SIMULATION WORLD 2024
INSPIRE / EMPOWER / EQUIP

RBF Morph

Enabling Medical Digital Twin through Advanced Mesh Morphing and High-Fidelity Patient-Specific Simulations

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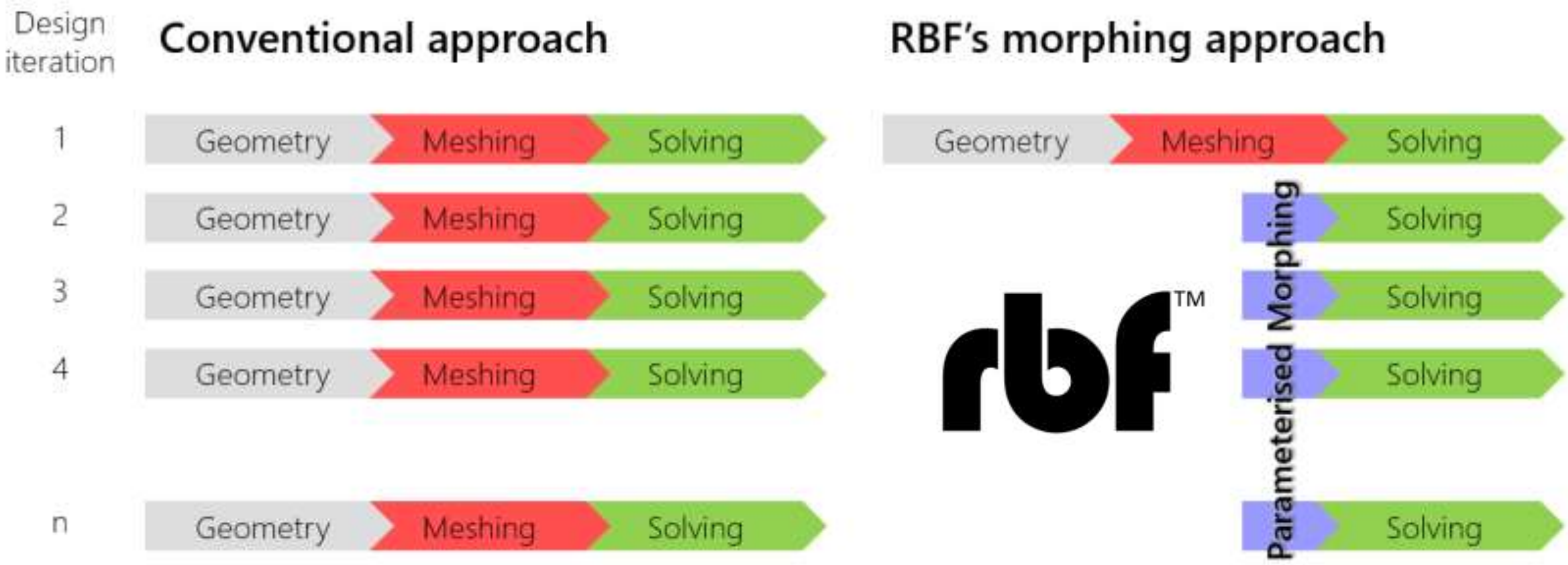
rbf™

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

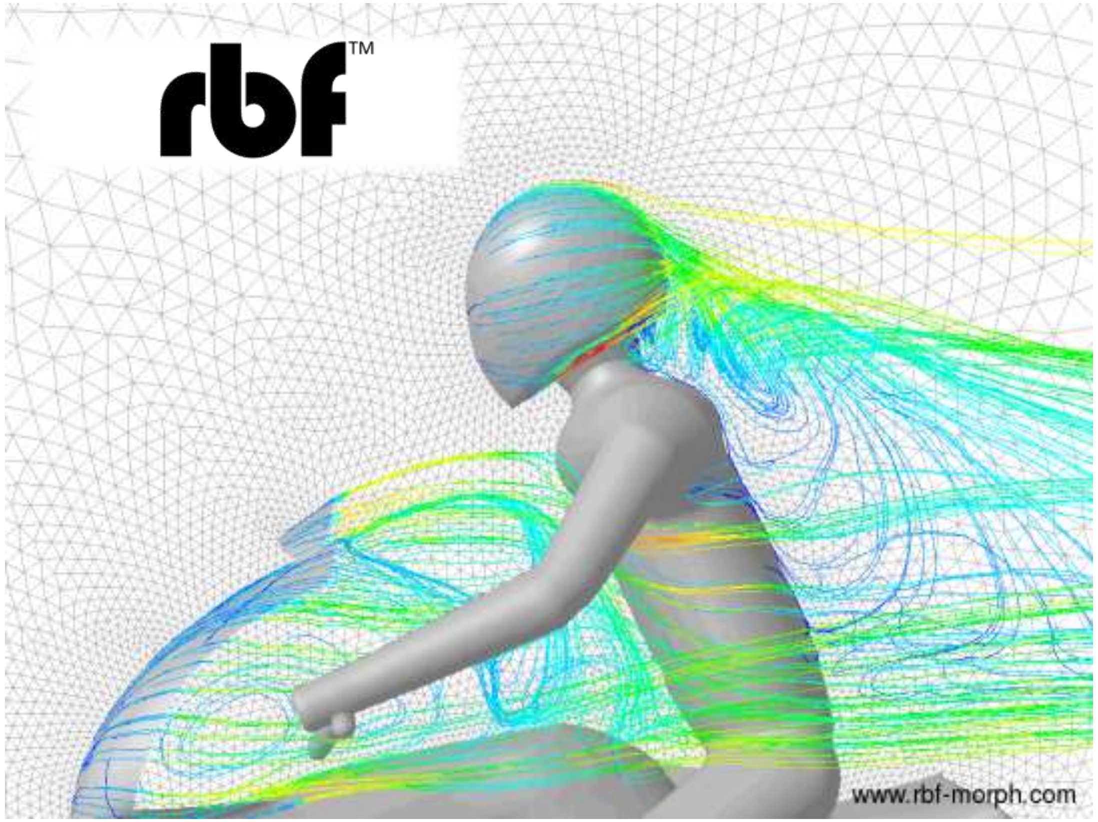
We make CAE models parametric

- RBF Morph makes the CAE model **parametric**
- Shape parameters are driven by **an orchestrator**
- Shape parameters can be used to generate snapshots for real time Digital Twins (**ROM/AI**)



Radial Basis Functions mesh Morphing

- Geometric control by **R**adial **B**asis **F**unctions mesh **Morphing**
  - Surface shape changes
  - Volume mesh adaption
- A **new shape** of the CAE model **ready to run**
  - for structures in the FEA solver
  - for flows in the CFD solver



Radial Basis Functions mesh Morphing

- We offer **Radial Basis Functions** (RBF) to drive mesh morphing (smoothing) from a list of source points and their displacements

$$
\begin{cases}
s_x(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^x \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{\boldsymbol{s}_i}\|) + \beta_1^x + \beta_2^x x + \beta_3^x y + \beta_4^x z \\
s_y(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^y \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{\boldsymbol{s}_i}\|) + \beta_1^y + \beta_2^y x + \beta_3^y y + \beta_4^y z \\
s_z(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^z \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{\boldsymbol{s}_i}\|) + \beta_1^z + \beta_2^z x + \beta_3^z y + \beta_4^z z
\end{cases}
$$

- RBF are recognized to be one of the **best mathematical tool** for mesh morphing

Main uses of RBF Morph

Usage	Mechanical	Fluent	optiSLang	Twin Builder
Automated and quick variable design space exploration.	✓	✓		
Optimization (Single physics or multi-physics). Shape optimization for stress reduction, mass reduction, fluid-structure interaction	✓	✓	✓	
Digital twin development (static ROMs)	✓	✓	✓	✓
Lifing applications Simulate defects such as corrosion pits, spalling of material, erosion, chips, etc.	✓	✓		
Examine the effects of non-conformance and manufacturing variability	✓	✓		
Robust Design	✓	✓	✓	

