# Simulation building blocks for predicting critical system changes

## The impact of crises on critical infrastructures

Jacopo Bonari,[1] Max von Danwitz,[1] Alexander Popp,[1,2]

1. Institute for the Protection of Terrestrial Infrastructures, German Aerospace Center (DLR)
2. Institute for Mathematics and Computer-Based Simulation, University of the Bundeswehr Munich

# The Institute for the Protection of Terrestrial Infrastructures, DLR-PI


- DLR-PI is dedicated to the **protection** and **security** of **critical infrastructures** on Earth;
- concepts, processes and technologies that strengthen and improve the **resilience** of **organizations** and **systems** are developed;
- the concept of **digital twin** (DT) is used as a key tool for responding to threats and improving the resilience of infrastructures.


Technical failure, lifetime


Extreme weather events


Terrorism


Sabotage


Accidents, damages, negligence


Cyber-crime

# Organization of the Institute

DLR

DLR Institute for the Protection of Terrestrial Infrastructures

Management

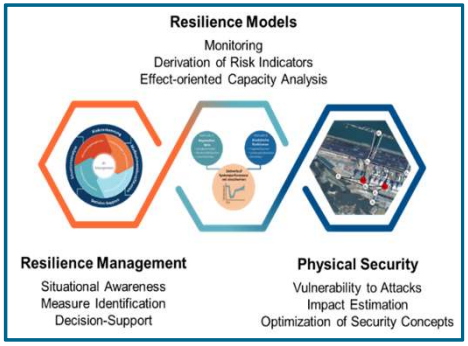
Administration

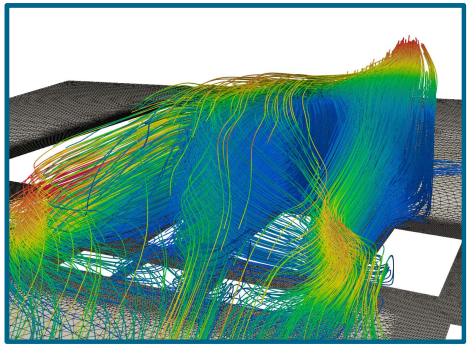
Resilience and Risk Methodology

Detection Systems

