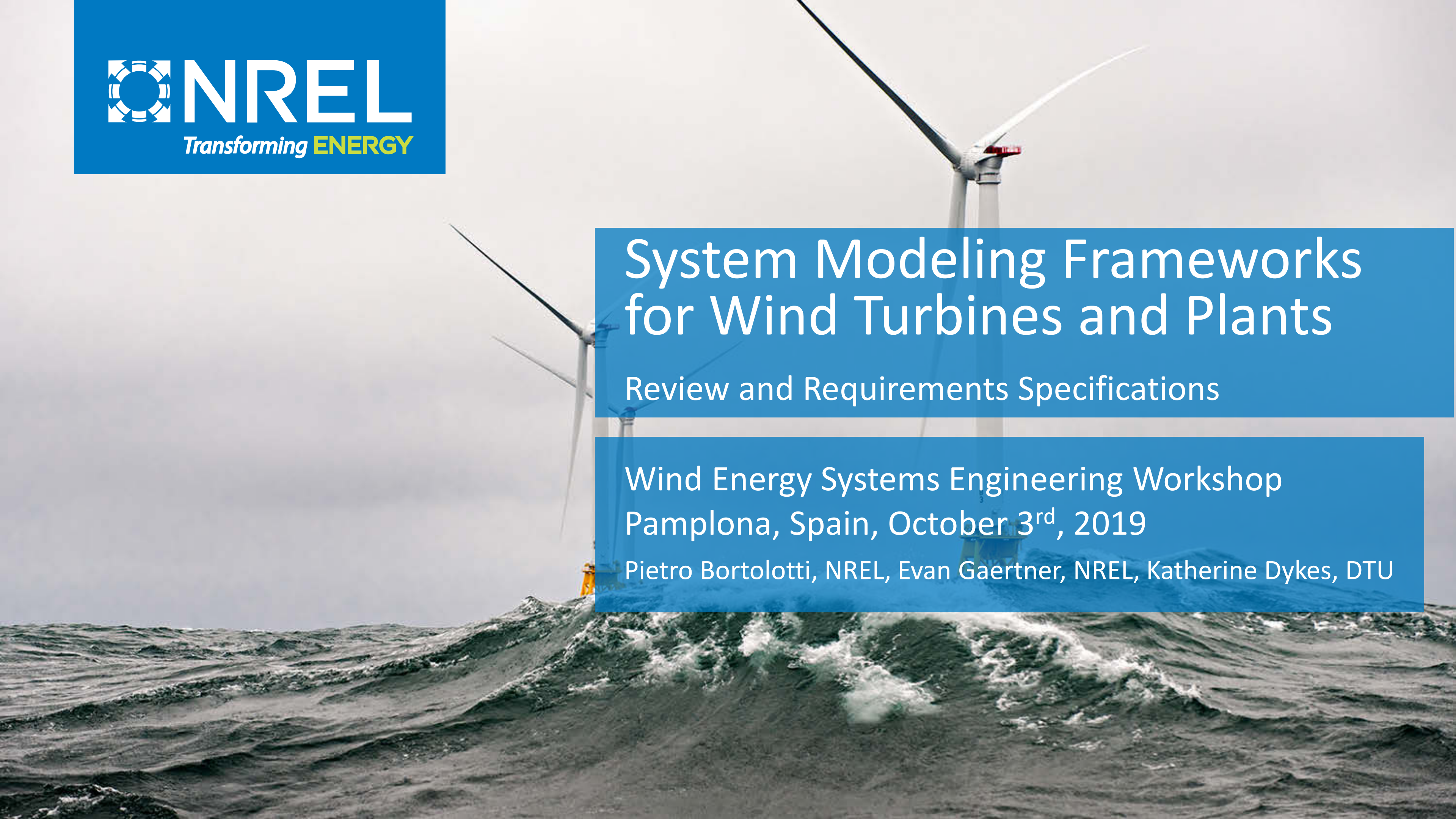


System Modeling Frameworks for Wind Turbines and Plants

Review and Requirements Specifications

Wind Energy Systems Engineering Workshop

Pamplona, Spain, October 3rd, 2019

Pietro Bortolotti, NREL, Evan Gaertner, NREL, Katherine Dykes, DTU

Agenda

1. Overview of IEA Wind Task 37
2. WP 1: Background, Motivation, and Goals
3. MDAO Workflows
4. Turbine and Plant Ontology Overview
5. A Dive into the Rotor Ontology
6. Conclusions and Next Steps

IEA Wind Task 37
Wind Energy
Systems Engineering

iea wind

Phase I:

WP 1: Guidelines for a common framework

WP 2: Reference systems

WP 3: MDAO case studies

Phase II starts now!