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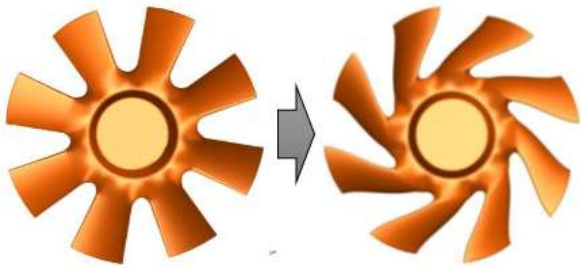
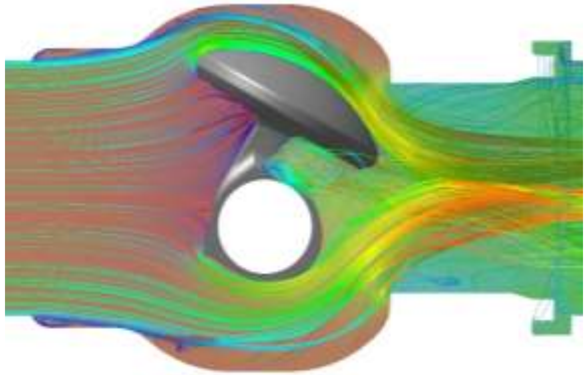
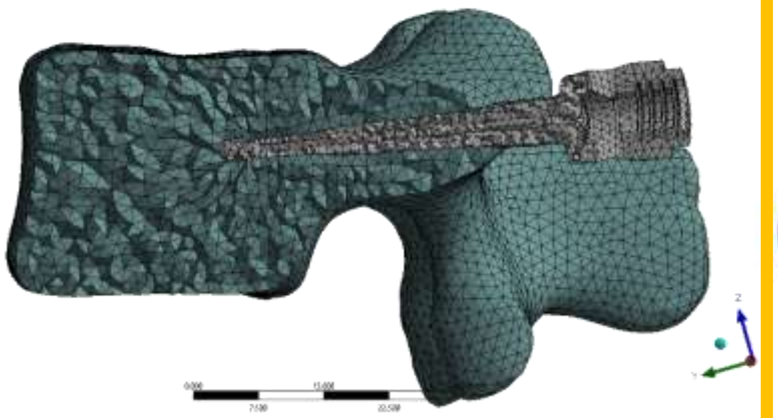
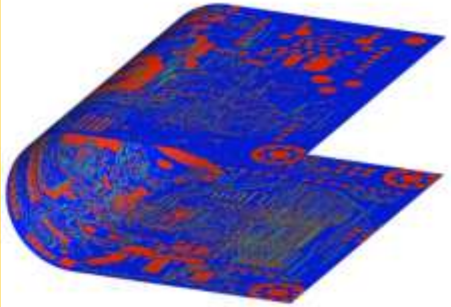
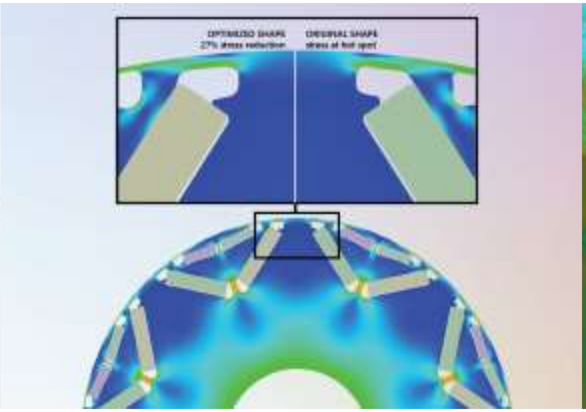
Applications