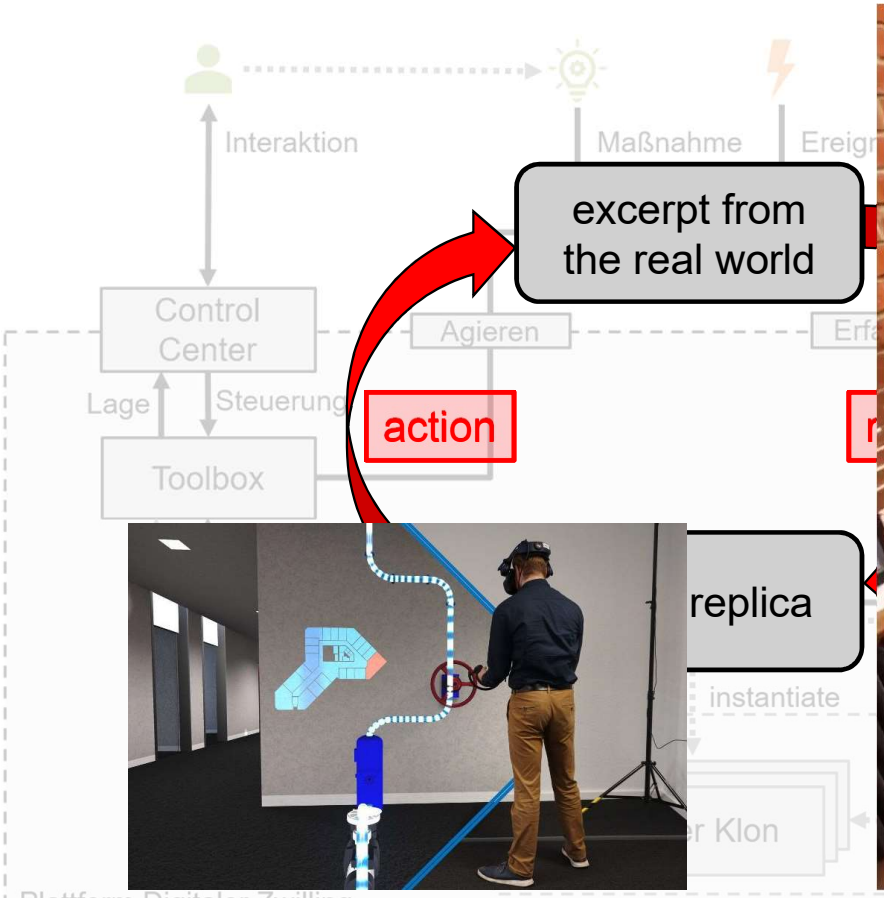
Digital Twins for Infrastructures

Simulation Methods for Digital Twins

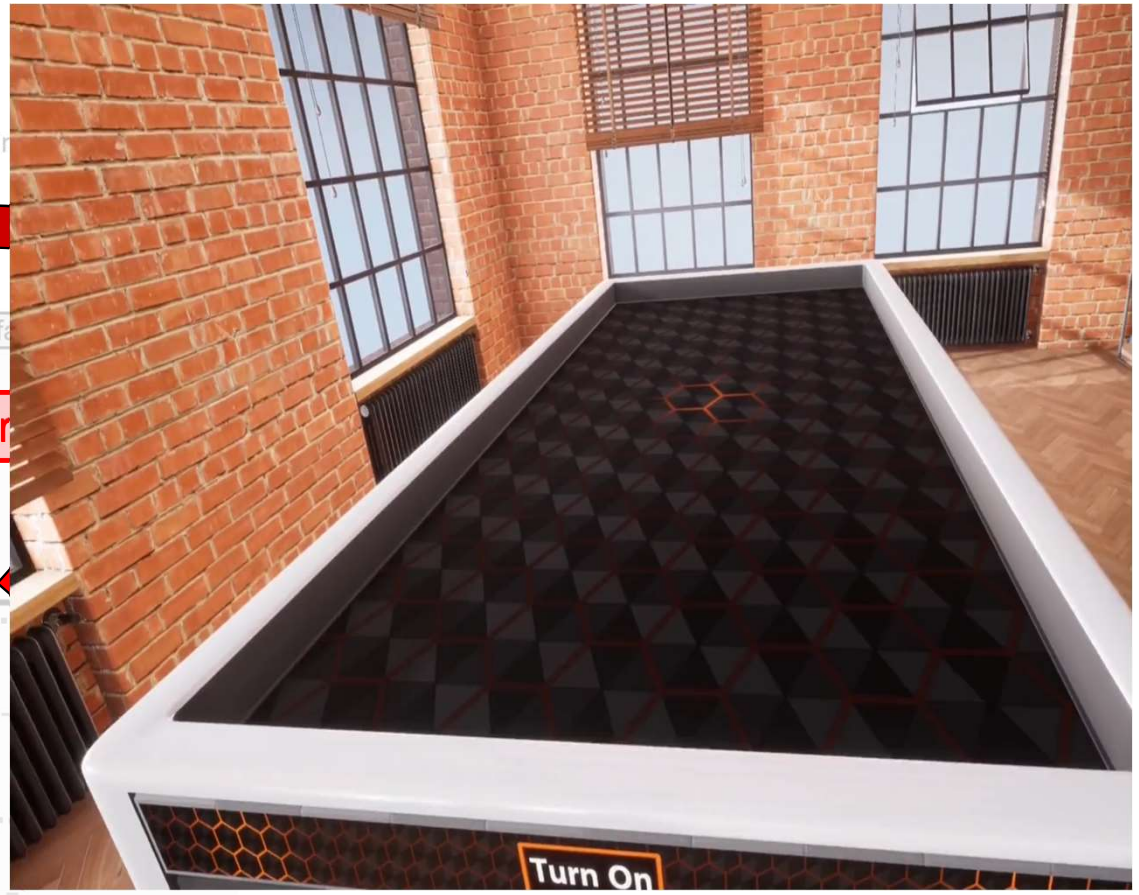


# Digital twins and hybrid digital twins for CIP




Coupling of simulators and sensors/actuators within a virtual reality environment at DLR-PI.



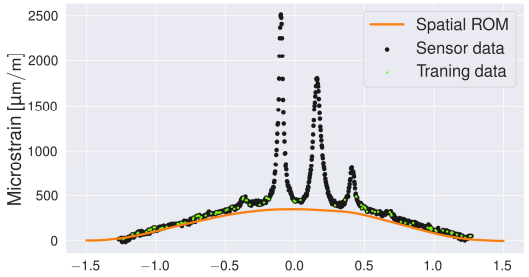

Situational awareness table built from open data coupled with risk analysis tool, Franke et al. [1].

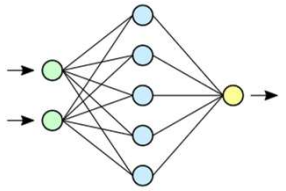
# Motivations

Modeling and predicting the dynamic behavior of complex critical infrastructure systems in normal operation and crisis situations has reached a **double dead-end**.

## Physics-based modeling and classical direct numerical simulation (DNS)


## Data-based modeling and classical machine learning (ML)

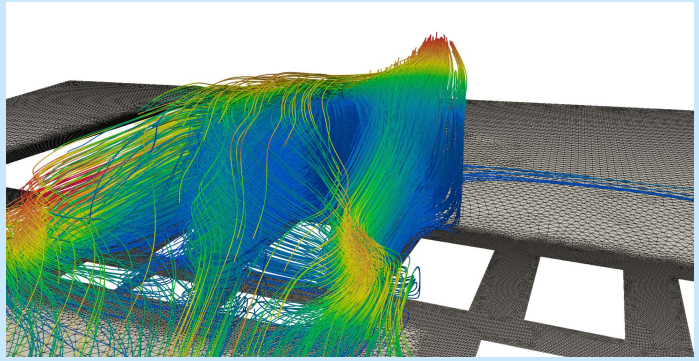


Sahin et al. [2]

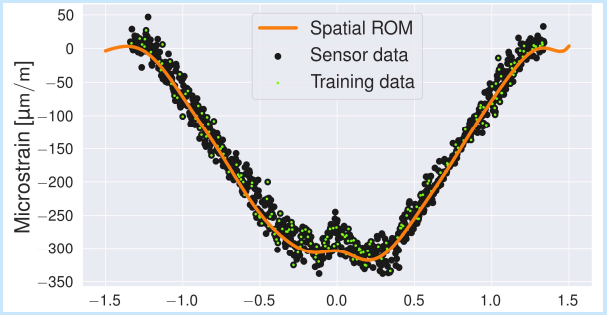
# Digital twins and hybrid digital twins for CIP

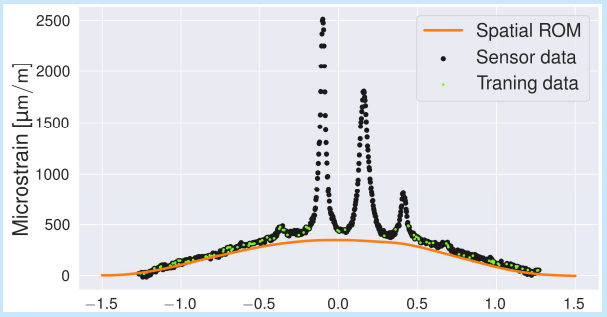
**Virtual twin**



**Hybrid digital twin**

**Digital twin**




Sahin et al. [1]

# Application (1/2): Responsive and Fast Planning of Safe Evacuation Paths

**Chemical accident forward problem**

- Where will the contaminant be transported?