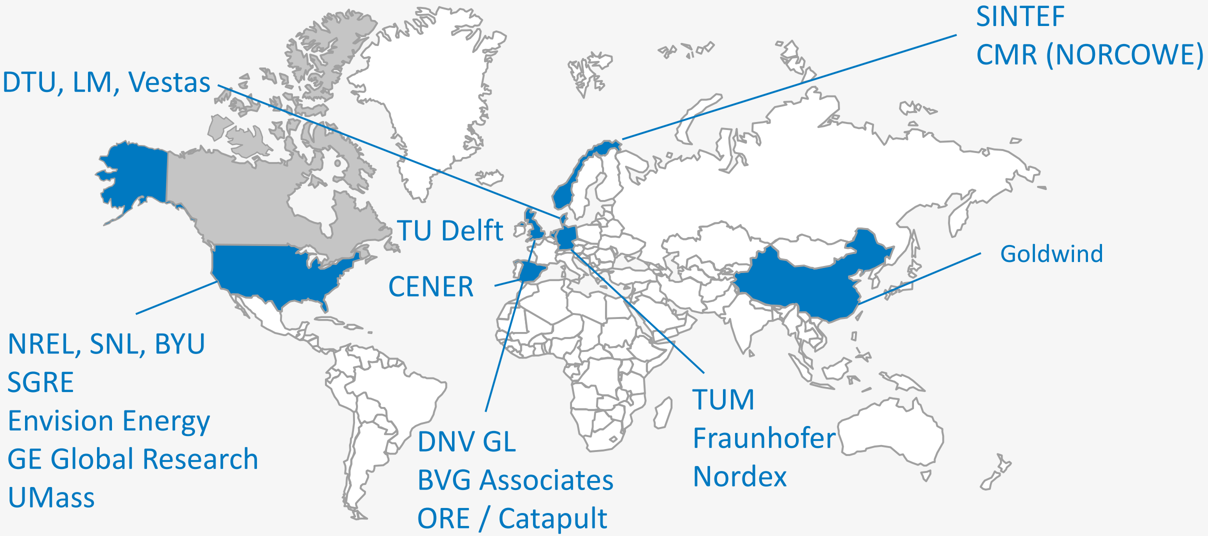
Project Objectives and Outcomes

Improve quality of systems engineering by practitioners through development of best practices and benchmarking exercises

Promote general knowledge and value demonstrations of systems engineering tools and methods applied to wind energy RD&D

Target audience

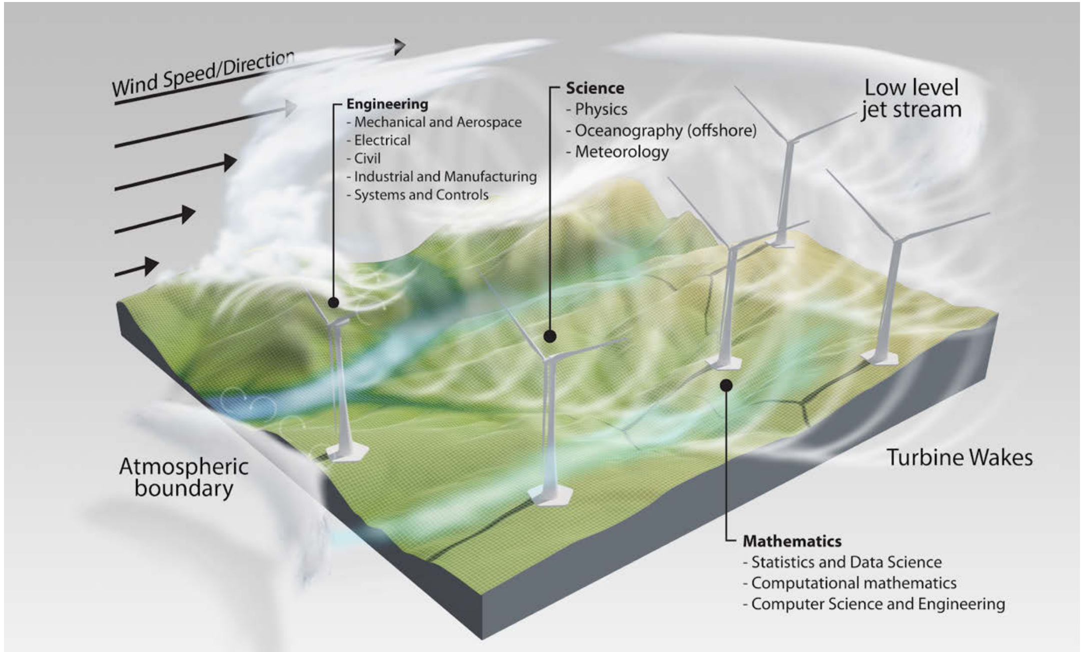
Wind turbine OEMs, developers, owner/operators, consultancies, and research community