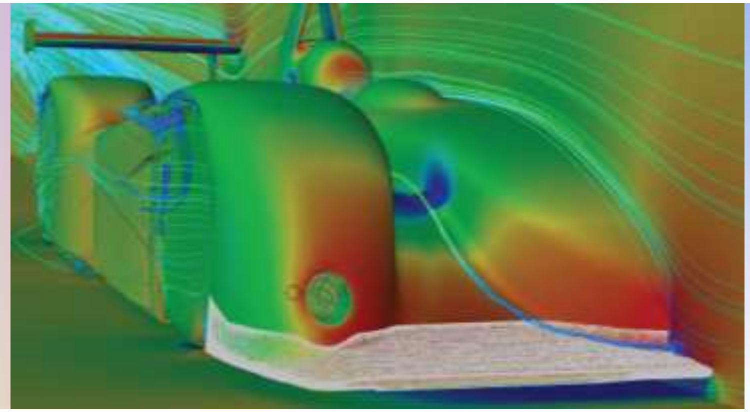












EU-funded research projects

RBF4AERO

FORTISSIMO

RIBES

CloudiFacturing

EUROfusion

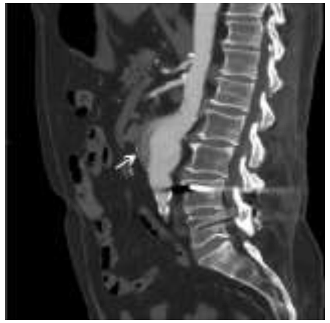
spinner
next generation spine experts

MEDITATE

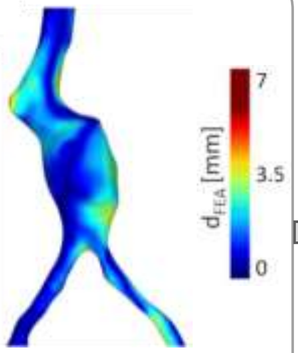
ff4EuroHPC

MeDiTATe Endovascular Abdominal Aneurysm Repair

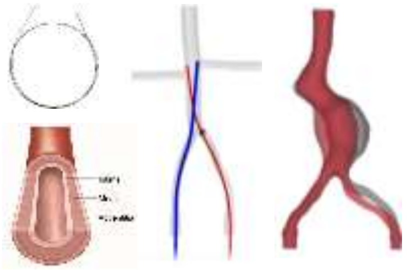
AAA patient case



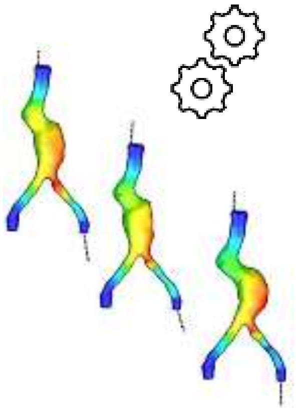
CT scan segmentation



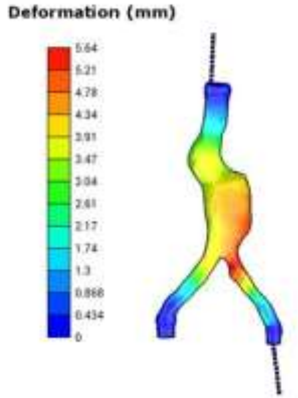
Baseline Finite Element case



Morphological, clinical, mechanical parameterization



