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Occupant-Specific Safety Assessment Using a Parametric THUMS Model

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Agenda

- About us – past and running projects
- Radial Basis Functions – Data Science and Geometrical Intelligence
- Parameter-based and parameter-free shape optimisation
- Parametric THUMS: Occupant Specific Morphing
- Conclusions

EU-funded research projects 2013-2025

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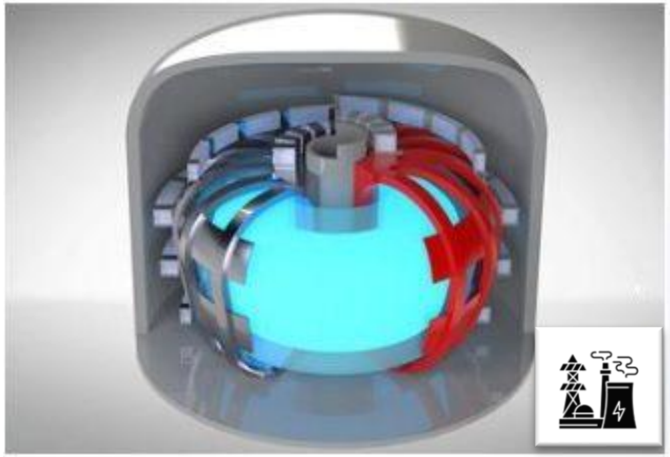
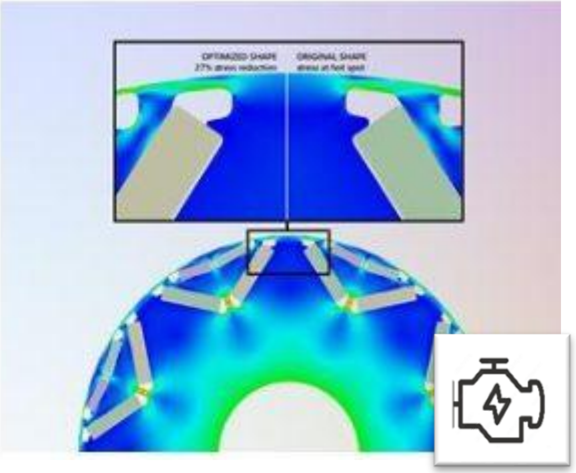
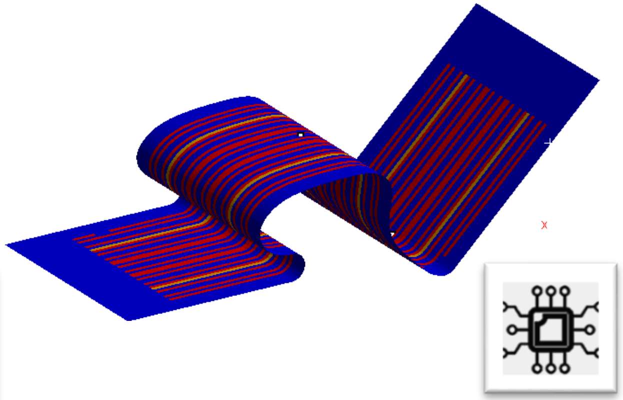
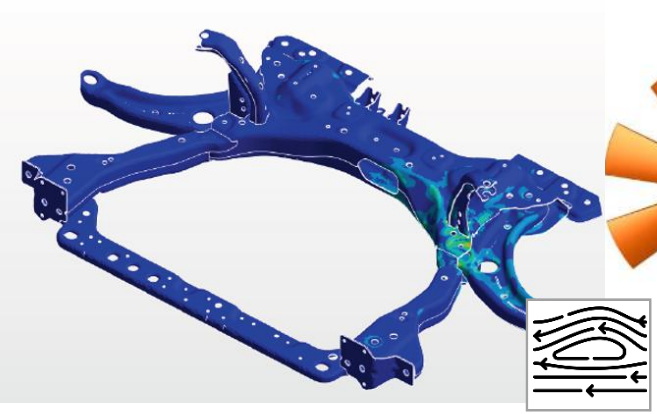
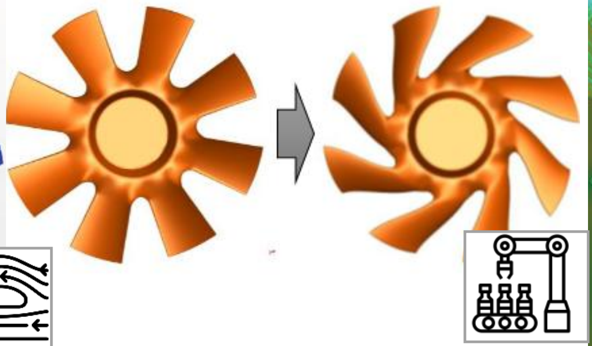
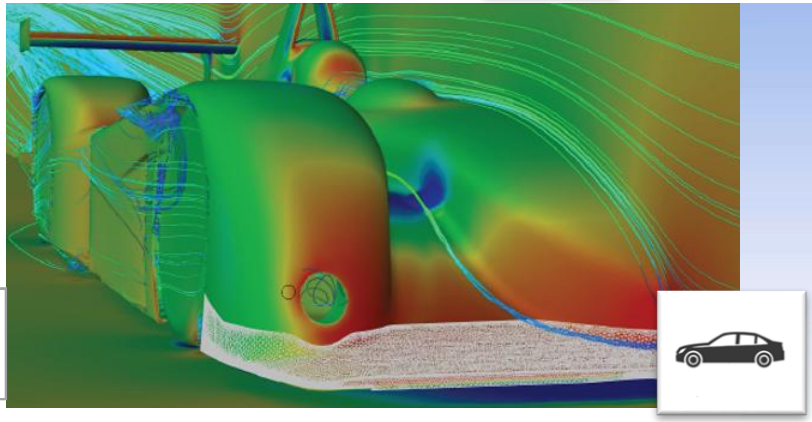
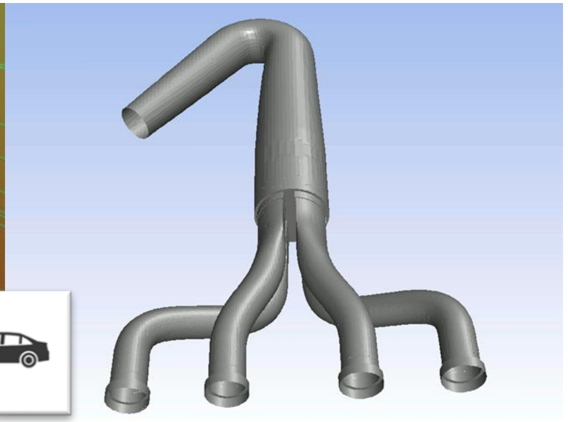


Radial Basis Functions

Data Science and Geometrical Intelligence

Radial Basis Functions (RBF) in a nutshell

source points

radial basis

$$s(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i \cdot \varphi\left(\left\|\mathbf{x} - \mathbf{x}_{\mathbf{k_i}}\right\|\right) + h(\mathbf{x})$$

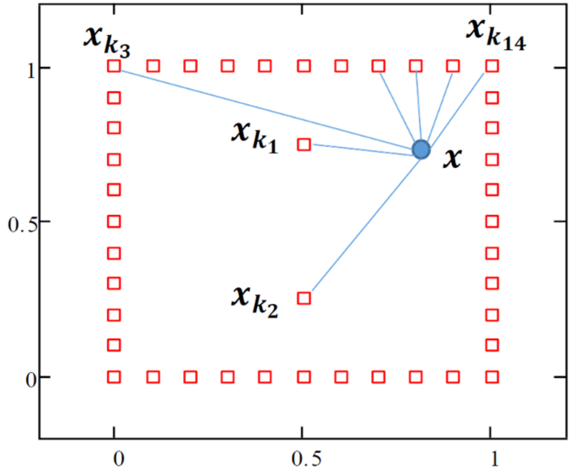
polynomial
e.g. $h(\boldsymbol{x}) = \beta_1 + \beta_2 x + \beta_3 y + \beta_4 z$

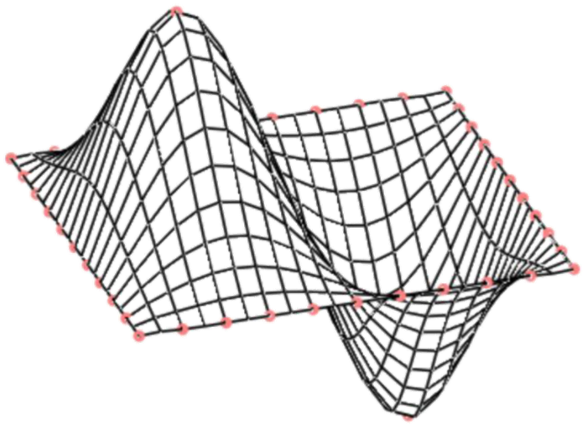
weight

shift of the target point to the i-th data site

RBF	φ(r)
Spline type (Rn)	r^n, *n odd*
Thin plate spline	$r^n \log(r)$ *n even*
Multiquadratic (MQ)	$\sqrt{1+r^2}$