WP 1

- Growing number of multi-disciplinary design, analysis and optimization (MDAO) approaches to tackle **system-level questions** for turbine and plant

- **Coordination** is needed to facilitate **interactions** and **comparisons**



Background

MDAO

Problem Formulation

Identification of the elements of an analysis or design optimization including variables, parameters, and outputs and quantities of interest (for analysis) or constraints and objective(s) (for optimization)

$$\max_{\mathbf{x}} f(\mathbf{x}) \quad \longleftarrow \quad \text{Objective function}$$

s.t.

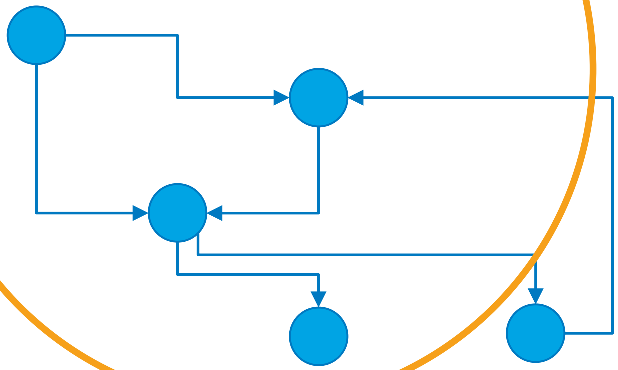
$$\mathbf{h}(\mathbf{x}) = \mathbf{0} \quad \longleftarrow \quad \text{Equality constraints}$$

$$\mathbf{g}(\mathbf{x}) \leq \mathbf{0} \quad \longleftarrow \quad \text{Inequality constraints}$$

$$\mathbf{x}_{\min} \leq \mathbf{x} \leq \mathbf{x}_{\max} \quad \longleftarrow \quad \text{Variable bounds}$$

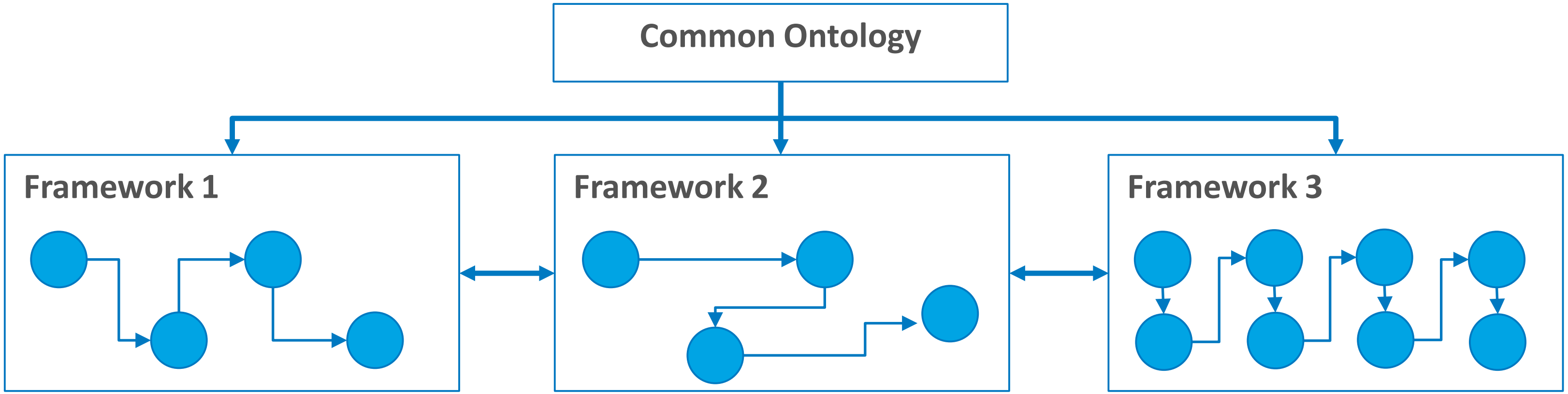
Workflow Architecture

How models pass information to one another within the overall analysis and/or optimization



Motivation

IEA Wind Task 37 have developed an **ontology** to help standardize the representation of information that flows **to** and **across** MDAO workflows applied to wind turbine and plant design, operation and control



What is an Ontology?