**Inverse problem**

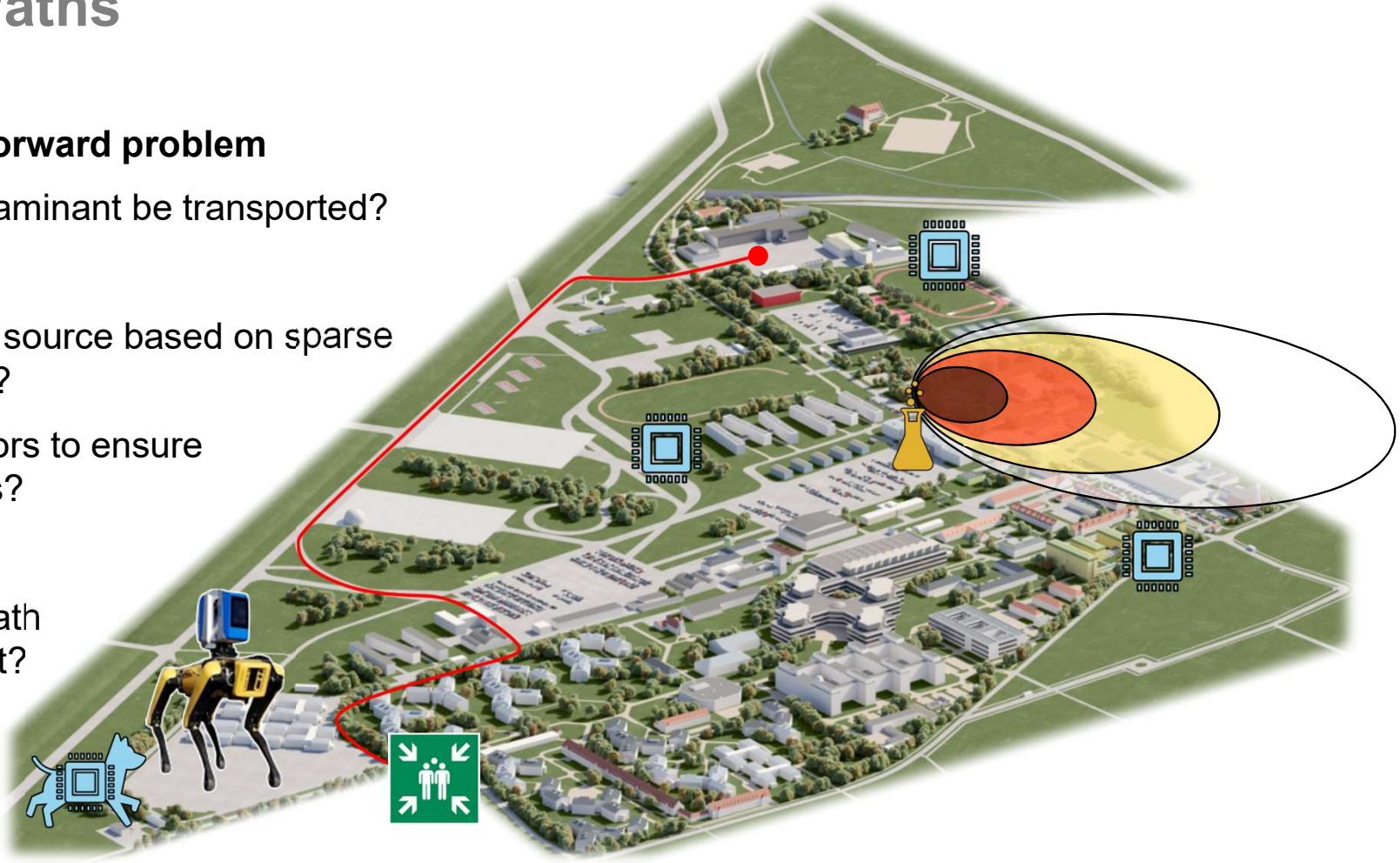
- Can we identify the source based on sparse measurement data?
- Where to add sensors to ensure safe meeting points?

**Optimization**

- Which is the best path to the meeting point?

**Routing**

- Where do we send spot?