ROM Build-up



ROM exploitation

ST. OLAVS HOSPITAL
UNIVERSITETSSYKEHUSET I TRONDHEIM

3DSlicer

Ansys
LS - DYNA

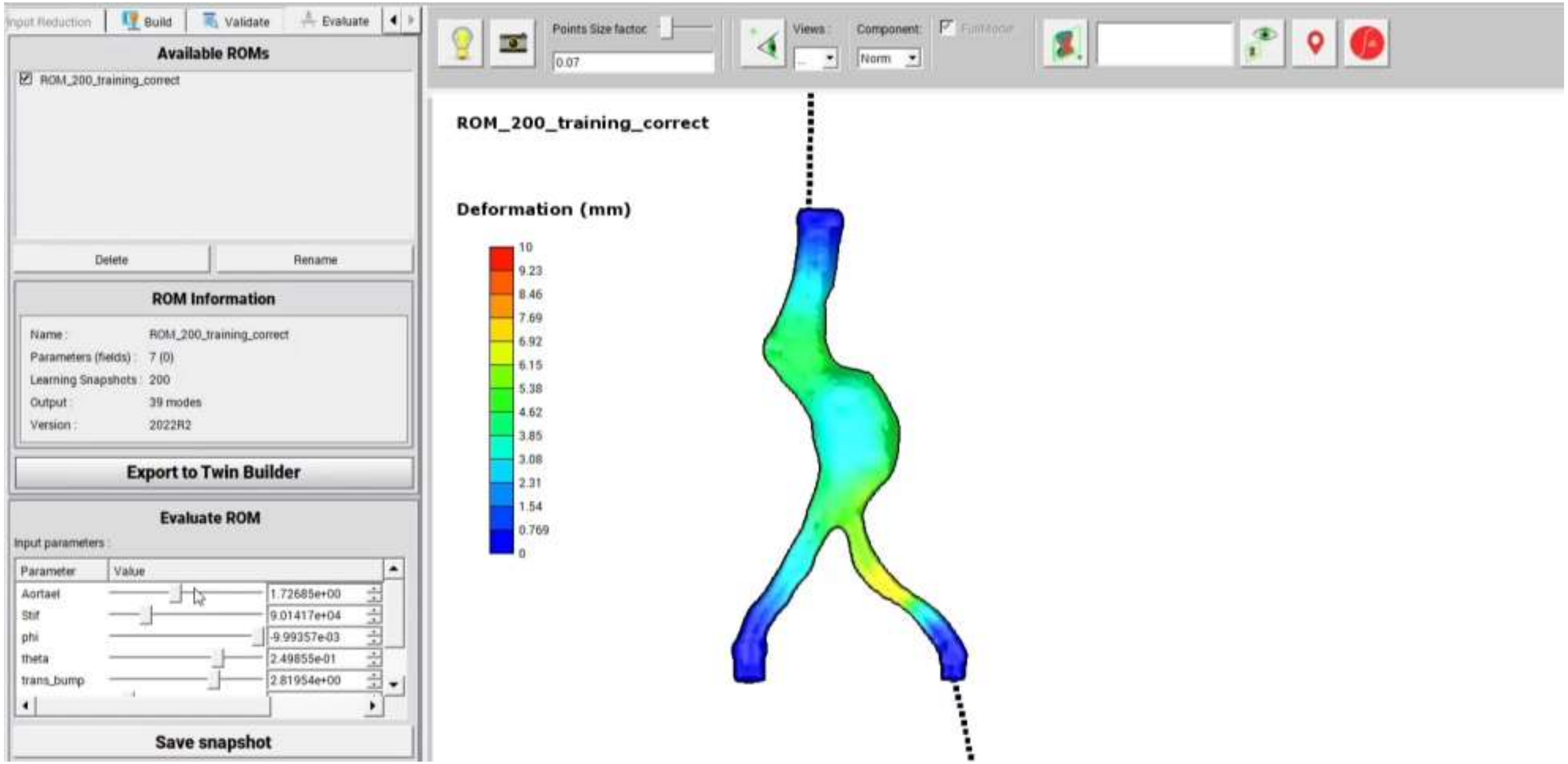
rbf
python

Ansys
TWIN BUILDER

Ansys
TWIN BUILDER

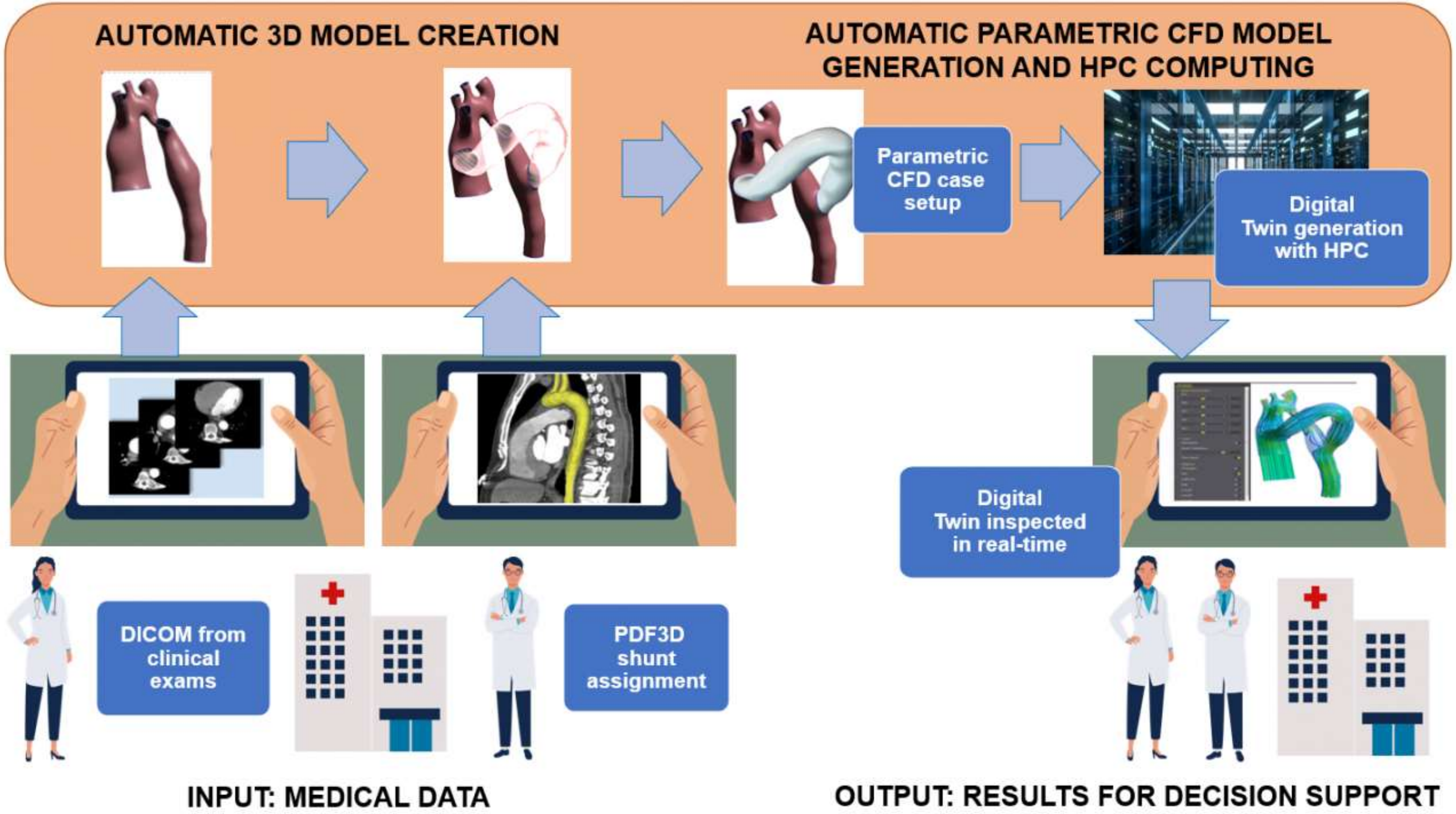
rbf

MeDiTATe Endovascular Abdominal Aneurysm Repair



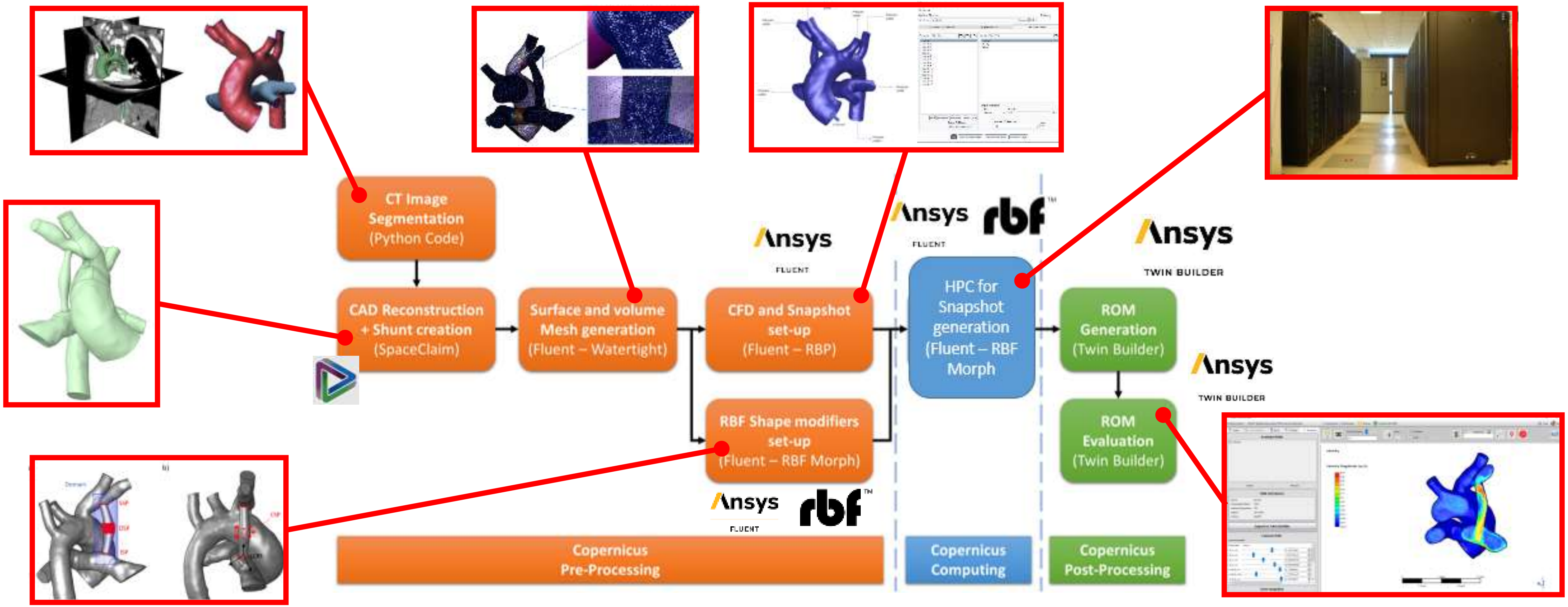
rbf

Medical Digital Twin Copernicus

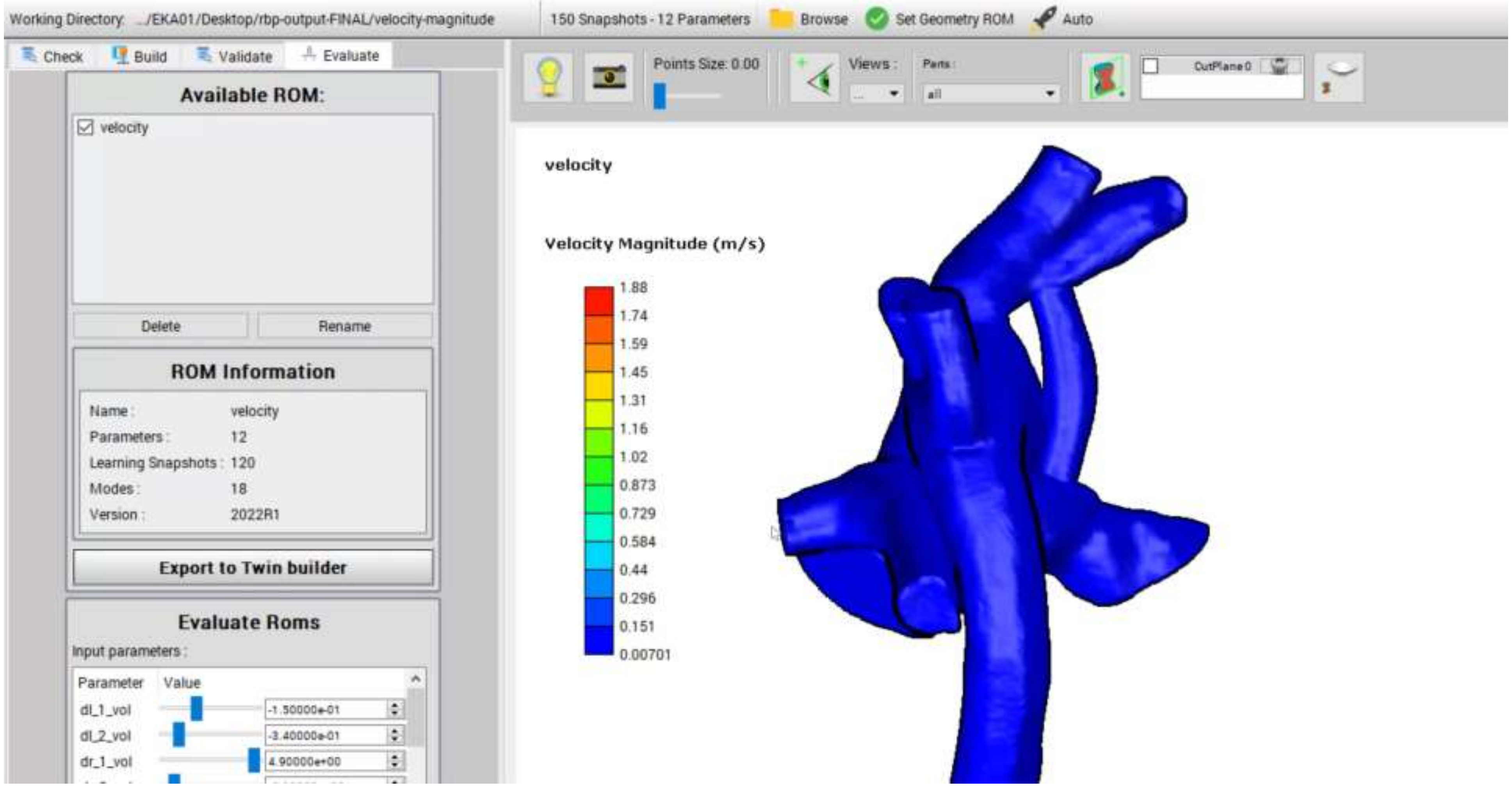


https://www.ff4eurohpc.eu/en/experiments/2021070910512579/cloudbased_hpc_platform_to_support_systemicpulmonary_shunting_procedures