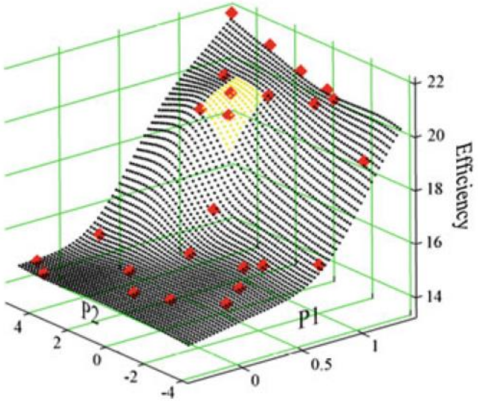
RBF are a very powerful mathematical tool able to interpolate **everywhere** in the $\mathbb{R}^n$ space a function given at scattered **source points**

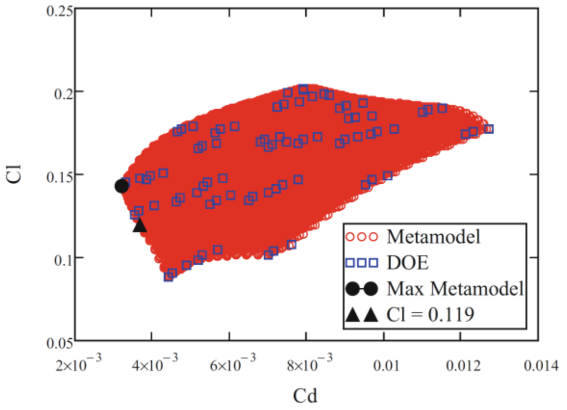




Interpolators in multi-dimensional spaces

- **Data science** problems
  - **Inference** $\mathbb{R}^n \Rightarrow \mathbb{R}^m$
  - Gaussian RBF is recognized as the "RBF neural network"
  - Useful for **surrogates** in **optimization**
- 3D space manipulation (shape deformation, data mapping)
  - Field manipulation is a key enabler for **geometric intelligence**
  - RBF mapping for multi-physics interfaces and as a "morphing extender"



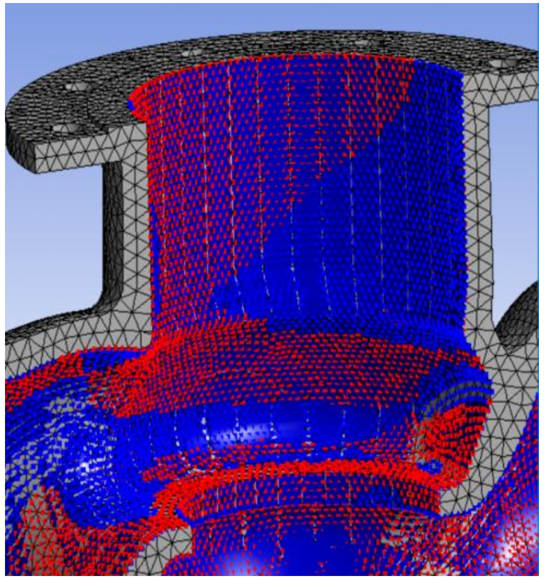


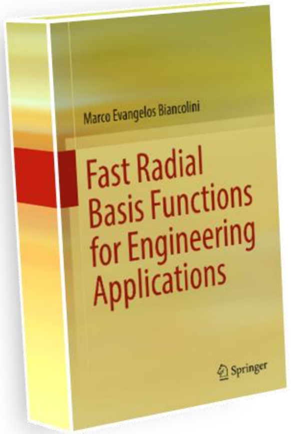
Shape optimization

Parameter-based and parameter-free workflows

RBF Mesh Morphing

- We adopt **Radial Basis Functions** (RBF) to drive mesh morphing (smoothing) from a list of source points and their displacements
  - Surface shape changes
  - Volume mesh smoothing
- RBF are recognized to be one of the **best mathematical tool** for mesh morphing

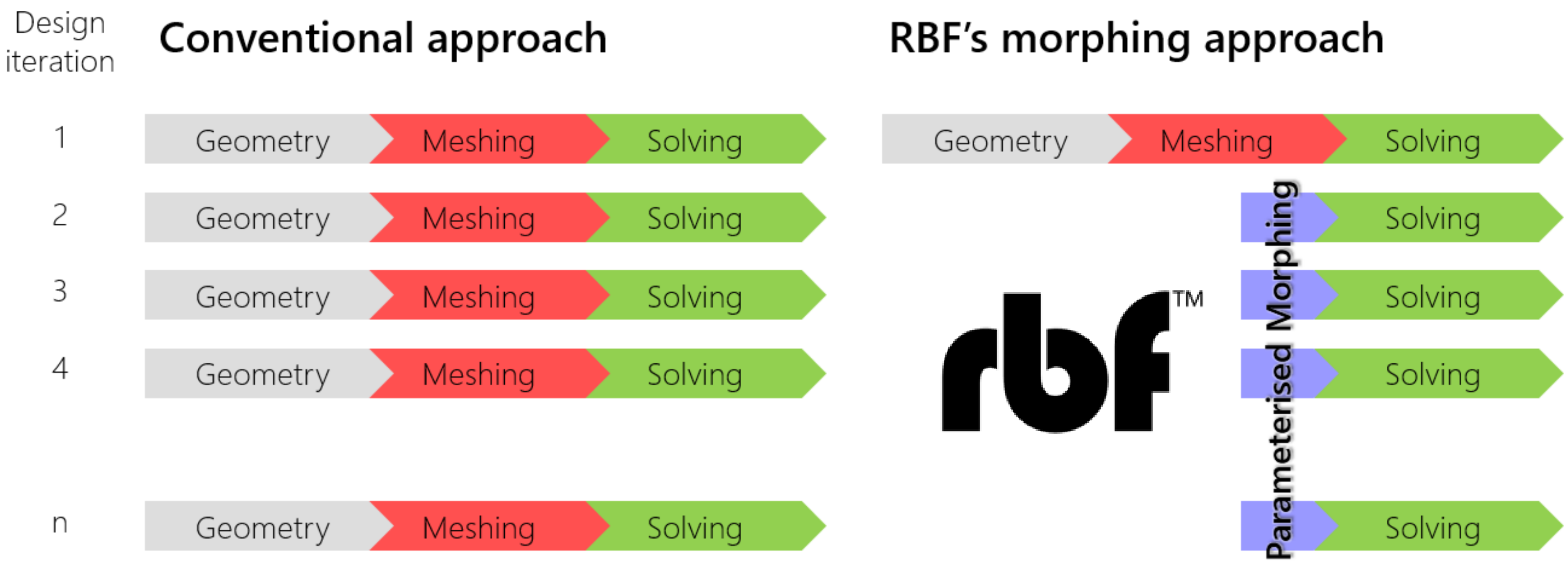




$$\begin{cases} s_x(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^x \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{s_i}\|) \\ s_y(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^y \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{s_i}\|) \\ s_z(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^z \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{s_i}\|) \end{cases}$$

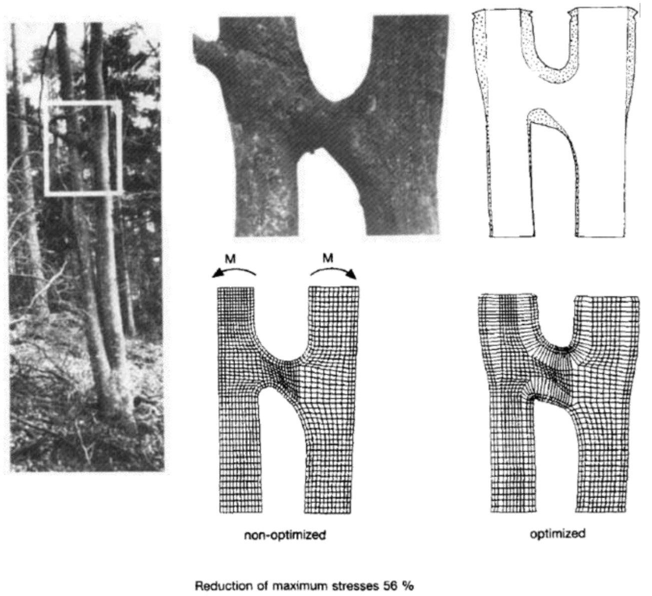
Parameter-based shape optimization

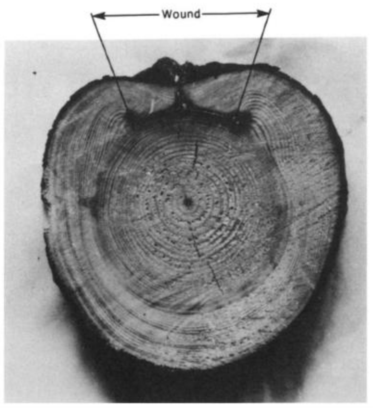
- Morphing is a **key enabler** for optimization and Digital Twins
- The turnaround time of the optimization is usually **reduced by a factor five** (weeks becomes days)