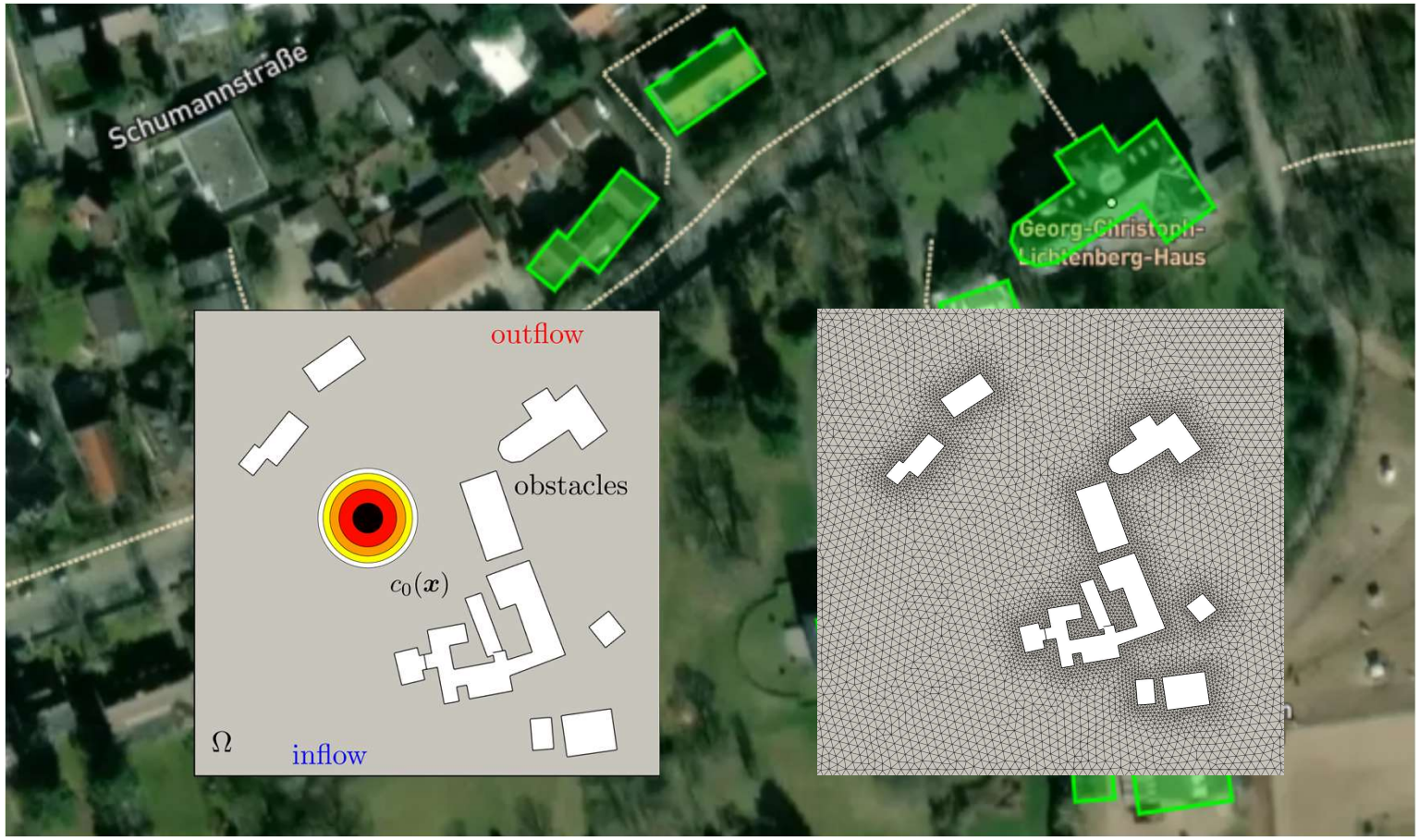


# Domain creation and mesh generation

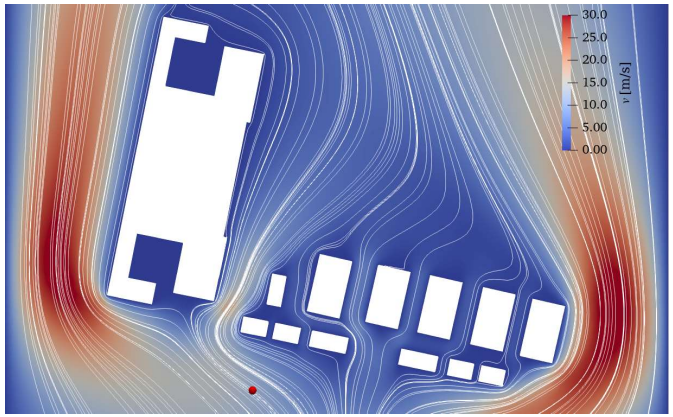
Data collection

Virtual replica

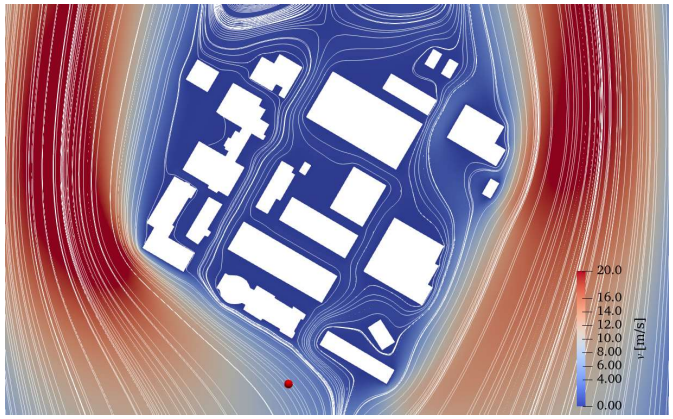
Model evaluation



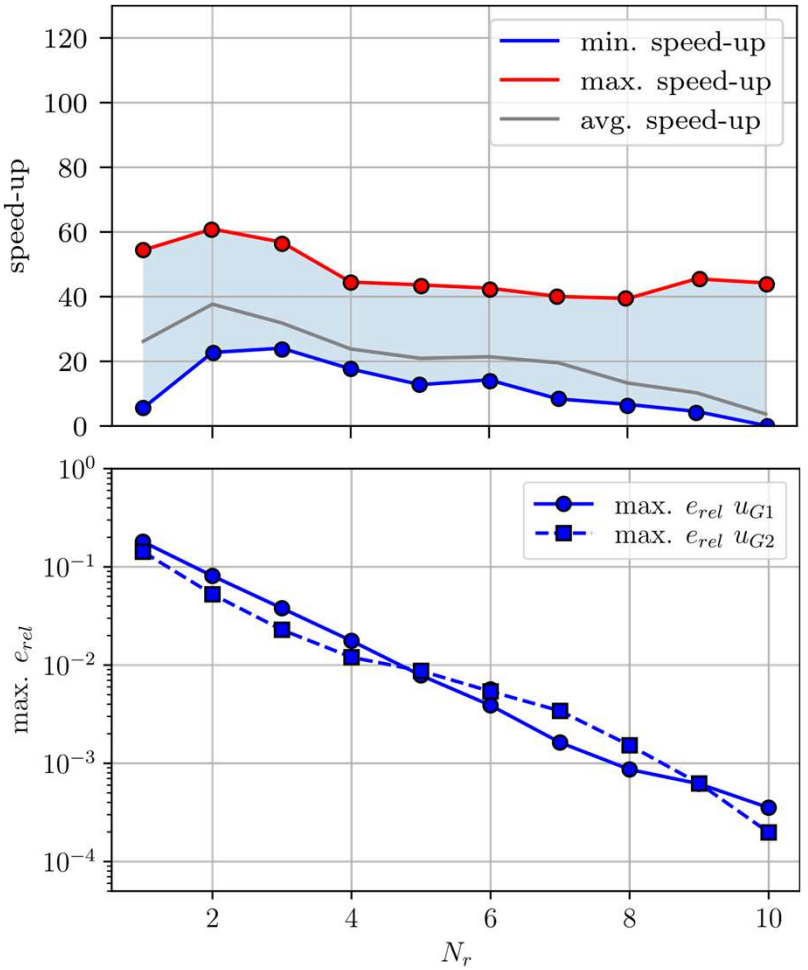