"In computer science and information science, an ontology is a formal naming and definition of the types, properties, and interrelationships of the **entities** that really or fundamentally exist for a particular **domain of discourse**.

It is thus a practical application of philosophical ontology, with a taxonomy. **An ontology compartmentalizes the variables needed for some set of computations and establishes the relationships between them**."

Goals

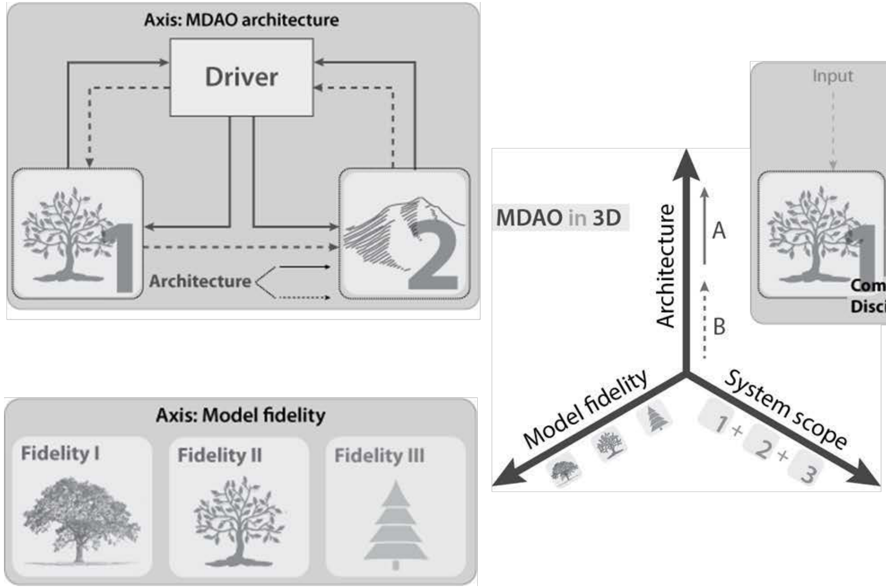
This wind energy MDAO ontology has two primary objectives:

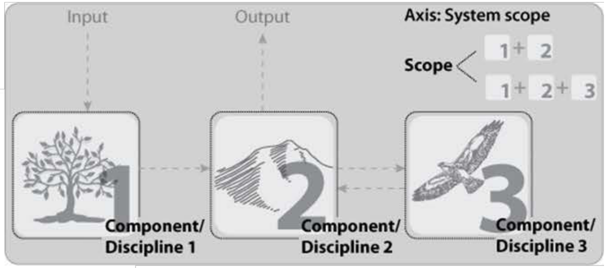
1. Share system descriptions and analysis results for supporting more **transparent benchmarking** and **comparison**
2. Integrate models together into streamlined workflows within and across organizations for **improving** the **efficiency** and **performance** of wind turbine and power plant **design processes**

All MDAO frameworks should use the common ontology as I/O!

Why is it difficult?

Every model is different (even for the exact same discipline and fidelity level) and **every workflow is different**





Source: Sanchez Perez-Moreno et al Torque 2016

MDAO Toolsets - Turbine

Survey on **existing toolsets** for turbine MDAO returned a fairly long list. Many more are for internal use only at OEMs

#	Name	Organization	Research/Commercial
1	BladeOASIS	CENER, ES	Research
2	Cp-Max	TU Munich, DE / Politecnico di Milano, IT	Research
3	FOCUS6	Knowledge Centre WMC, NL	Commercial
4	HAWTOPT2	DTU Wind Energy, DK	Research, partially open-source
5	LMS Samtech Samcef Wind Turbines	LMS Samtech (Siemens), DE	Commercial
6	OneWind Modelica Library	Fraunhofer IWES, DE	Research, partially open-source
7	QBlade	TU Berlin, DE	Research, fully open-source
8	Turbine.Architect	DNVGL, UK	Commercial
9	WISDEM	NREL, USA	Research, fully open-source