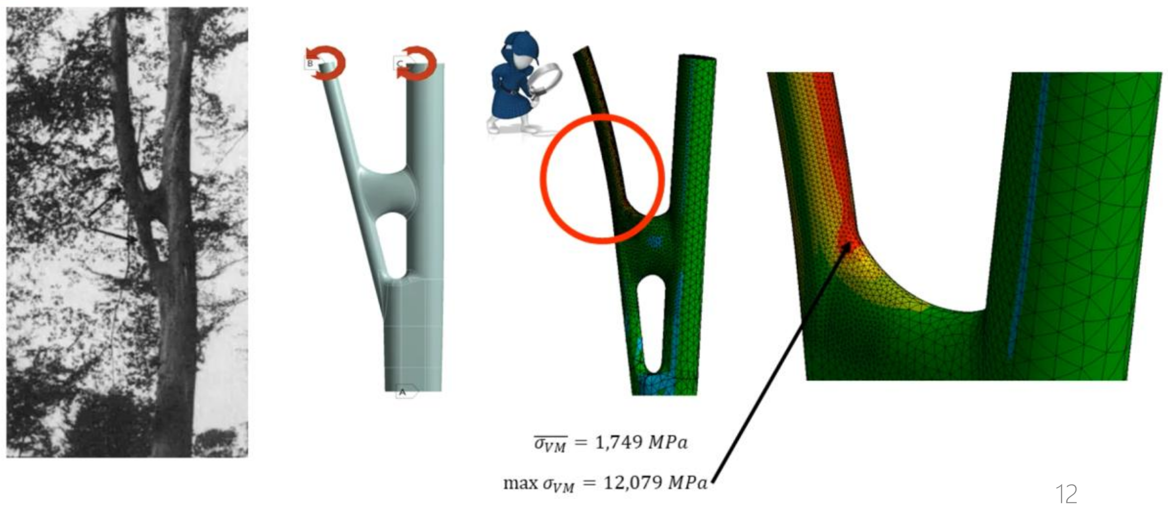


BGM Background

- **BGM** approach is based on the observation that **biological** structures growth is driven by **local** level of **stress**.
- Bones and trees' trunks are able to **adapt the shape** to mitigate the stress level due to external loads.
- The process is driven by stress **value at surfaces**. Material can be **added or removed** according to local values.
- Was proposed by Mattheck & Burkhardt in 1990







Parameter-free shape optimization

- The BGM idea is that surface growth can be expressed as a **linear law** with respect to a given threshold value:

$$\dot{\varepsilon} = k\left(\sigma_{Mises} - \sigma_{ref}\right)$$

- Waldman and Heller refined this first approach proposing a **multi peak** one:

$$d_i^j = \left(\frac{\sigma_i^j - \sigma_i^{th}}{\sigma_i^{th}}\right) \cdot s \cdot c\,, \qquad \sigma_i^{th} = max(\sigma_i^j) \text{ if } \sigma_i^j > 0 \quad \text{or} \quad \sigma_i^{th} = min(\sigma_i^j) \text{ if } \sigma_i^j < 0$$

- A different implementation is present and different **stress types** can be used to modify the surface shape:

$$S_{node} = \frac{\sigma_{node} - \sigma_{th}}{\sigma_{max} - \sigma_{min}} \cdot d$$

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Parametric THUMS

Extending Virtual Human Modelling for Personalized Safety Design

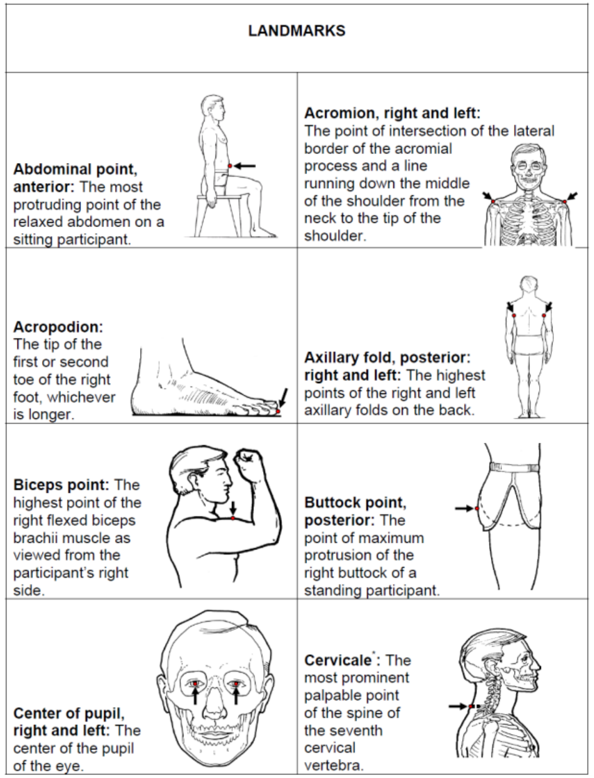
Parametric THUMS

- **T**otal **HU**man **M**odel for **S**afety (**THUMS**)
  https://www.toyota.co.jp/thums/
- Standard crash tests use a few **fixed-size THUMS** models, in particular AM50 and AM95 for adult male
- Real occupants vary in size, weight, and posture
- Injury prediction accuracy limited by model variability
- Goal: create **Parametric THUMS** able to match any occupant percentile automatically and efficiently.

Parametric THUMS

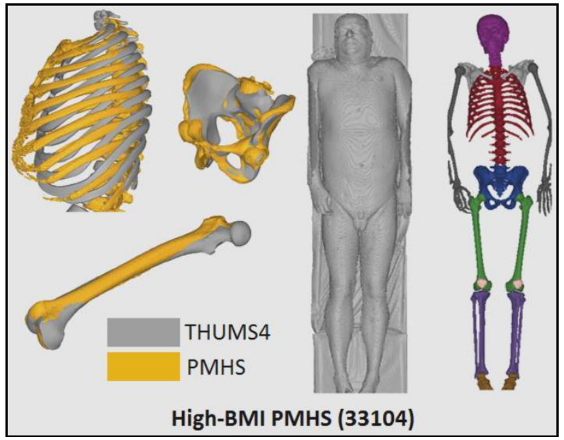
Anthropometric data

- The actual shape is defined according to 93+41 dimensions
- Statistical shape modelling based



Full body scan

- The actual shape is extracted by image segmentation
- Local control of individual districts



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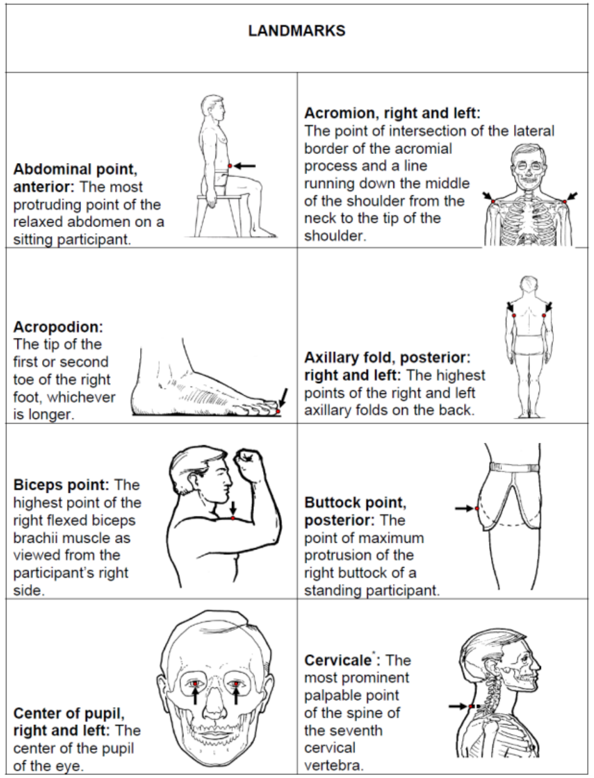