# Wind field evaluation and model order reduction (MOR)




Geometry 1 (G1)

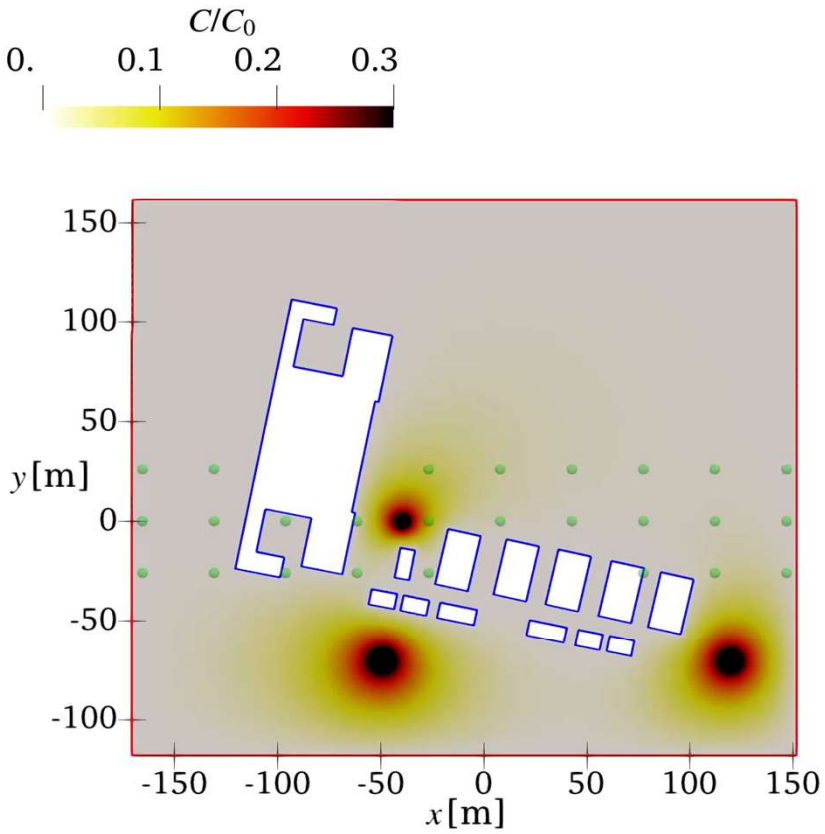



Geometry 2 (G2)

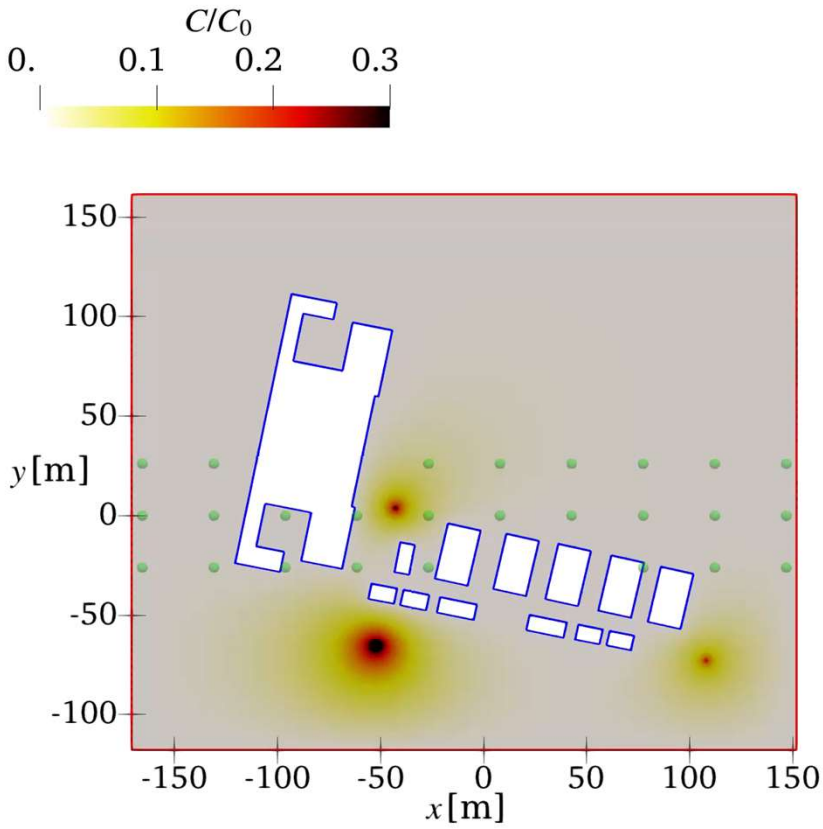



Different wind field evaluations based on MOR, Bonari at al. [3].