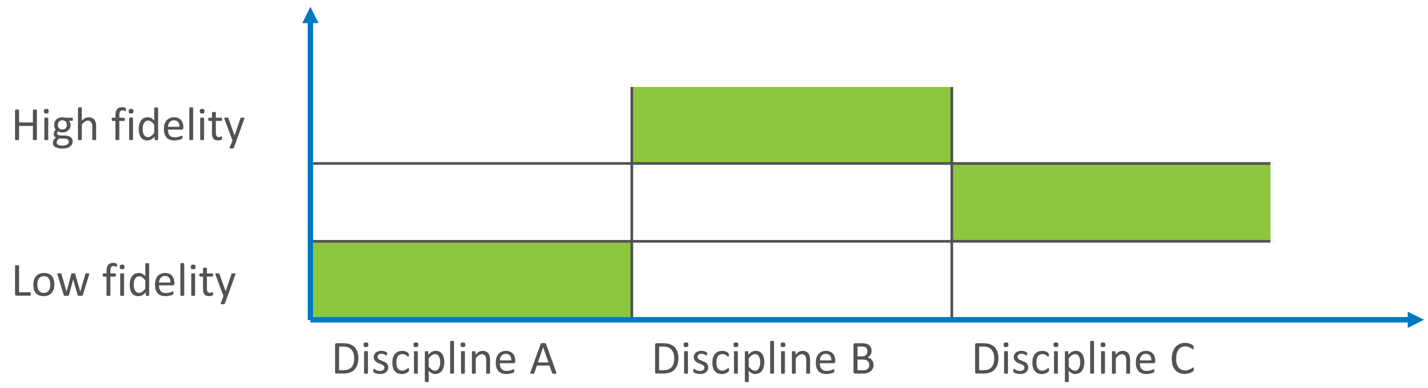
MDAO Toolsets - Plant

Similar effort for plant MDAO tools

#	Name	Organization	Research/Commercial
1	Openwind	UL - AWS Truepower	Commercial, partially open-source
2	TopFarm	DTU Wind Energy	Research, partially open-source
3	WindFarmDesigns Park Optimizer	WindFarmDesigns	Commercial
4	Windfarmer	DNV-GL	Commercial
5	Window	TU Delft	Research, fully open-source
6	WindPRO	EMD	Commercial
7	WISDEM	NREL	Research, fully open-source

Discipline/Fidelity Matrices

From the toolsets, **discipline/fidelity** matrices were created for each component. Green cells highlight the **most common combinations**



Discipline/Fidelity Matrices

The results for the **WT rotor** and **wind farm AEP** look like this:

Modeling Fidelity

Inflow aero	Airfoil aero	Rotor aero	Structures	Cross-sectional analysis	Controls	Aeroacoustics	Cost
		Hi-fi time resolved turbulence modelled CFD	3D solid				
Time resolved LES CFD		Blade resolved CFD	3D shell			Time resolved LES	
Vortex methods	LES	Actuator Line CFD	Super-element		Supervisory controllers		
DWM	RANS CFD	Actuator Disc CFD	Elemental non-linearity (GEBT)	Generalized 6x6	Safety protection functions		Full BOM and end-to-end virtual factory model
Engineering unsteady 3D (Veers/Mann)	Inviscid Euler methods	Vortex methods	Multi-body (linear/non-linear)	Timoshenko	Load mitigation	Time- and frequency-based models	Full BOM and manufacturing process flow
Unsteady uniform	Panel methods	BEM	Modal	Euler	Power/speed regulation	Frequency-based models	Empirical design-based
Steady inflow	Look-up Table	Look-up Table CT&Power	Rigid	Analytical solid	Prescribed operation	Semi-empirical	Empirical parametric

System Scope: Disciplines Included

Modeling Fidelity

Resource / inflow	Rotor (aero and control)	Wind farm Control	Wakes / plant flow	Power conversion	Energy Aggregation	Loss model - non wakes
CFD: LES	Hi-fi time-resolved turbulence modeled CFD		CFD: LES			
CFD: Rans (2D and 3D) (Unsteady)	Blade resolved CFD		CFD: Rans (2D and 3D) (Unsteady)			
CFD: Rans (2D and 3D) (Steady State)	Actuator Line CFD		CFD: Rans (2D and 3D) (Steady State)			
Semi-empirical turbulent inflow Semi-empirical turbulent inflow	Actuator Disc CFD	Dynamic closed-loop	DWM / Linearized CFD			
	Vortex methods	Closed-loop	Vortex methods			
Non-uniform resource distribution	BEM	Open-loop	Steady - Field PDE (Ainslie)		Time-series	Semi-empirical explicit electric array cable
Uniform resource distirbution	Look-up table Thrust & Power curves	Prescribed Operation / Look-up table	Steady - Analytic - Semi-empirical	Analytic - Empirical	Convolution	Empirical