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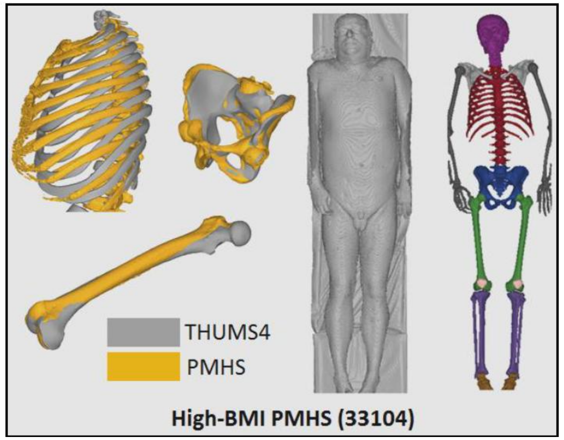
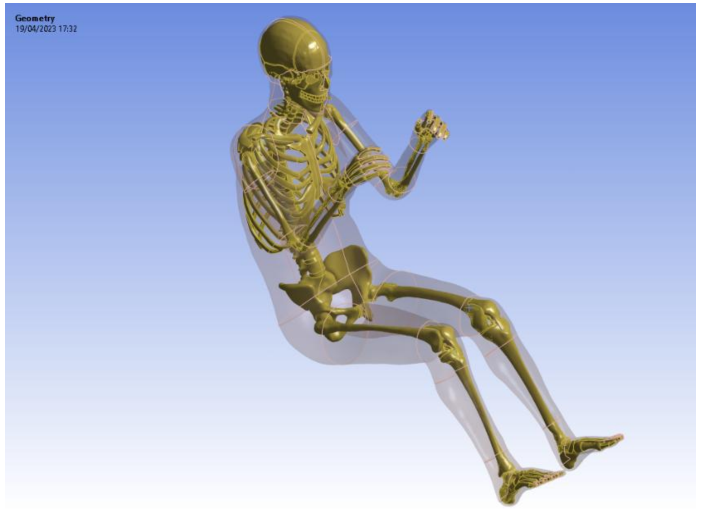
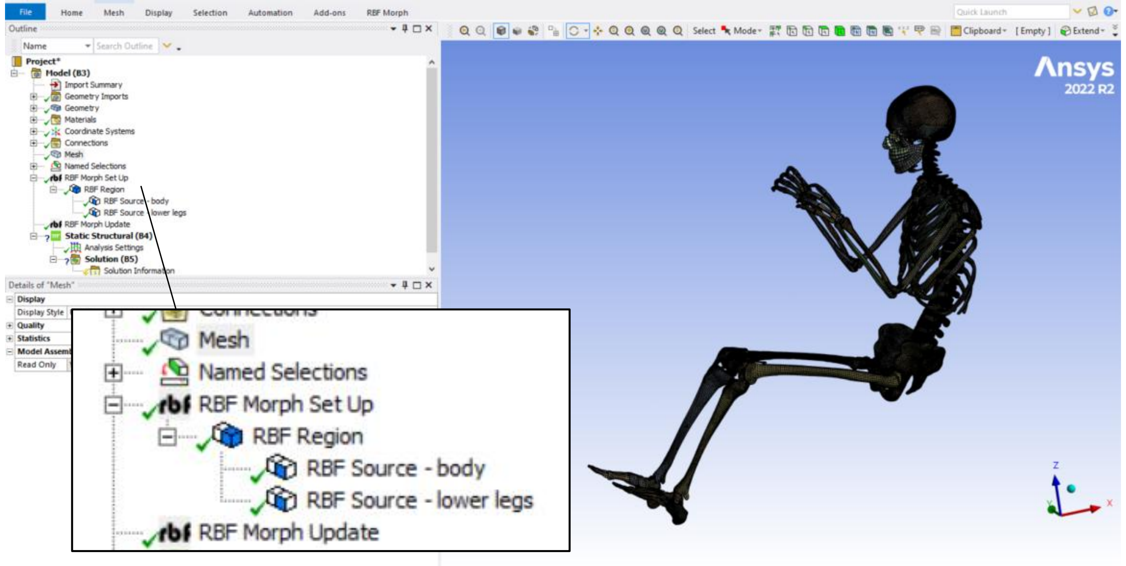


Parametric THUMS | Skin-Bones Model

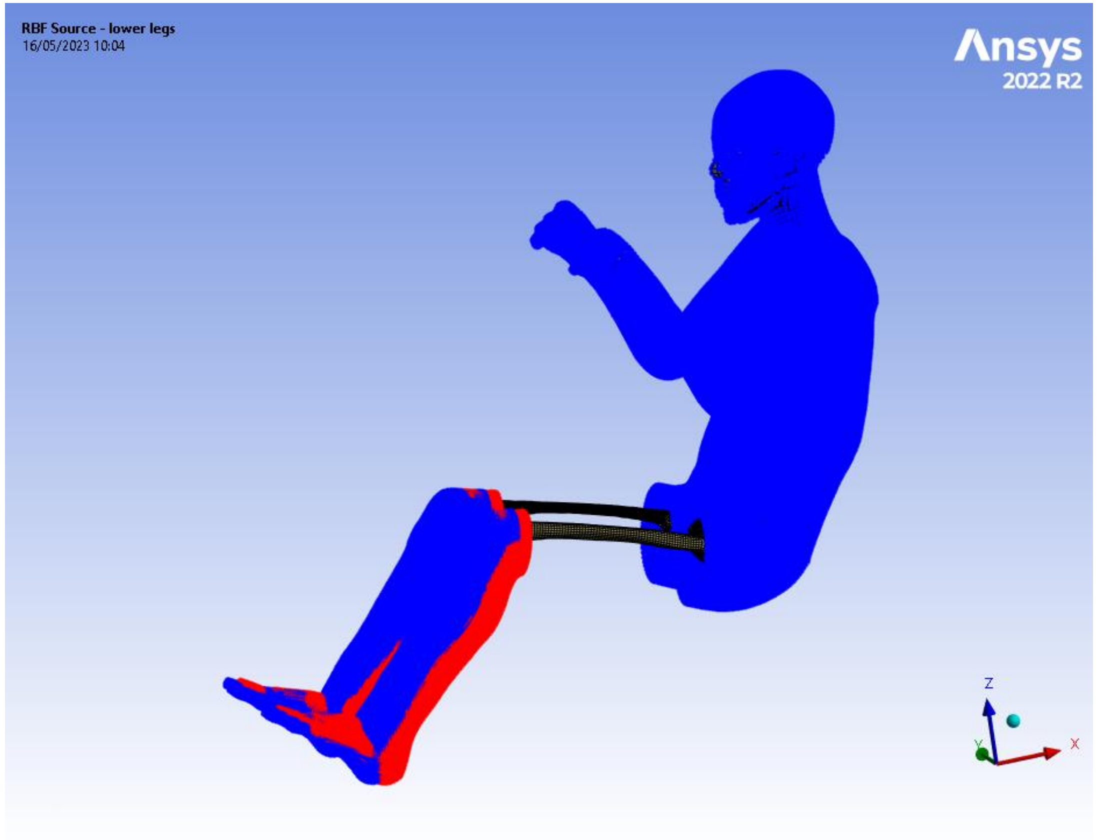
- A simplified skin-bones model is defined in the Workbench LS-DYNA environment
- RBF Sources (that could be nested) define the morphing action – we used in the first trial only the **skin** and the **bones**
- RBF Regions receive the final morphing (full **.k file** ready to run)





Parametric THUMS | Skin-Bones Model

- In this test we use the **skin** to control the morphing
- The shins and feet are moved along the thigh direction
- Thighs are shortened
- The process (66.000 RBF sources 273.000 nodes moved) takes **less than 1 minute**



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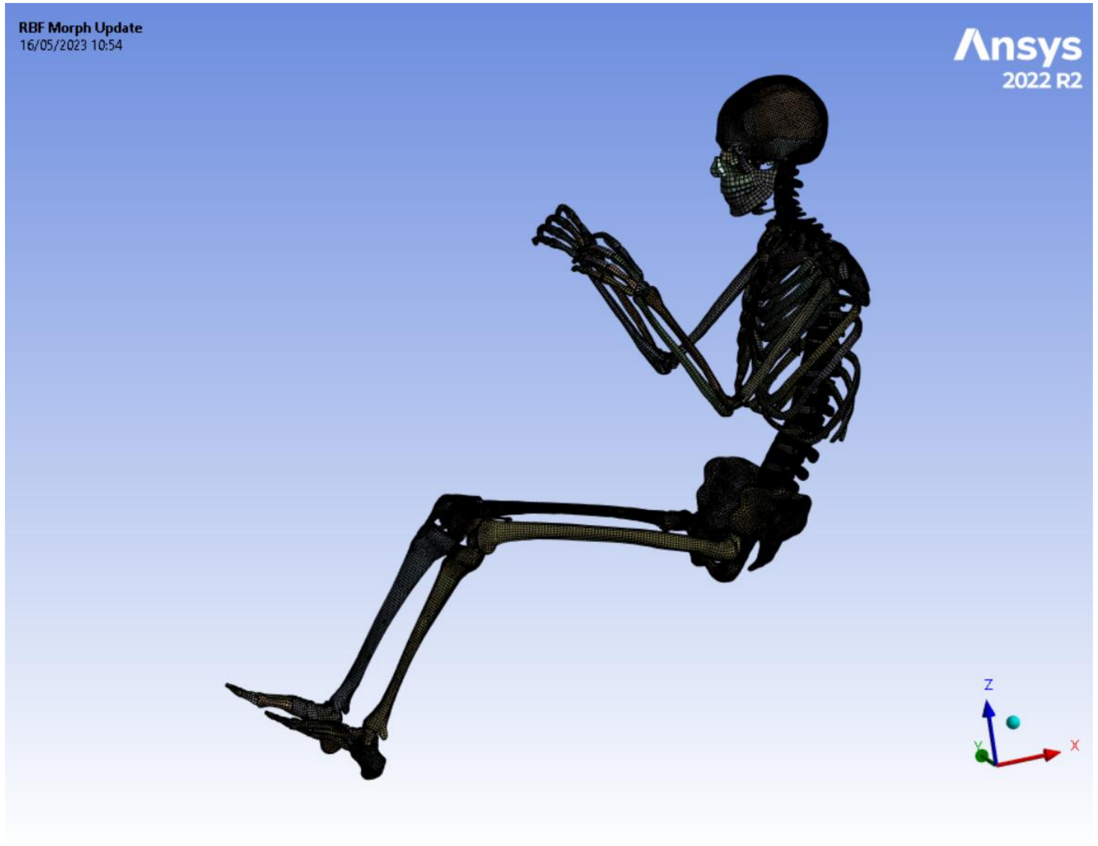