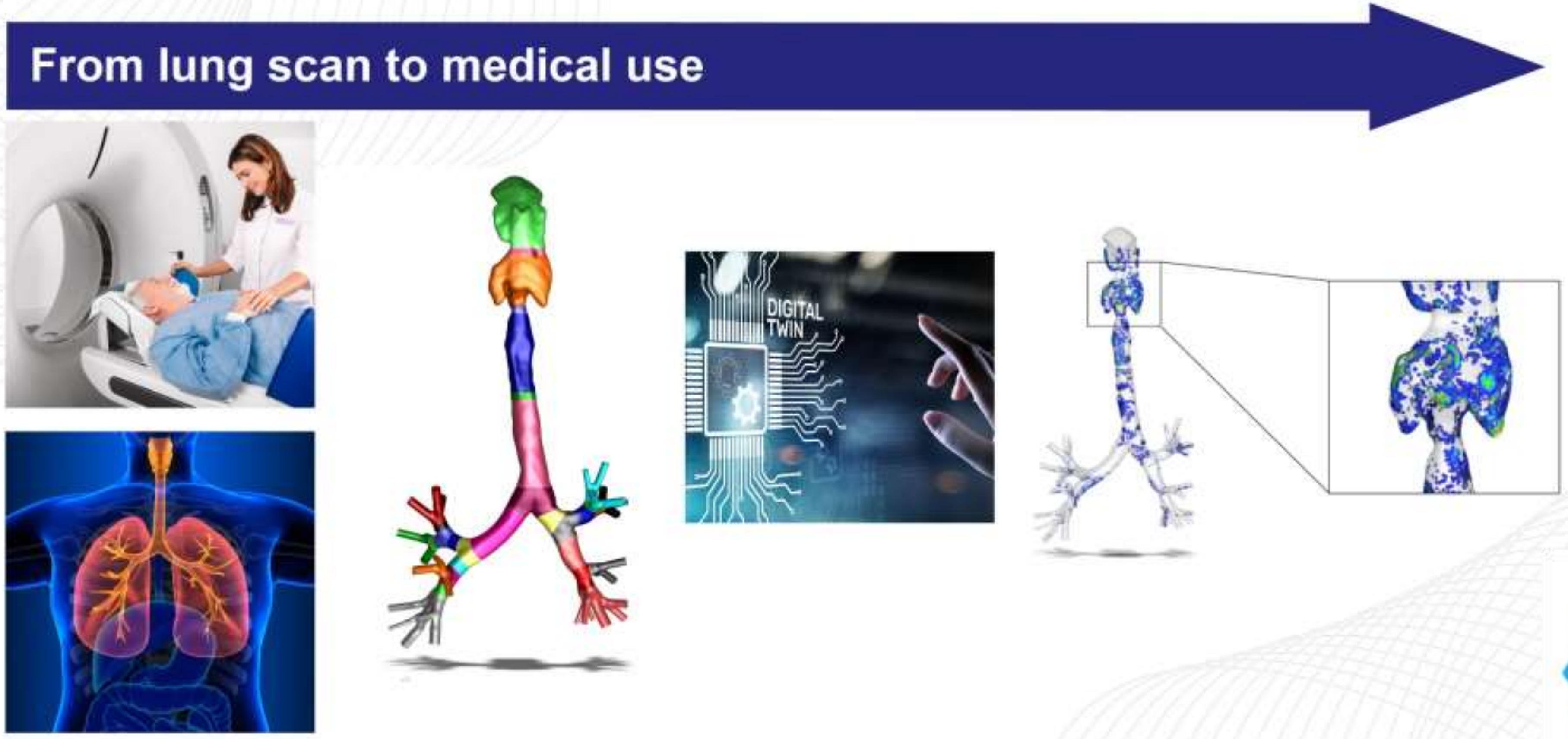
Medical Digital Twin Copernicus



Medical Digital Twin Copernicus



Medical Digital Twin
DiTAiD



1) Scan of lungs

2) Extraction of lung shape parameters

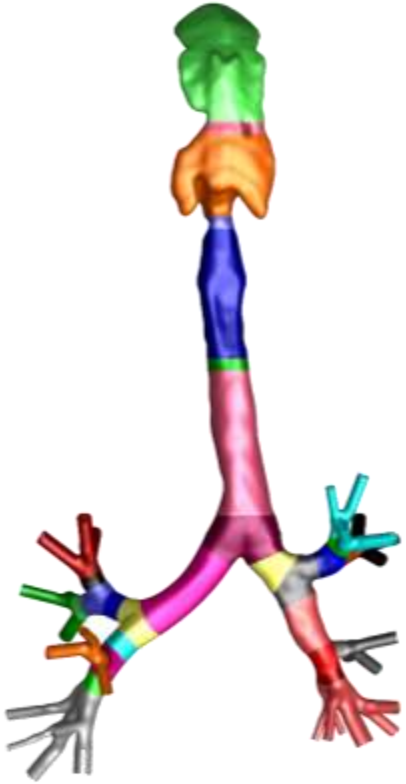
3) Digital twin

4) Visualization and interpretation for medical use

https://www.ff4eurohpc.eu/en/experiments/2022031514424665/digitaltwin_for_airflow_and_drug_delivery_in_human_airways

Medical Digital Twin DiTAiD

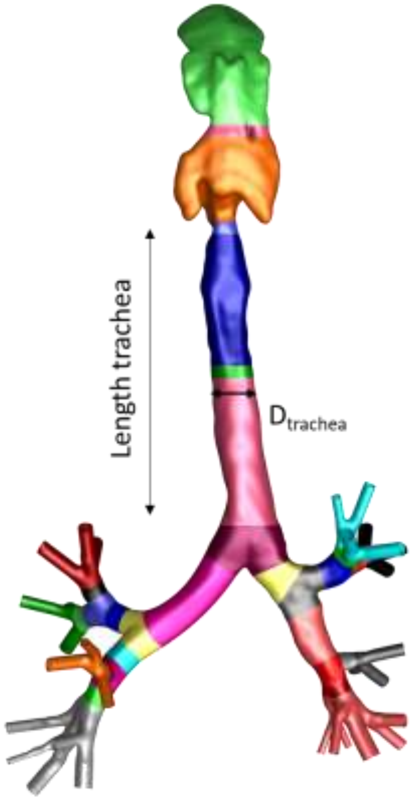
- Base geometry is obtained from literature
  - ✓ Constructed from several high-resolution CT scans of 47 year old healthy volunteer
  - ✓ The base geometry has been studied in multiple experimental and numerical studies
  - ✓ Includes up to the 4th generation (note, human lungs go up to 23 generations)
- Identify relevant input parameters for the digital twin
  - ✓ Shape
  - ✓ Flow
  - ✓ Particle



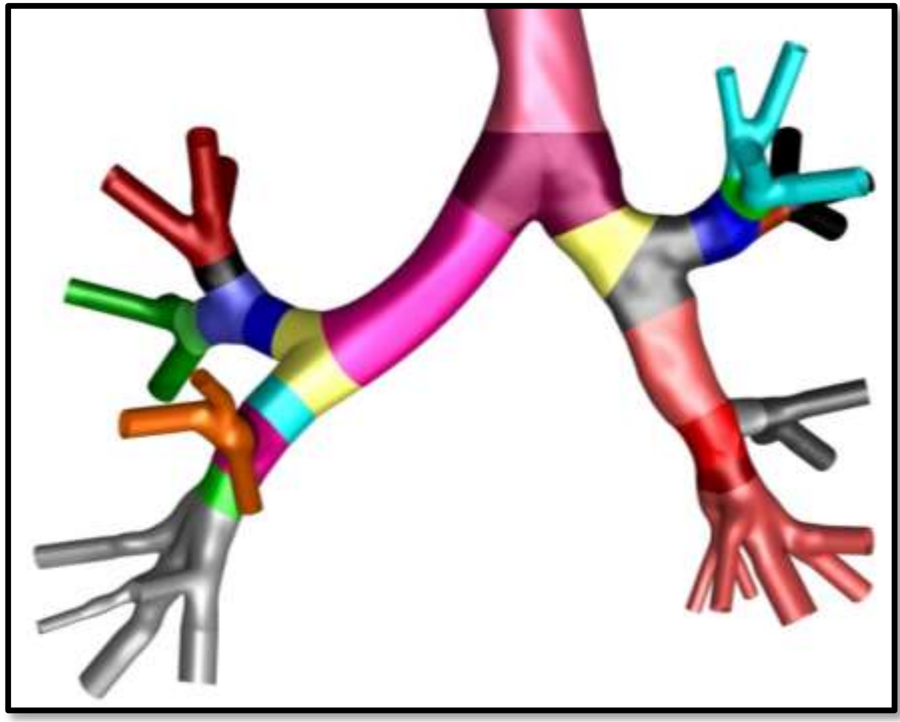
Z. Zhang, C. Kleinstreuer and S. Hyun, "Size-change and deposition of conventional and composite cigarette smoke particles during inhalation in a subject-specific airway model," *Journal of Aerosal Science*, vol. 46, pp. 34-52, 2012.
S. Kenjereš and J. L. Tjin, "Numerical simulations of targeted delivery of magnetic drug aerosols in the human upper and central respiratory system: a validation study," *Royal Society Open Science*, vol. 4, no. 12, p. 170873, 2017.

Medical Digital Twin
DiTAiD

- Potentially a huge amount of shape parameters!
- Amount of input parameters is limited by assuming:
  - ✓ Circularity is kept constant
  - ✓ Only considered angle is the branching angle
  - ✓ Diameter follows a fixed ratio6 of h=0.79
- Mouth-throat part: 3 parameters
- Lower airways: 23 parameters
  - ✓ Generation 0 (trachea): 1L, 1D, 1A
  - ✓ Generation 1: 2L, 2A
  - ✓ Generation 2: 4L, 4A
  - ✓ Generation 3: 8L



T. Van de Moortele et al.; *"Morphological and functional properties of the conducting human airways investigated by in vivo computed tomography and in vitro MRI"*



Generation	Diameter [mm]	Length [mm] Left	Right	Branching angle [deg]
0 (Trachea)	15 - 20	100 - 120		80 - 95
1		51 - 57	24 - 28	75 - 90
2		12 - 16	15 - 28	65 - 95
3		7 - 10	7 - 10	55 - 70