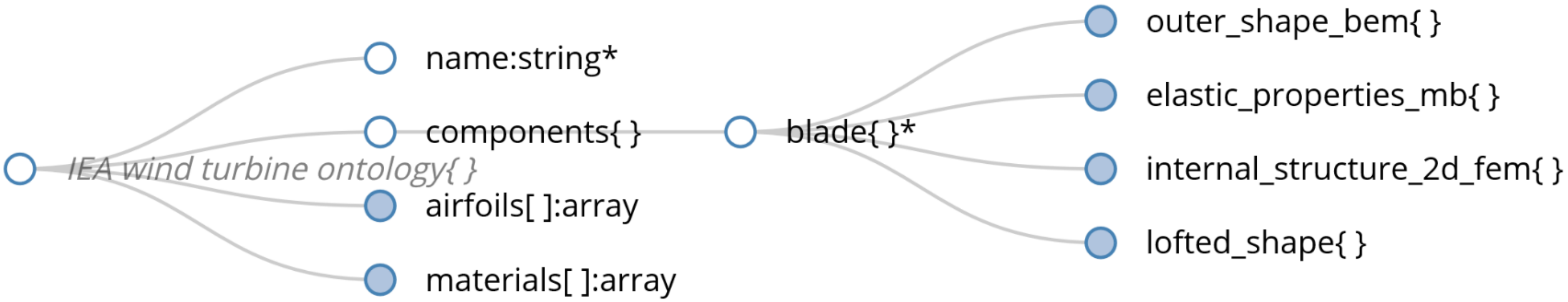
System Scope: Disciplines Included

Similar tables were populated for other components

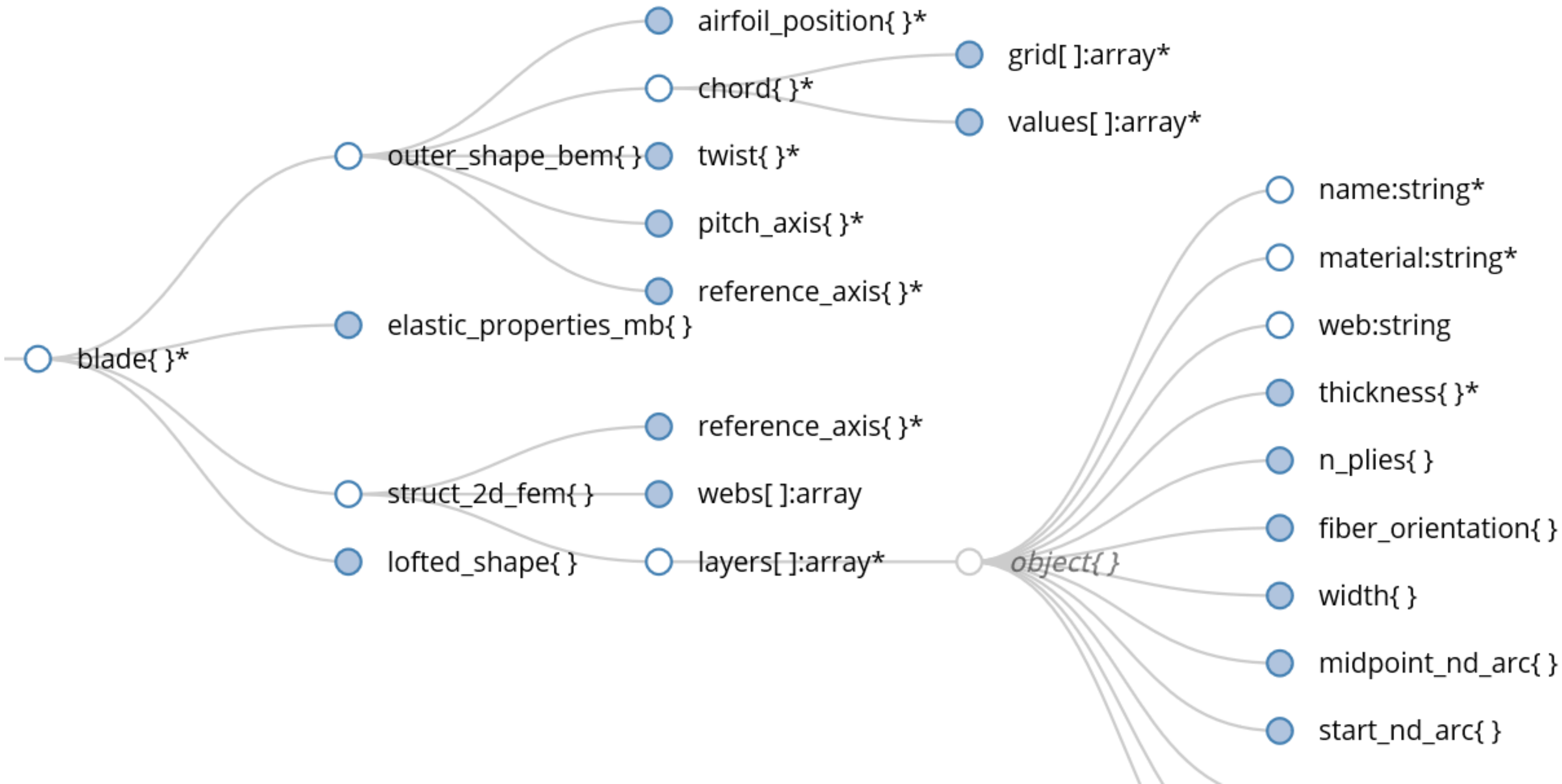
Blade Ontology

From the green cells, a **wind turbine ontology** was initiated, starting with the **rotor blades**

The blade ontology has been developed with an **aerostructural MDAO approach** in mind