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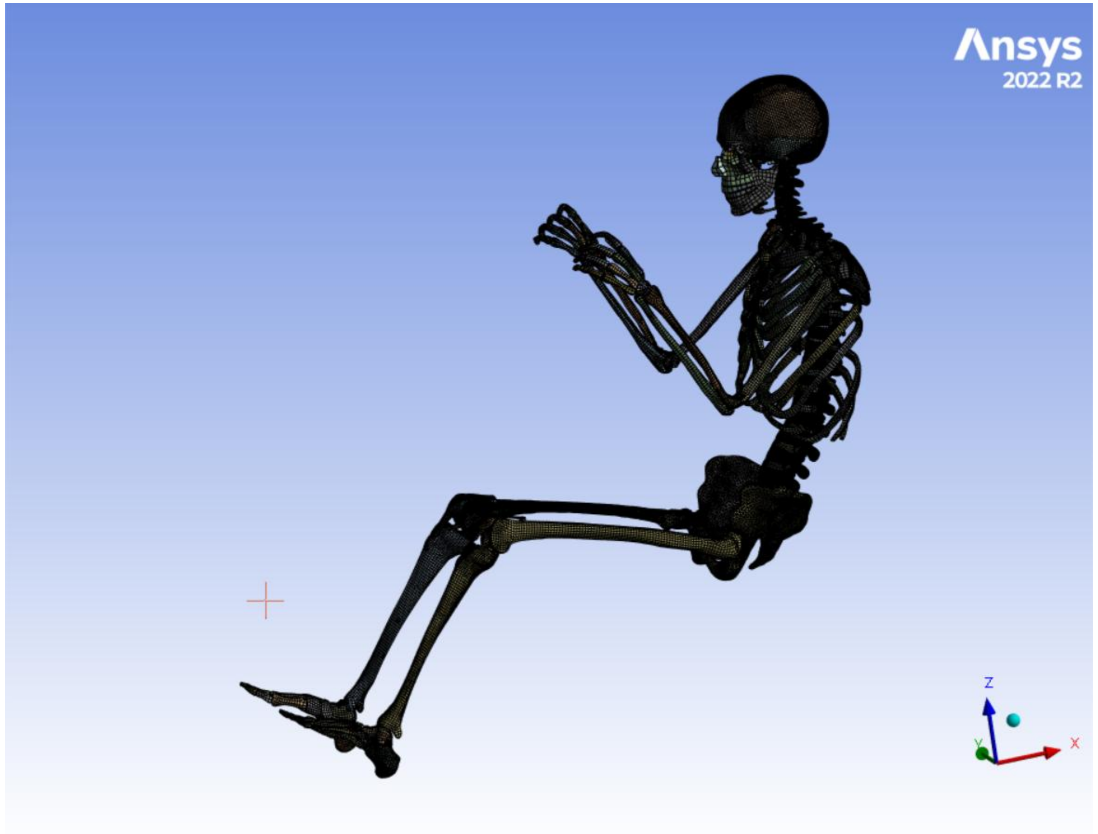
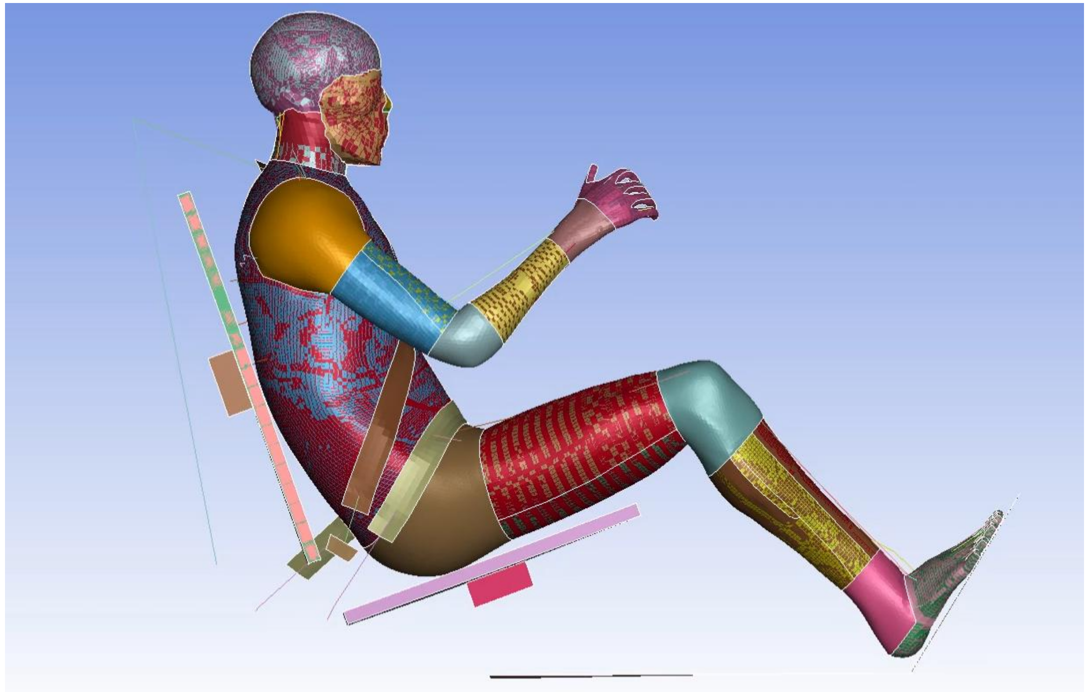


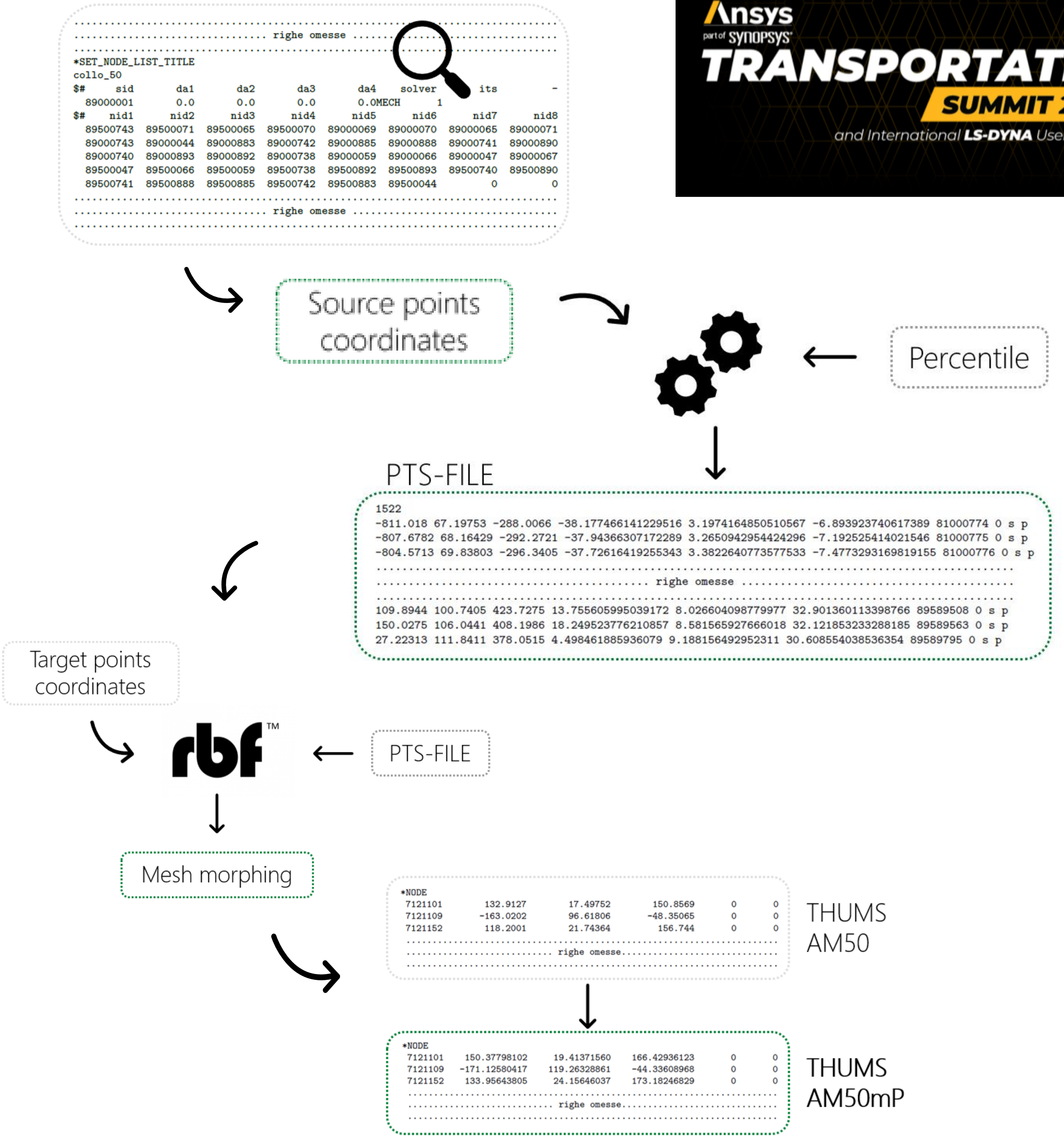
Parametric THUMS

- The morphing is performed on the THUMS Occupant AM50 full model through an **automated pyRBF procedure**
- Source points defined on anatomical landmarks (bones, skin edges)
- Homologous edges extracted from AM50 and AM95 models (via LS-PrePost)
- RBF interpolation computes 3D displacement field
- Displacements applied to the entire mesh, producing new percentile models