# Identification of the source locations of a pollutant released and transported by the wind

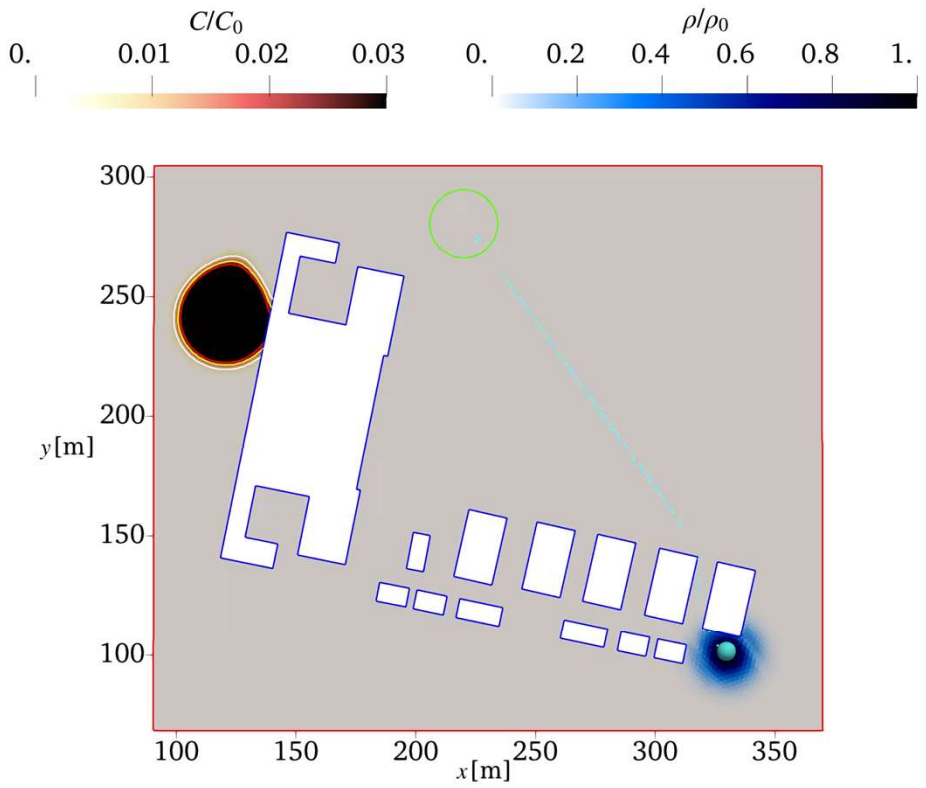



- Simulation of pollutant dispersion with known sources, von Danwtiz et al. [4].

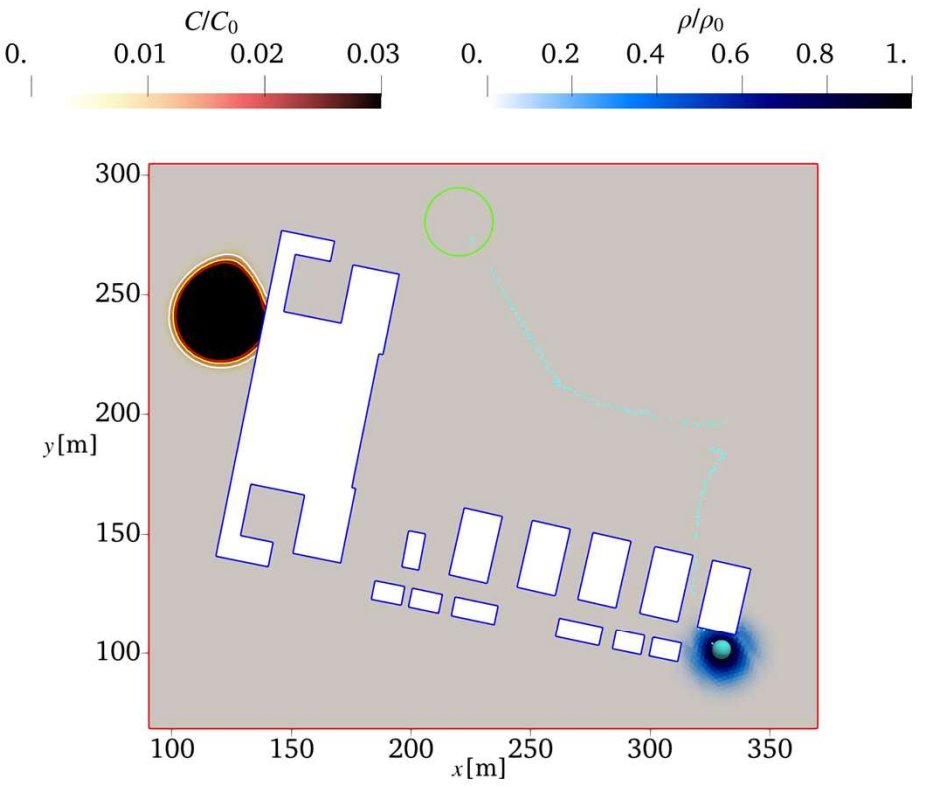



- Simulation of pollutant dispersion with algorithmically determined sources, ibid.