Medical Digital Twin DiTAiD

https://www.flickr.com/photos/aceofknaves/25604600281/

Physical parameters: 3 parameter

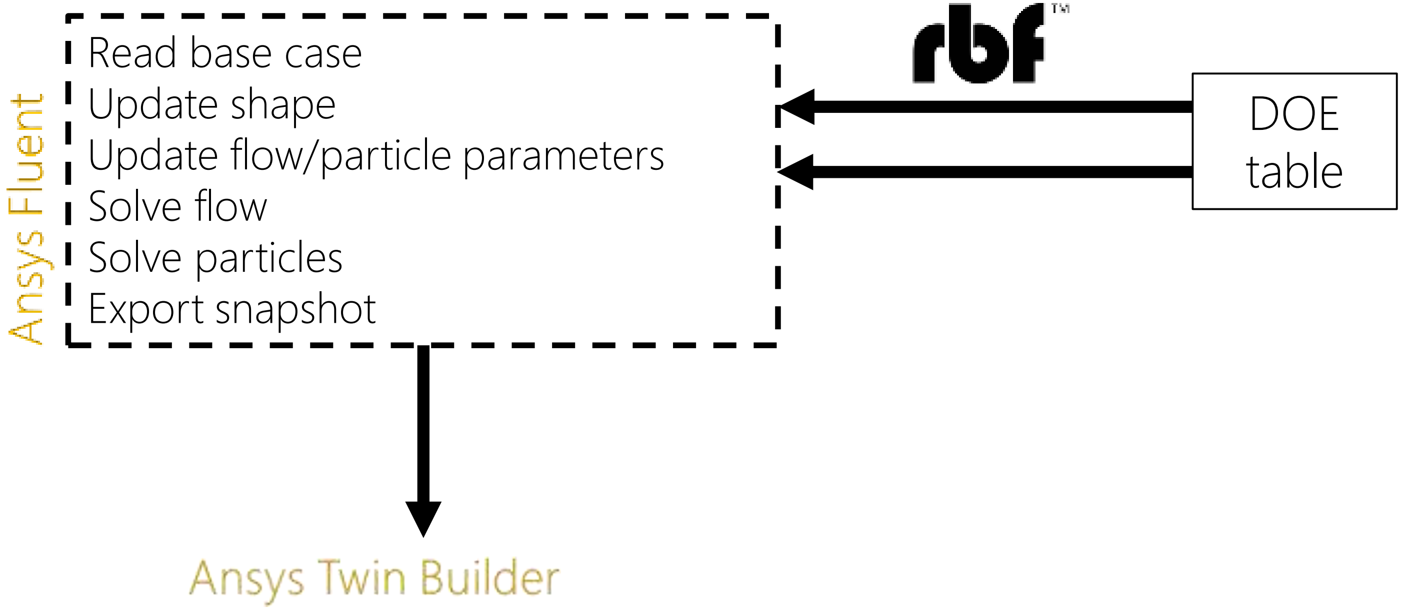
- ✓ Flow rate varies between 15 L/min and 120 L/min
- ✓ Particle size varies between 0.1 μm and 10 μm
- ✓ Particle injection rate varies between 0 m/s and 10 m/s

26 shape parameters and 3 physical parameter

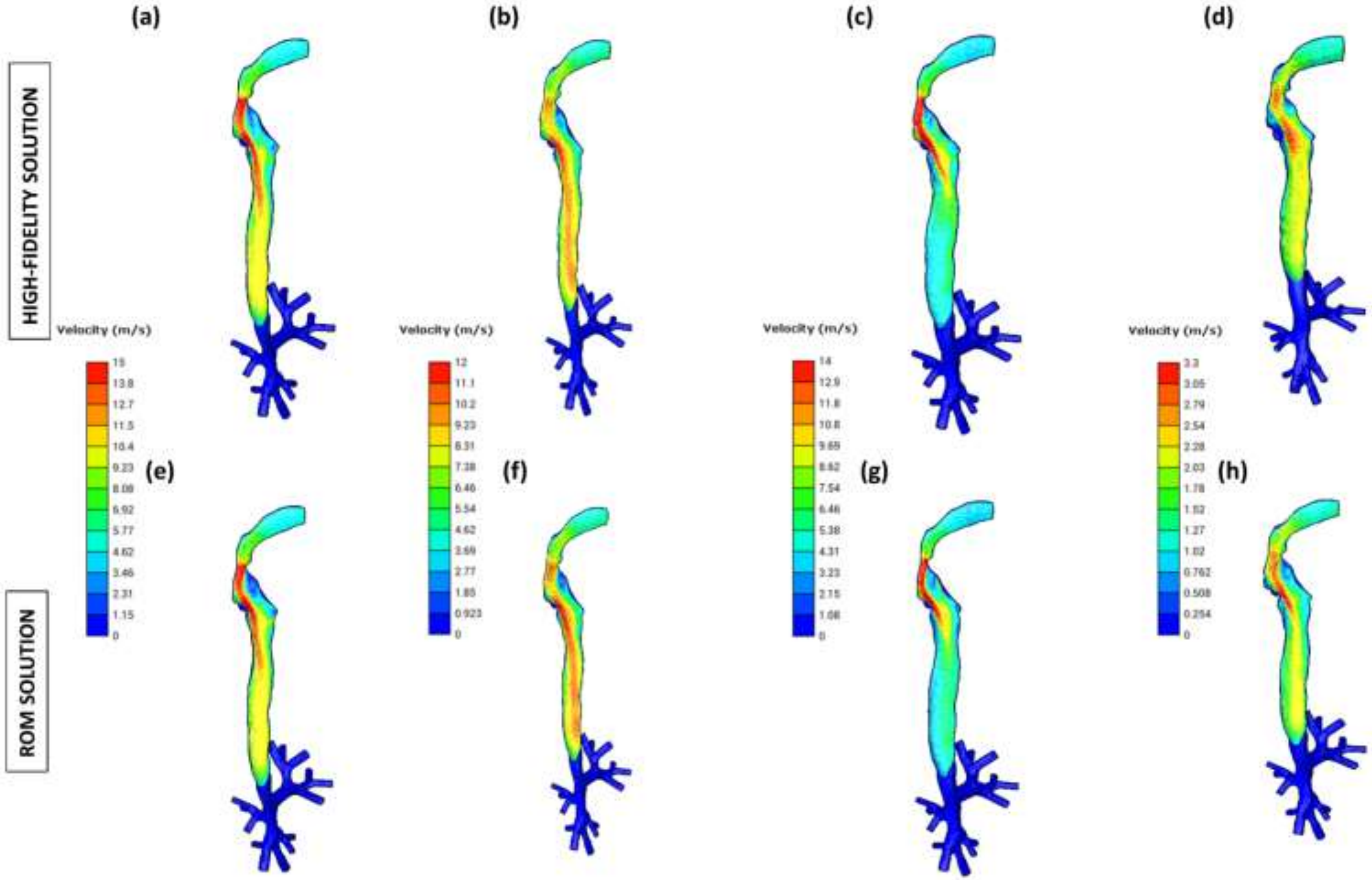
29 input parameters in total

Medical Digital Twin DiTAiD

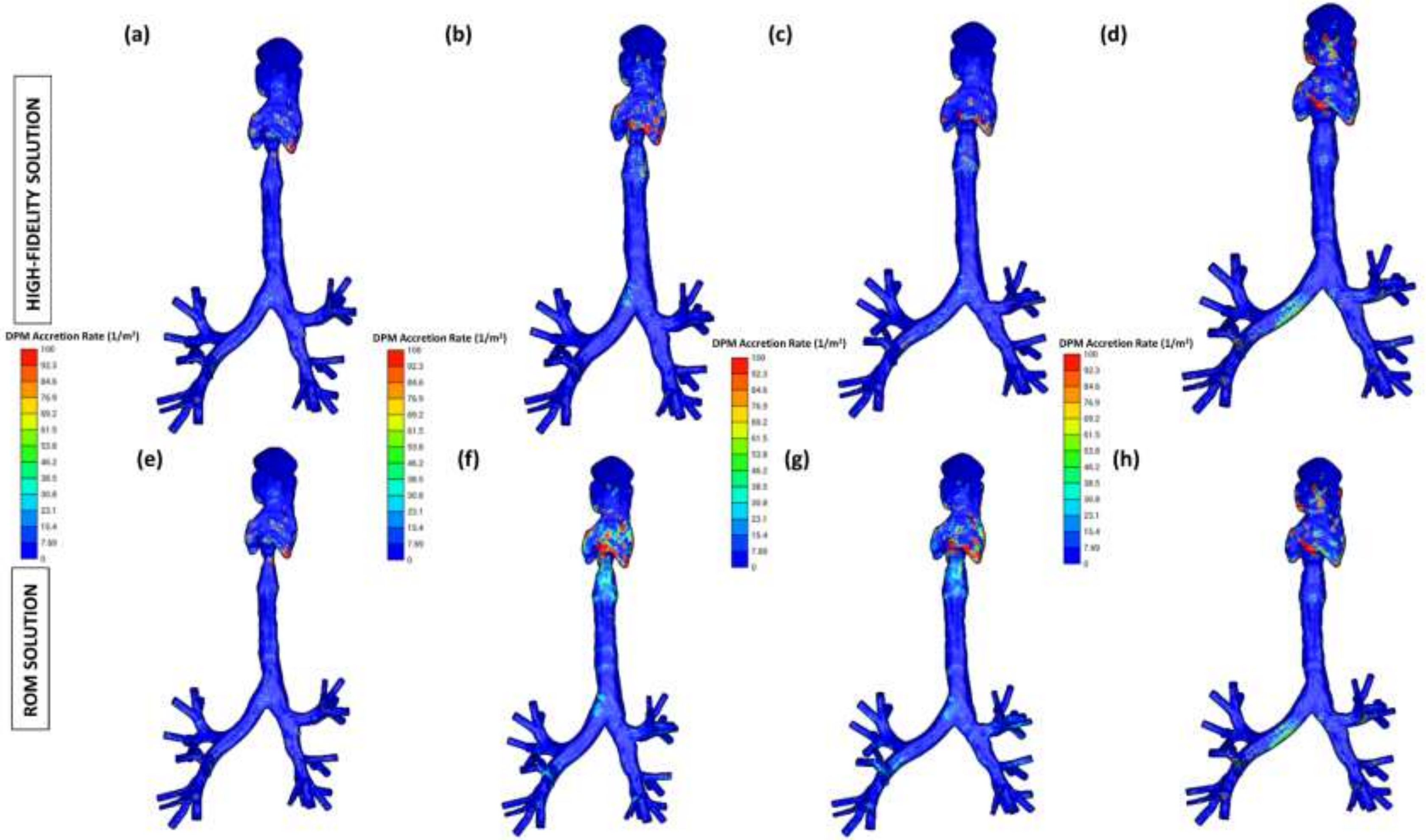
- Design Of Experiments (DOE) table is generated:
  - ✓ For the 29 input parameters
  - ✓ Using the Latin Hypercube Sampling for optimal spacing
  - ✓ Creating 1000 design points
- Fluent settings validated in literature
  - ✓ Steady state
  - ✓ RANS, transitional SST (4eq)
  - ✓ Particles are one-way coupled