Parametric THUMS

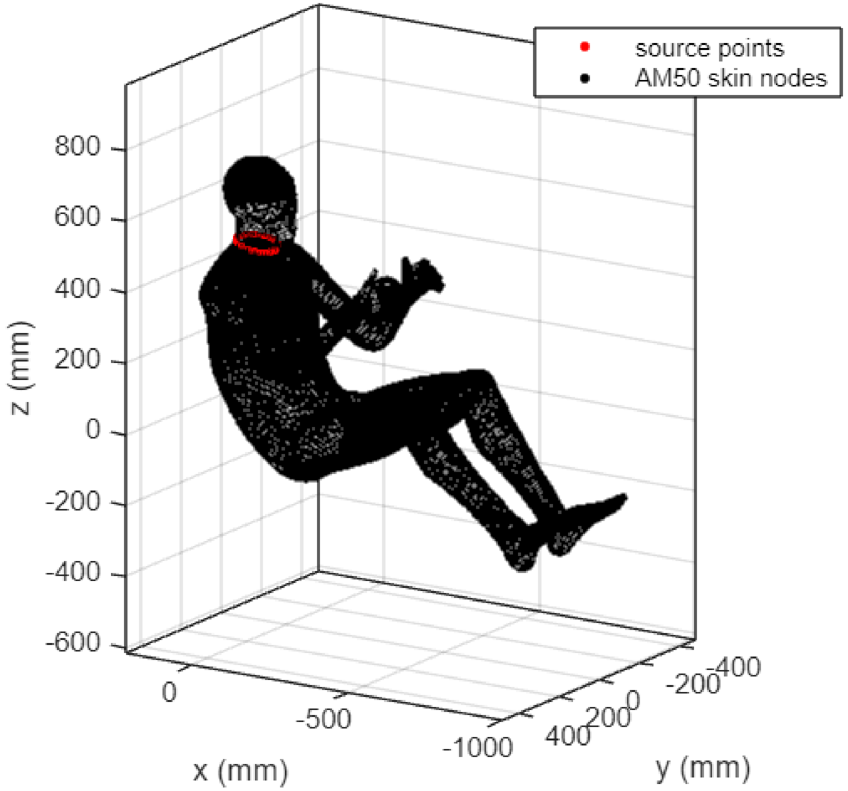
- The setup is performed in three steps:
  - **Source points** identification (LS PrePost)
  - **Mesh Morphing** (RBF Morph)
  - Morphing **verification** (Python script)



Parametric THUMS – Source Points

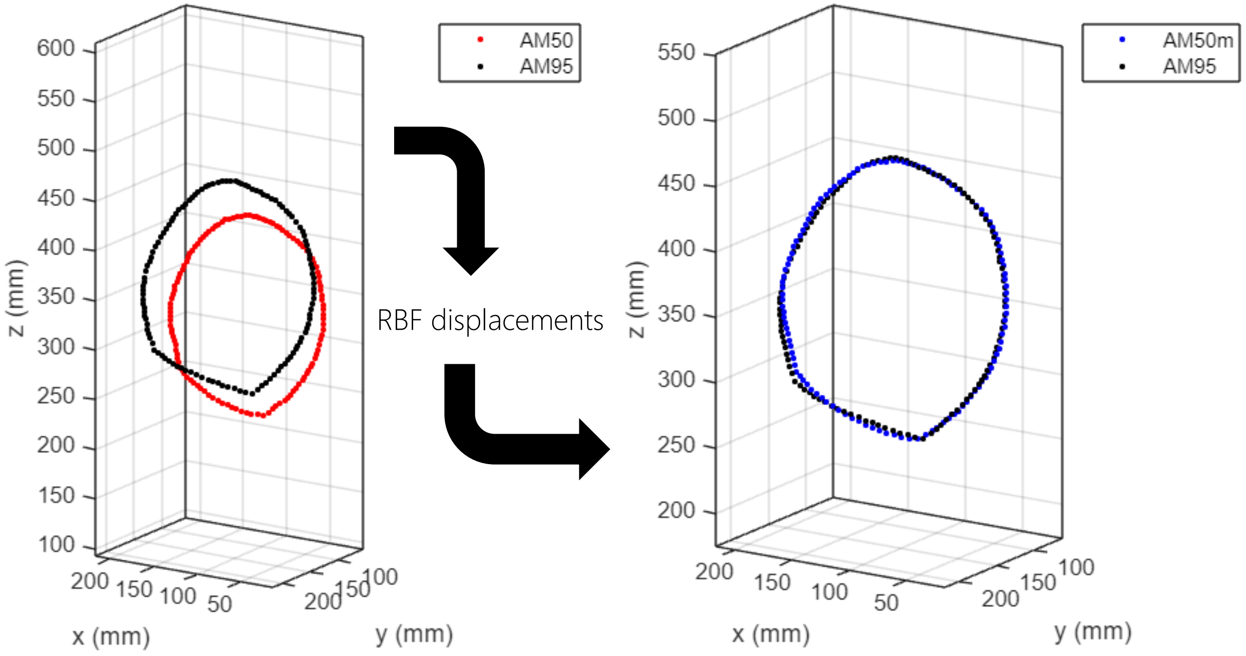
- **Source points** identification is performed in LS PrePost by exporting specific entities corresponding to the THUMS model edges on **AM50** and **AM95**

```
*SET_NODE_LIST_TITLE
collo_50
$#     sid       da1       da2       da3       da4    solver       its         -
  89000001       0.0       0.0       0.0       0.0MECH         1
$#    nid1      nid2      nid3      nid4      nid5      nid6      nid7      nid8
  89500743  89500071  89500065  89500070  89000069  89000070  89000065  89000071
  89000743  89000044  89000883  89000742  89000885  89000888  89000741  89000890
  89000740  89000893  89000892  89000738  89000059  89000066  89000047  89000067
  89500047  89500066  89500059  89500738  89500892  89500893  89500740  89500890
  89500741  89500888  89500885  89500742  89500883  89500044         0         0
```