# Safe evacuation routes: coupled simulation of pollutant transport and pedestrian flows

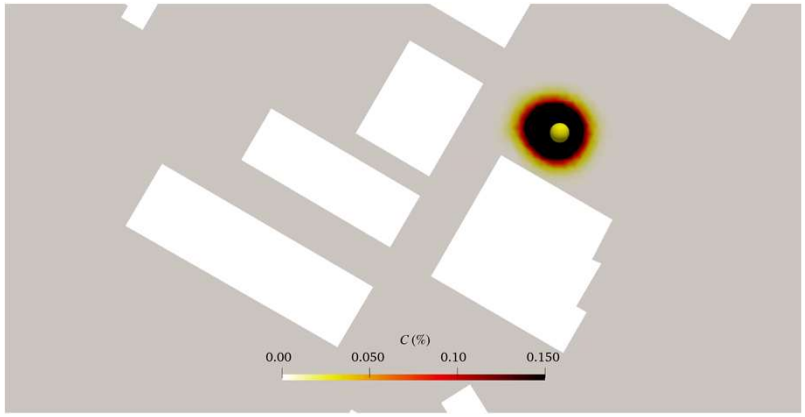



- Evacuation path according to minimum exit distance.

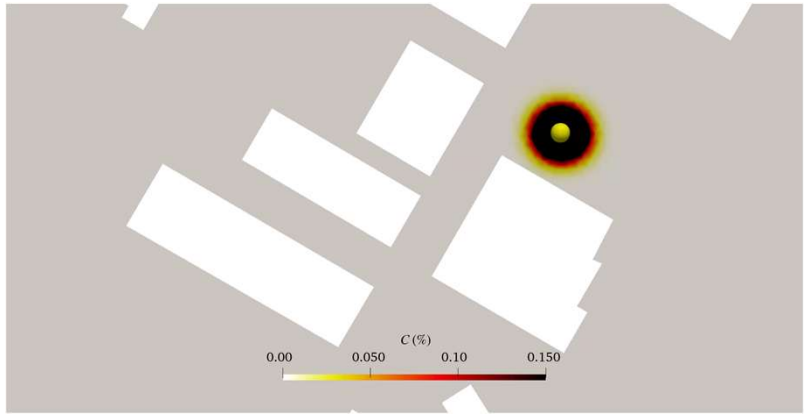



- Evacuation path according to minimum exit distance and presence of contaminant.

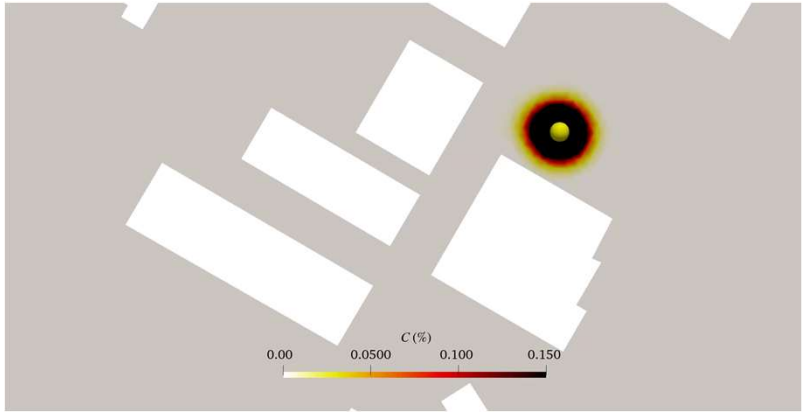
# Data assimilation techniques



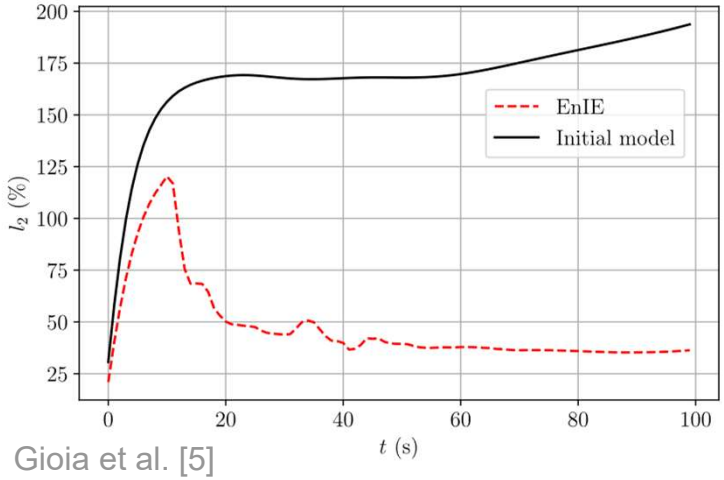

- True model used for reference.




- Initial model based on wrong assumptions.



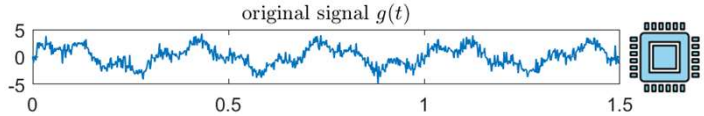

- Model based on data assimilation filter.

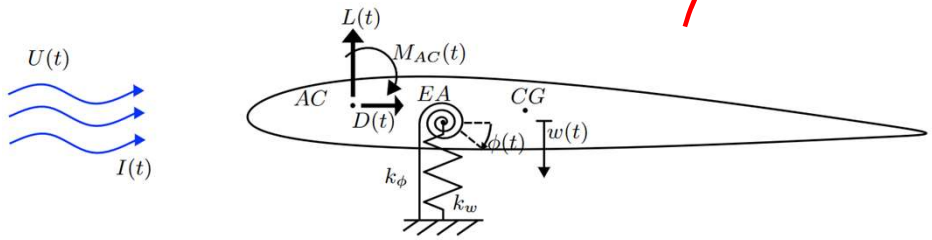


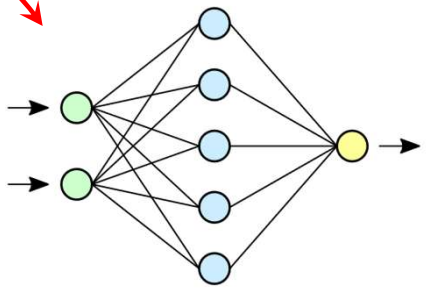

Gioia et al. [5]

# Application (2/2): scientific machine learning for damage detection on wind turbine blades (SHM), framework

- in collaboration with **ETH Zürich** and **Ostschweizer FH**;
- use aerodynamic pressure distribution around airfoil for structural identification;
- classify multivariate pressure distribution time series assuming different damage scenarios;
- use convolutional neural networks for time series classification.