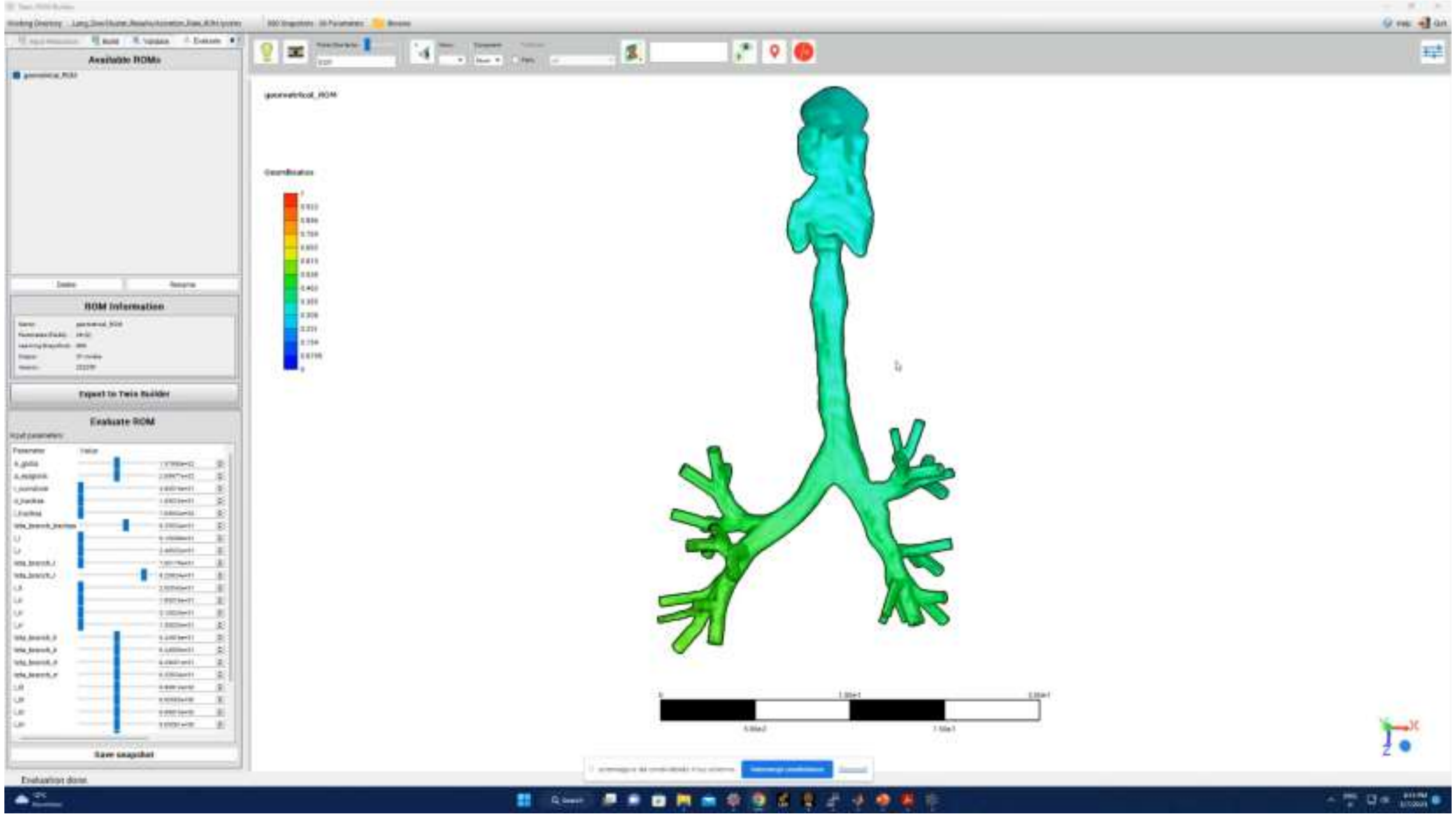
Medical Digital Twin DiTAiD



Medical Digital Twin
DiTAiD



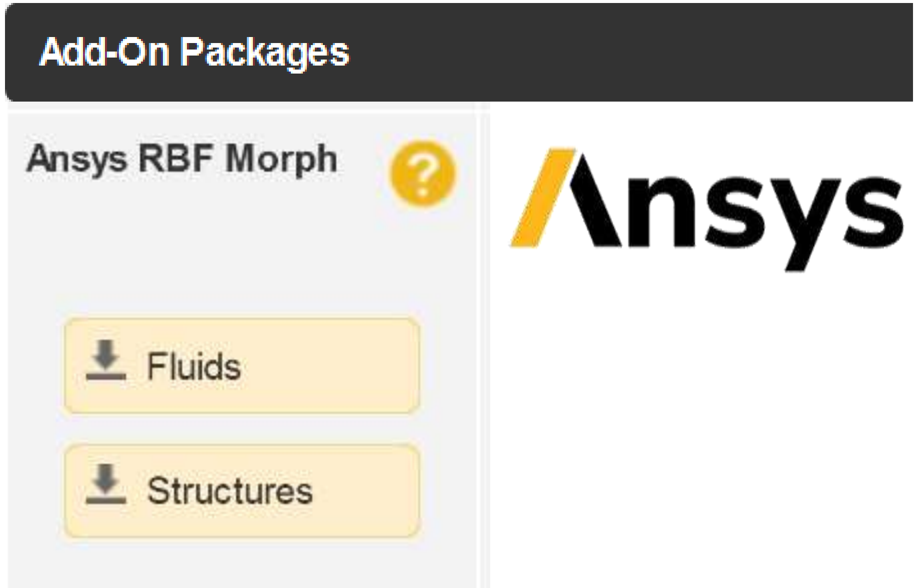
Medical Digital Twin DiTAiD



https://www.ff4eurohpc.eu/en/experiments/2022031514424665/digitaltwin_for_airflow_and_drug_delivery_in_human_airways