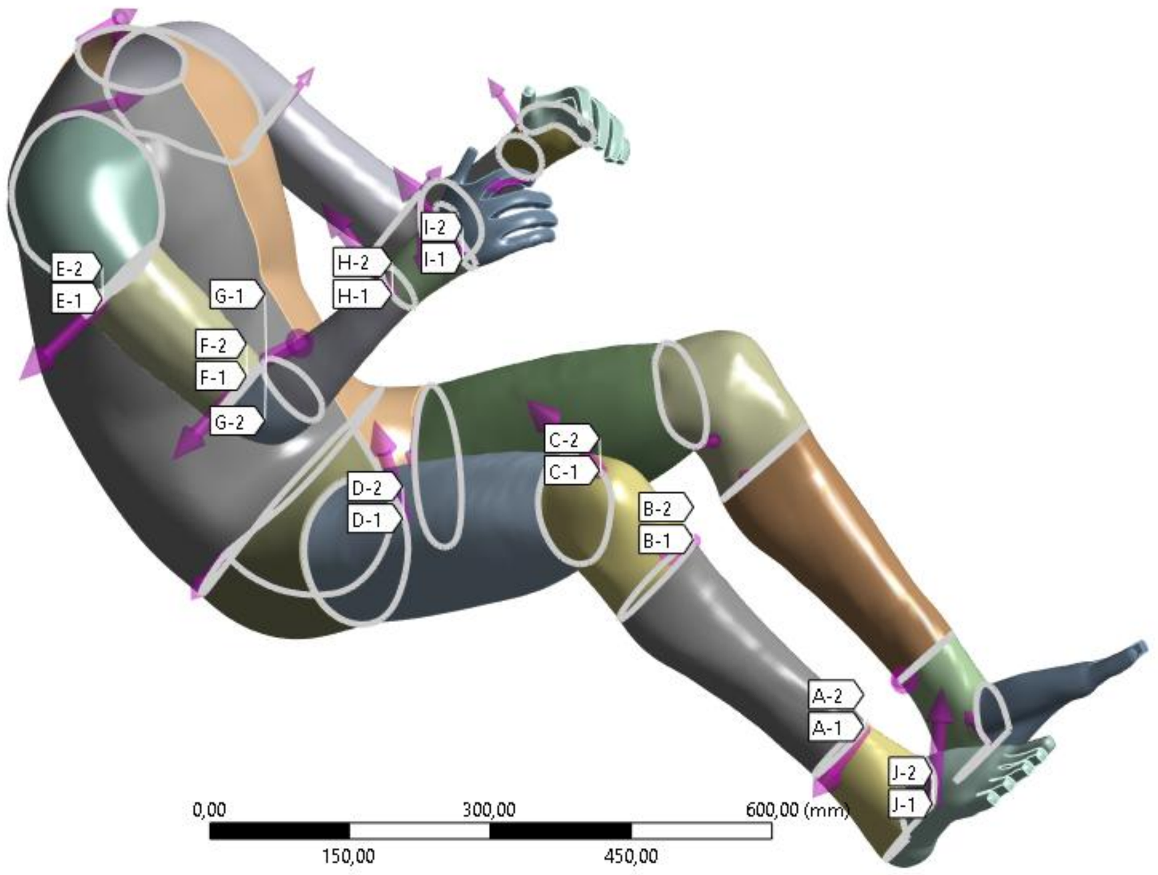
Parametric THUMS – Mesh Morphing

- RBF displacements are calculated for all the nodes on selected entities
- Based on all RBF displacements, the PTS-file is generated to take AM50 nodes to AM95 position
- This step is needed to apply displacement to the AM50 model keeping it iso-topological



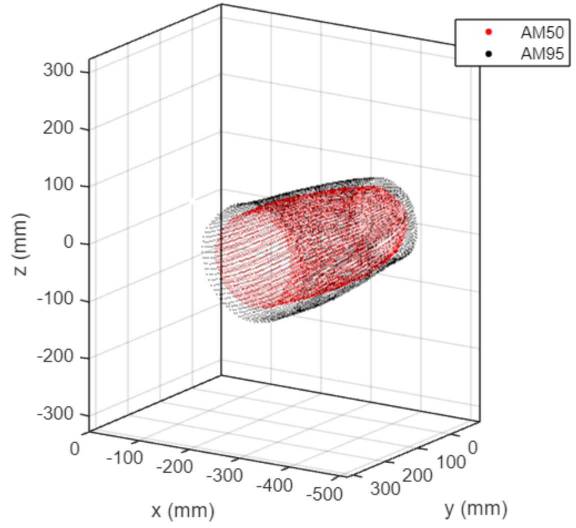
Parametric THUMS – Morphed model

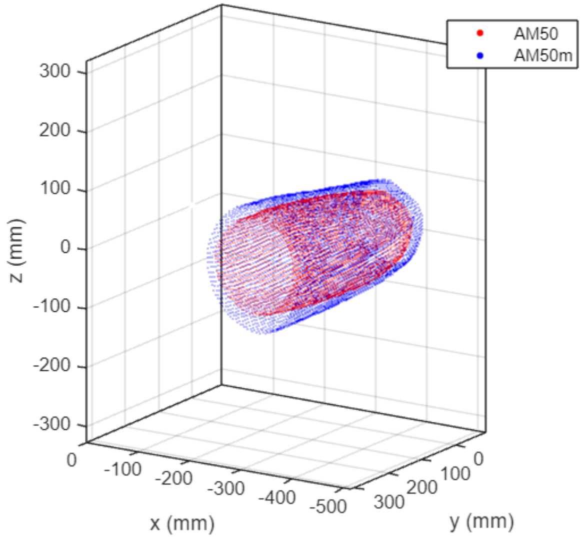
- This setup has been replicated for each region (except from the head) obtaining a morphed working case in **less than 10 seconds**
- THUMS model can be adapted to both intermediate and smaller shapes through a scaling factor

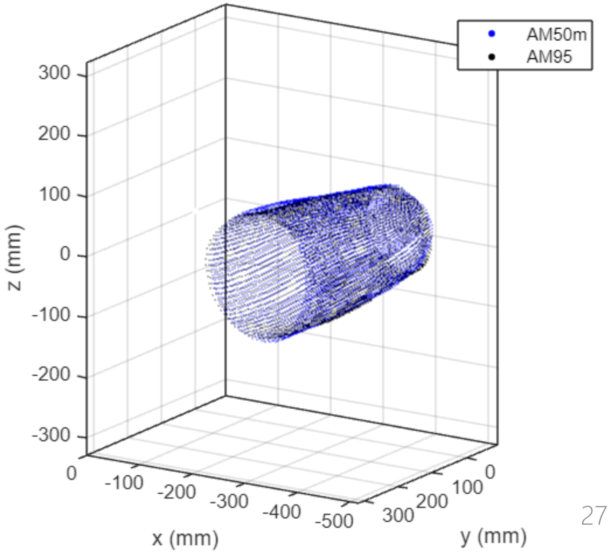


Parametric THUMS – Morphing validation

- To validate the mesh morphing a minimum **pinball mean radius** has been defined
- A comparison between original and morphed nodes on the **thigh** skin is shown in these images