Goal: damage detection and classification of proof of concept in wind tunnel

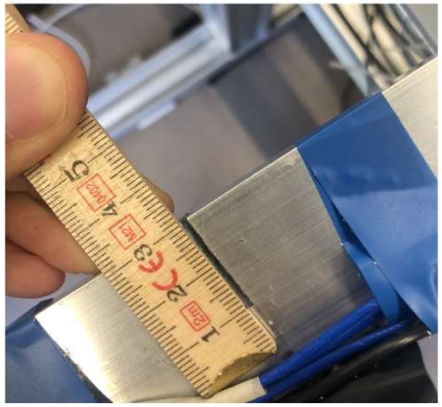
# Application (2/2): scientific machine learning for damage detection on wind turbine blade (SHM), experimental setup

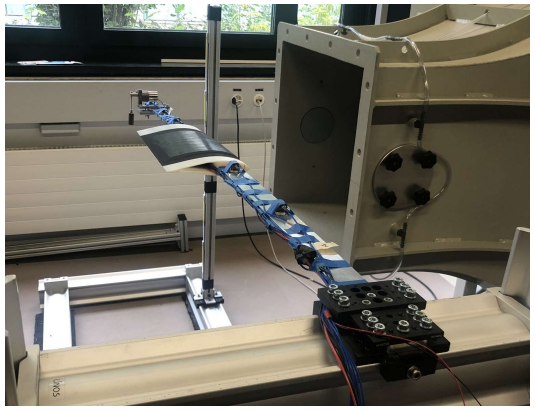
Crack

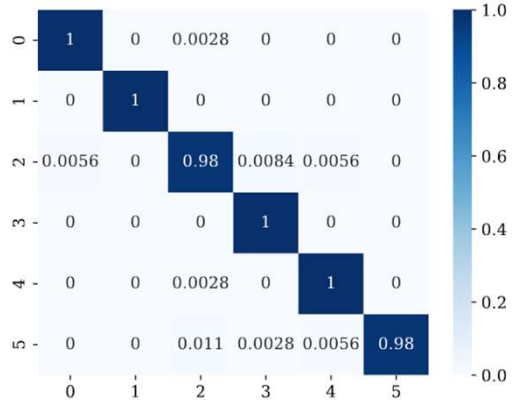
Change in structural properties

Change in vibrations

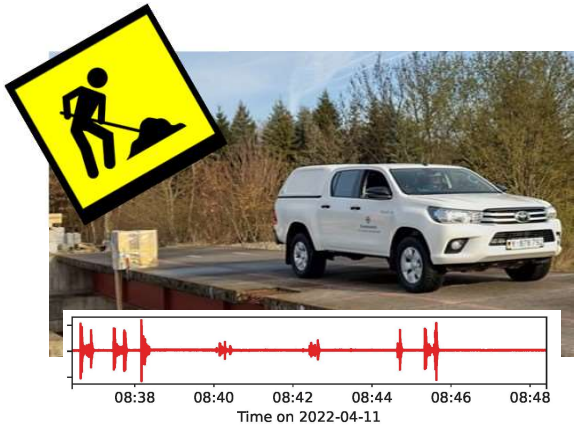
Change in pressure coefficient








Franz et al. [6]




# Thank you for your attention!

jacopo.bonari@dlr.de
www.dlr.de/pi

Our collaboration partners:

Universität der Bundeswehr München
Institut für Mathematik und Computergestützte Simulation

- Fundamental research in computational mechanics;
- currently sixteen scientific staff.

www.unibw.de/imcs

dtec.bw
Zentrum für Digitalisierungs- und Technologieforschung der Bundeswehr

- Project RISK.twin since 2021, application-motivated research in CIP;
- nine PIs, fourteen scientific staff.

www.dtecbw.de/risk.twin

[1] Franke, K., St¨urmer, J. M., & Koch, T., (2023). *Automated simulation and virtual reality coupling for interactive digital twins*, Winter Simulation Conference (WSC), pp. 2615–2626.

[2] Sahin, T., Wolff, D., von Danwitz, M., & Popp, A. (2024). *Towards a Hybrid Digital Twin: Physics-Informed Neural Networks as Surrogate Model of a Reinforced Concrete Beam*, http://arxiv.org/abs/2405.08406

[3] Bonari, J., Kühn, L., von Danwitz, M., & Popp, A. (2024). *Towards Real-Time Urban Physics Simulations with Digital Twins*, http://arxiv.org/abs/2405.10077

[4] von Danwitz, M., Bonari, J., Franz, P., Kühn, L., Mattuschka, M., & Popp, A. (2024). *CONTAMINANT DISPERSION SIMULATION IN A DIGITAL TWIN FRAMEWORK FOR CRITICAL INFRASTRUCTURE PROTECTION*, https://arxiv.org/abs/2409.01253

[5] Gioia, D., Bonari, J. (in press). *Sequential drone routing for data assimilation on a 2D airborne contaminant dispersion problem.*