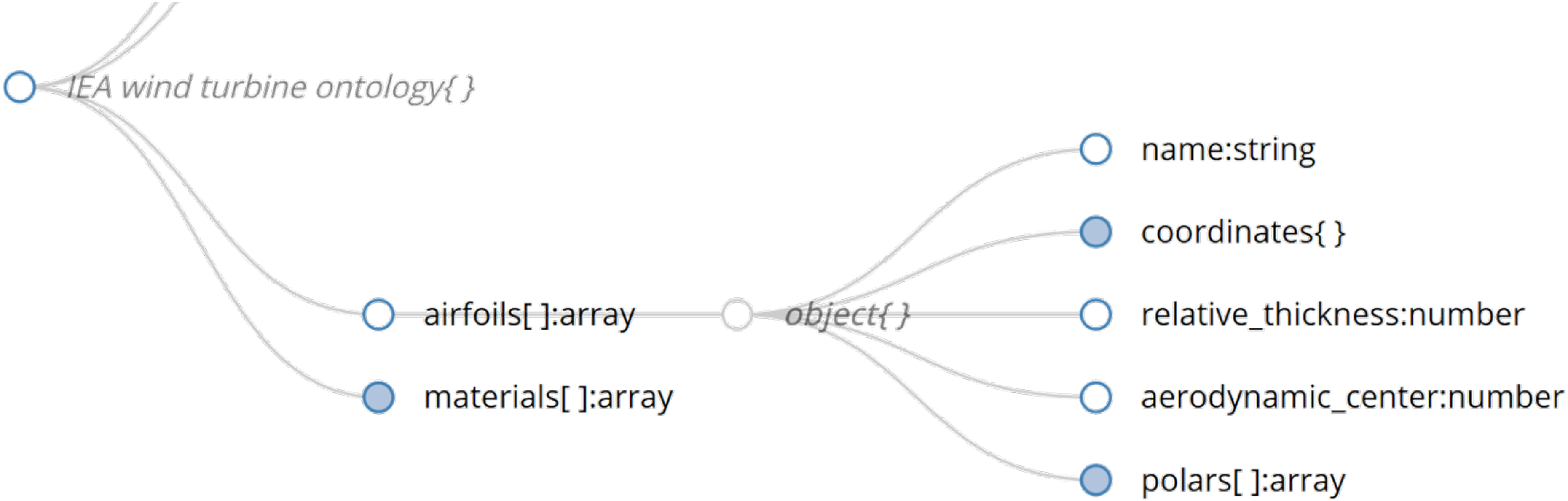


Blade Ontology



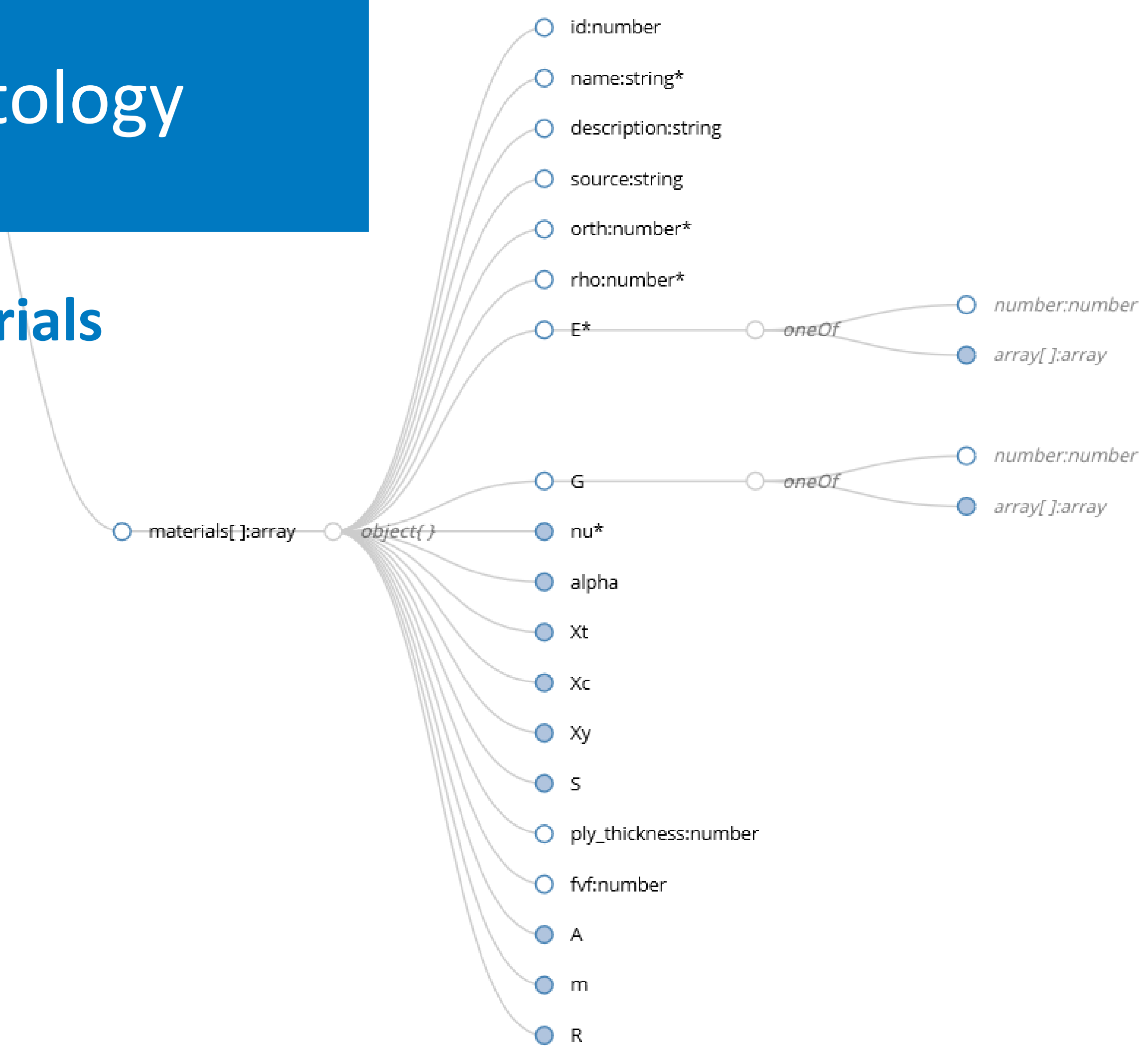
Blade Ontology

Database of airfoils, each airfoil can have multiple sets of polars



Blade Ontology

Database of materials



Blade Ontology

The ontology has been coded into a **.yaml** file, which offers some nice features:

1. yaml is a **human- and machine- readable** data-serialization language
2. It supports commenting and descriptions
3. User-friendliness and flexibility to accommodate **multiple disciplinaries and fidelity levels** for each component
4. It supports JSON schema, which is a vocabulary that allows to annotate and **validate** JSON and YAML documents, providing clear human- and machine- readable documentation

Conclusions and Future Work

The IEA Wind Task 37 community has converged to a common ontology for wind energy systems

- It is being adopted by multiple institutions worldwide
- It is used to define the reference wind turbines from WP2:
  - https://github.com/IEAWindTask37/IEA-3.4-130-RWT/
  - https://github.com/IEAWindTask37/IEA-10.0-198-RWT
- It will be expanded to cover the whole wind turbine and wind farm components and disciplines
- It will be soon fully documented in an IEA technical report

Common Ontology

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The **IEA Wind Task 37** community:

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TU Delft	-	Erik Quaghebeur, Sebastian Sanchez Perez-Moreno, Michiel Zaaijer			

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Thank You

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