digital Twins through a critical asset's Life Cycle

Design





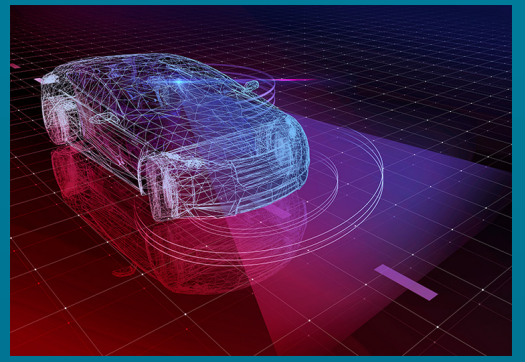
Manufacturing





Operation



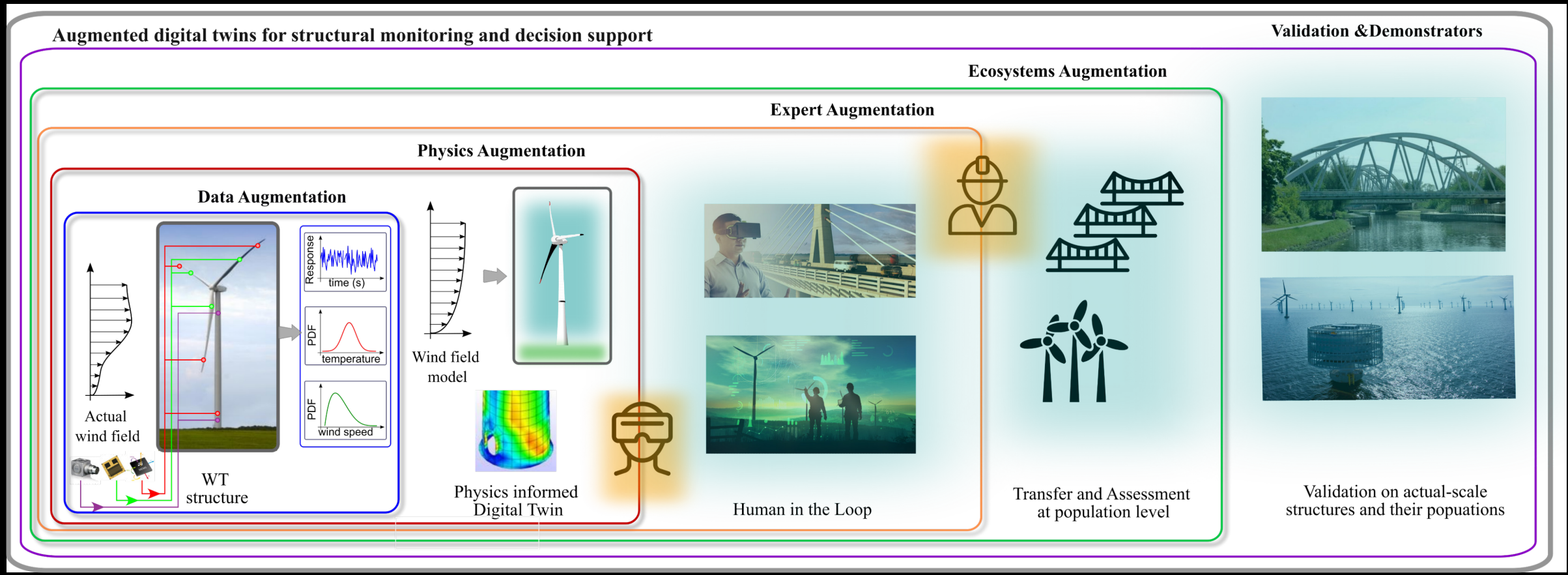


Decommissioning



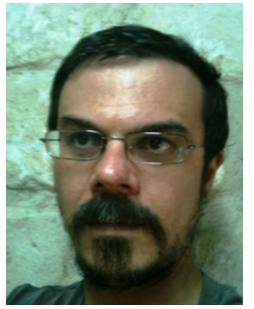


Augmented digital twins for structural monitoring & decision support



Acknowledgments

- The European Research Council via the ERC Starting Grant WINDMIL (ERC-2015-StG #679843) on the topic of Smart Monitoring, Inspection and Life-Cycle Assessment of Wind Turbines.
- ITN Training Network, MSCA-ITN-2017, DyVirt: Dynamic Virtualisation: modelling performance of engineering structures
- H2020-MSCA-IF-2017 Grant, SiMAero, Simulation-Driven and On-line Condition Monitoring with Applications to Aerospace Proposal
- SANDIA National Labs



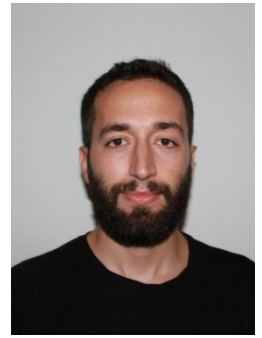
Dr. V. Dertimanis



Dr. K. Agathos



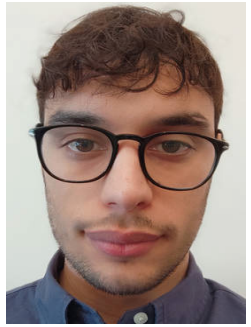
Dr. I.Abdallah



K. Tatsis



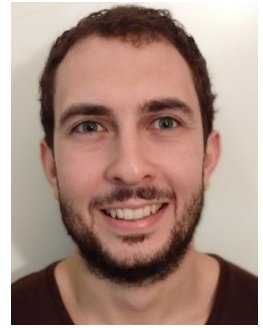
G. Duthé



G. Arcieri



T. Simpson



K. Vlachas