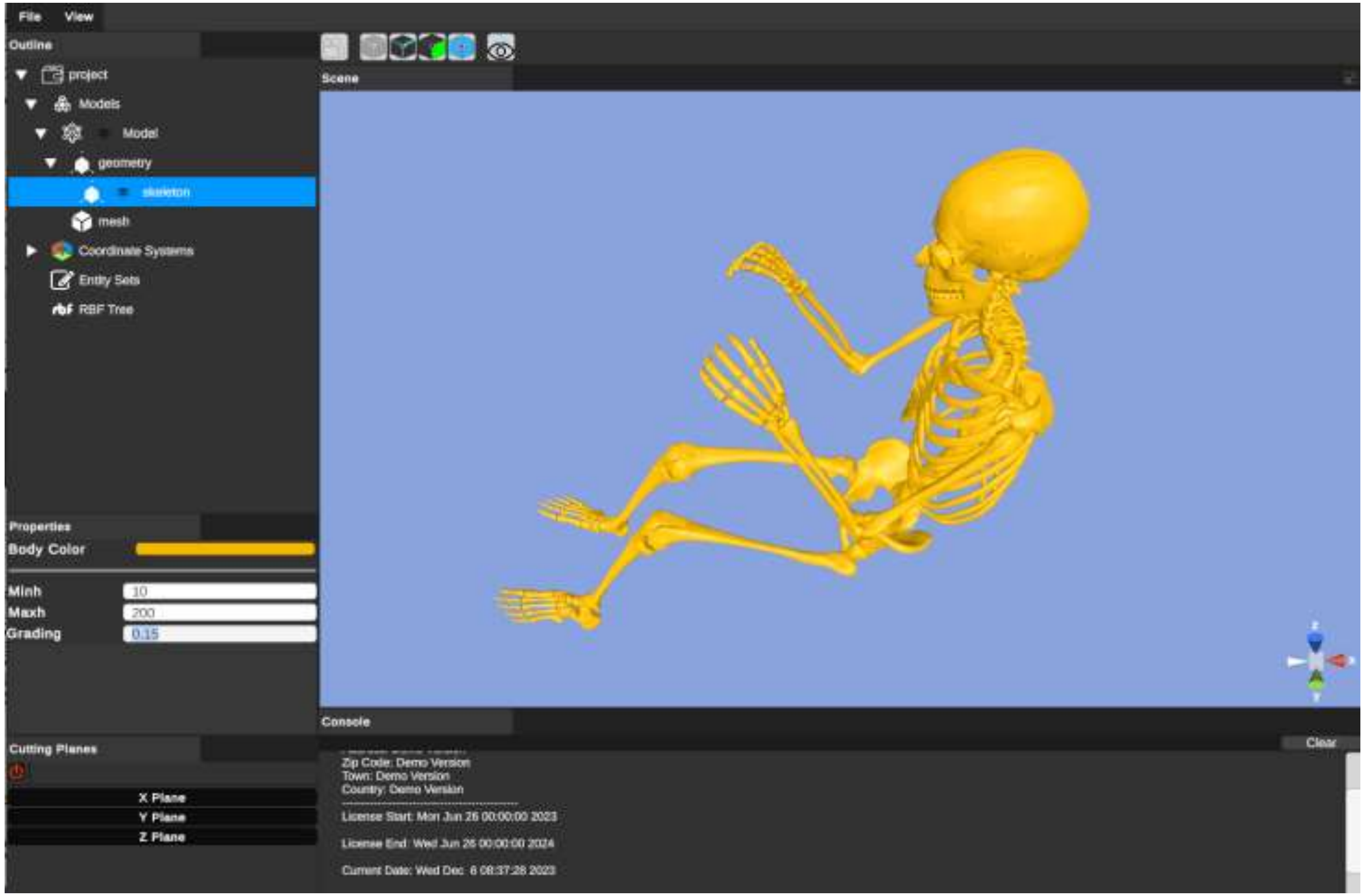
Ansys RBF Morph products

- An RBF mesh morphing solution fully embedded in **Ansys**
  - **RBF Morph Fluids** – an Add On for Fluent
  - **RBF Morph Structures** – an ACT App for Mechanical
- Full integration with **optiSLang** and **Twin Builder**
- Support for **LS-DYNA** and **APDL**



https://www.rbf-morph.com/wp-content/uploads/2023/05/RBFMorph_Brochure.pdf

New RBF Morph Stand Alone

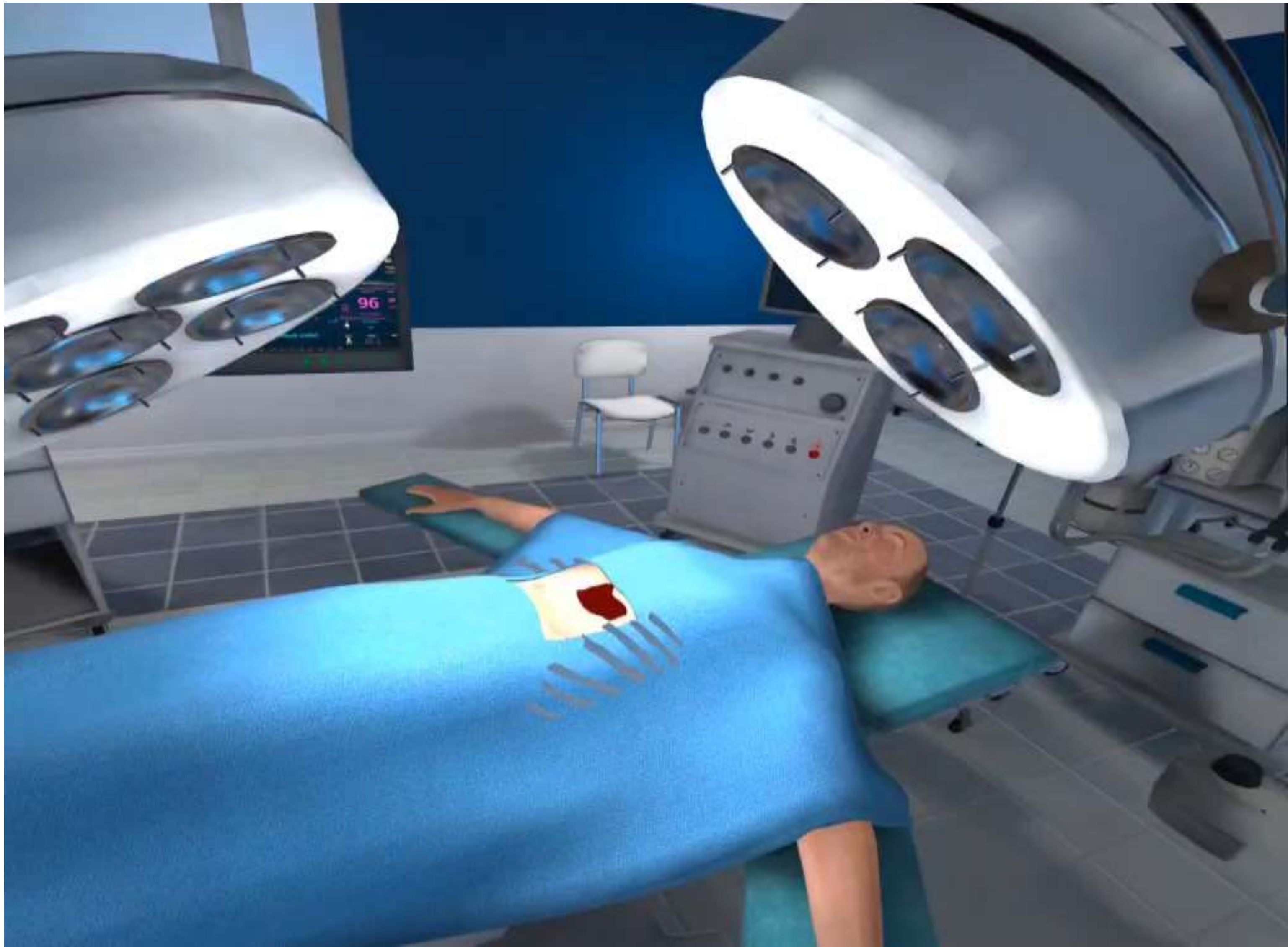


- To be released in 2024
- Read in **STL, STEP**
- **Unity - OpenCascade**
- Solver independent process that supports **many mesh formats**
- **Scriptable** via python

Next step?

A complete solution to deliver interactive digital twins with AR/VR custom UI

- FMU are translated to ARM
- Meta Quest 3
- Input parameters are controlled by hands



Conclusions

- Medical Digital Twins are feasible today!
- The **In Silico** path, i.e. MDT driven by high fidelity simulations, is ready and requires
  - Patient specific data (from images)
  - State of the art multi-physics simulation
  - Reduced order models and advanced mesh morphing
- A clear **business model** is required
  - Public funds are today the major resource
  - Certification is complex
- We are moving in the right direction and there is **mainstream focus** on Medical Digital Twins

Thank you!

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