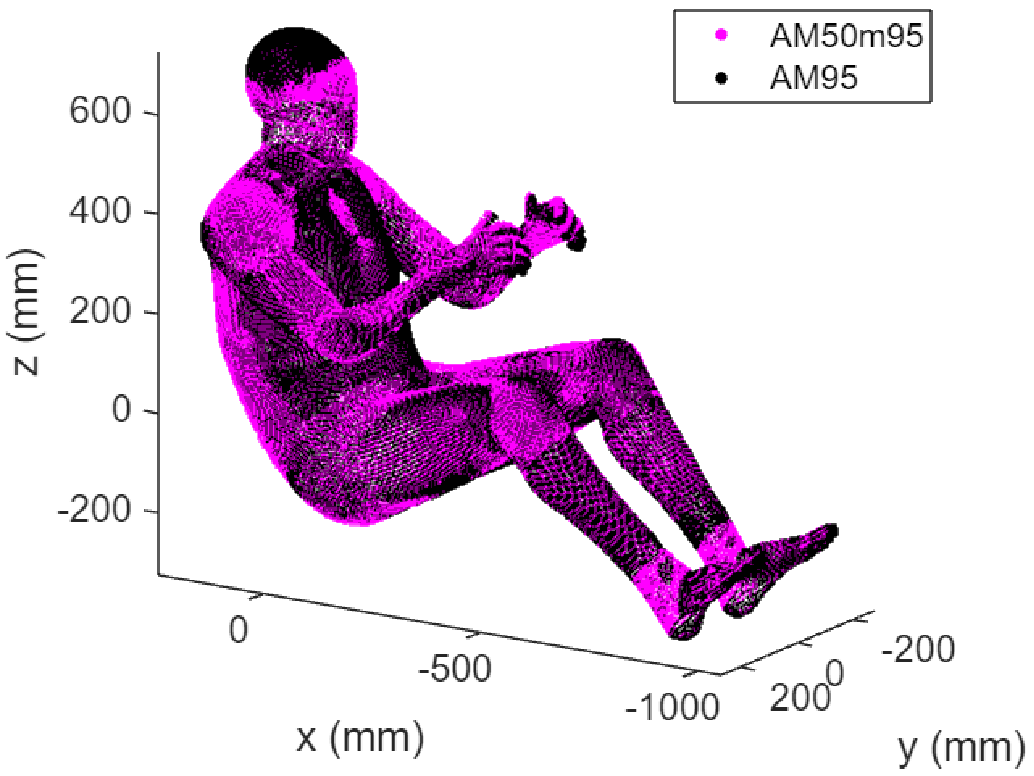


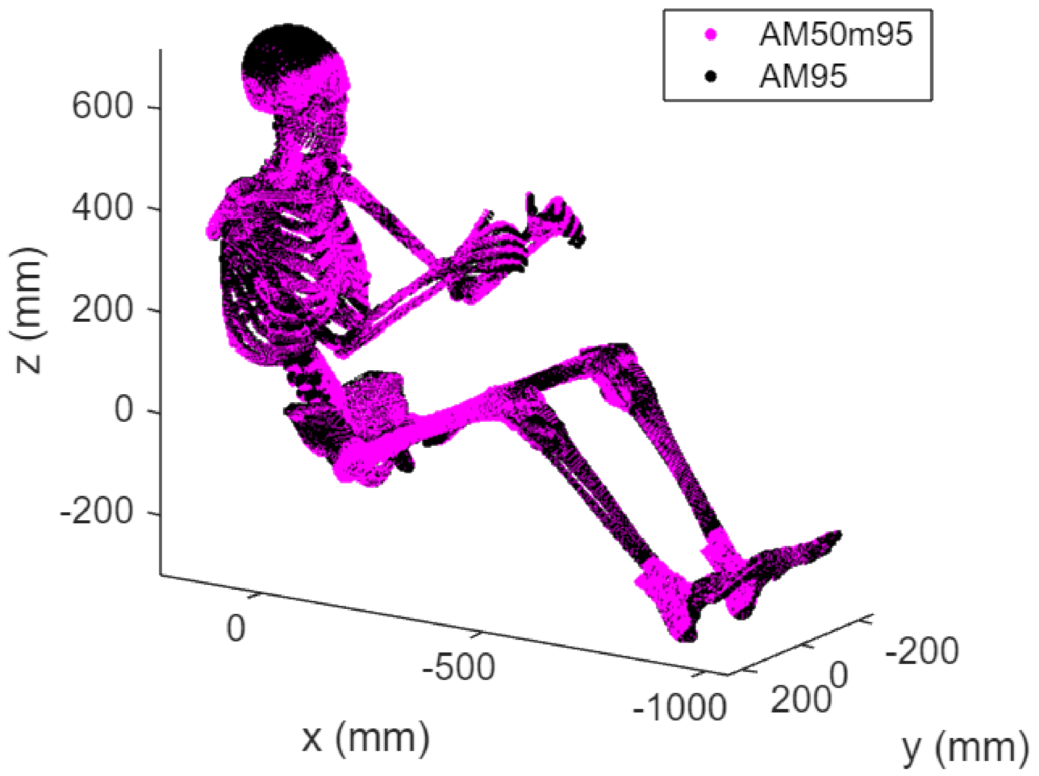




Parametric THUMS – Morphing validation

- Geometry quality: AM50m95 vs AM95

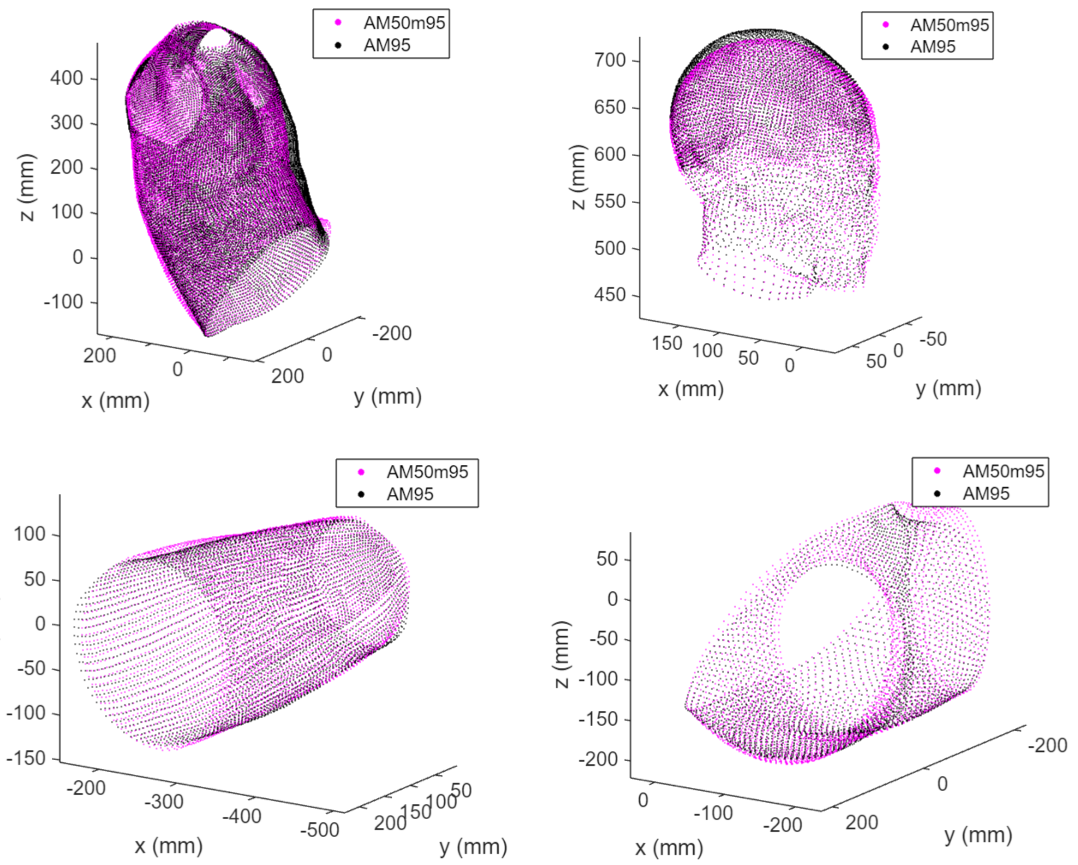




Parametric THUMS – Morphing validation

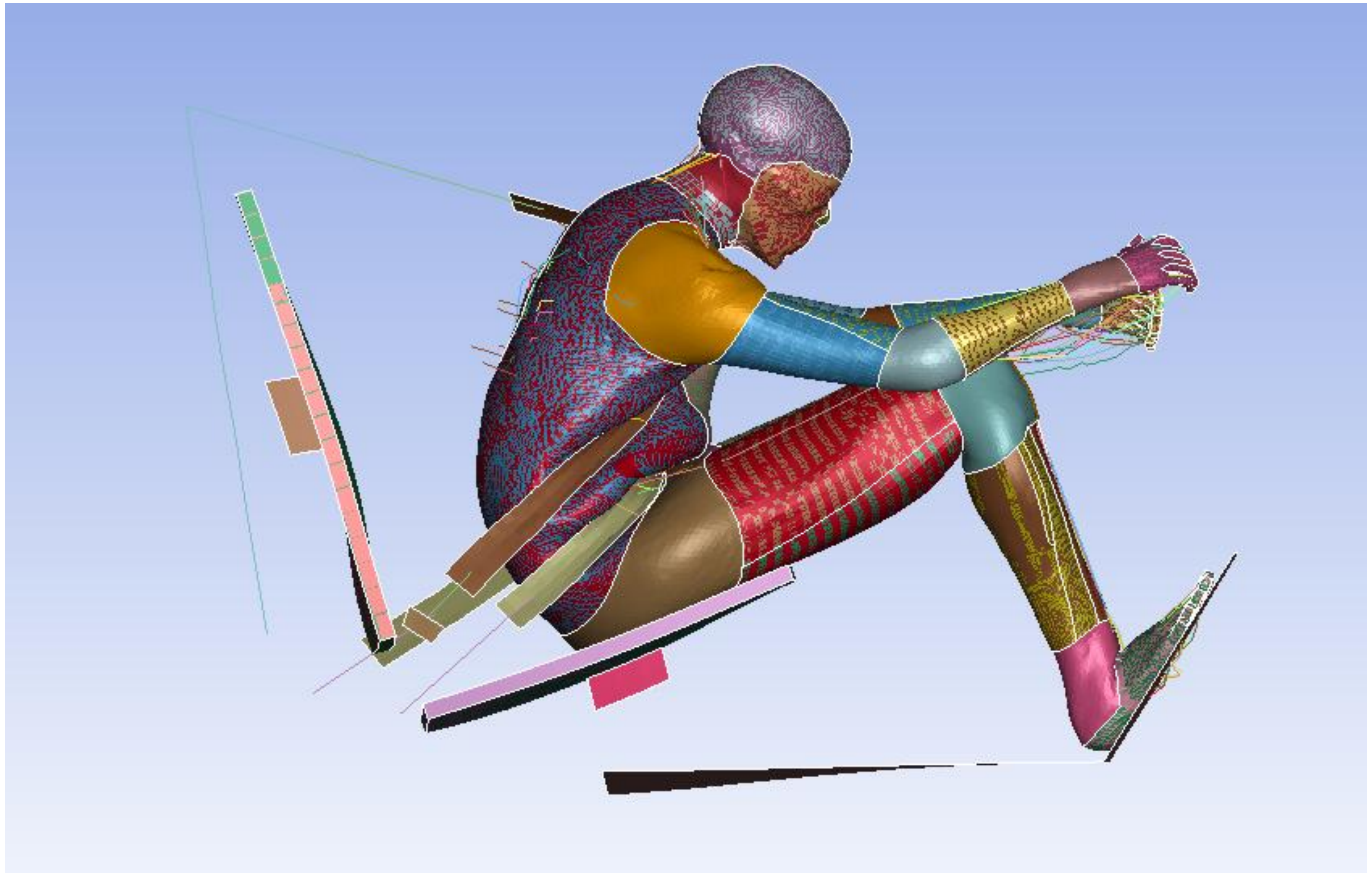
- MDA: average displacement existing between homologous zones of distinct meshes
- MDM: maximum displacement

Body areas comparison			
area	MDA *[mm]*	MDM *[mm]*	MDA/MDM
Chest	7.10	24.36	29%
Head	4.05	11.45	35%
Shoulder	3.42	9.06	37%
…	…	…	…
Shin	1.68	3.14	53%
Rib Cage	1.97	6.31	31%
Pelvis	2.48	7.52	32%
Average	3.65	8.46	34%



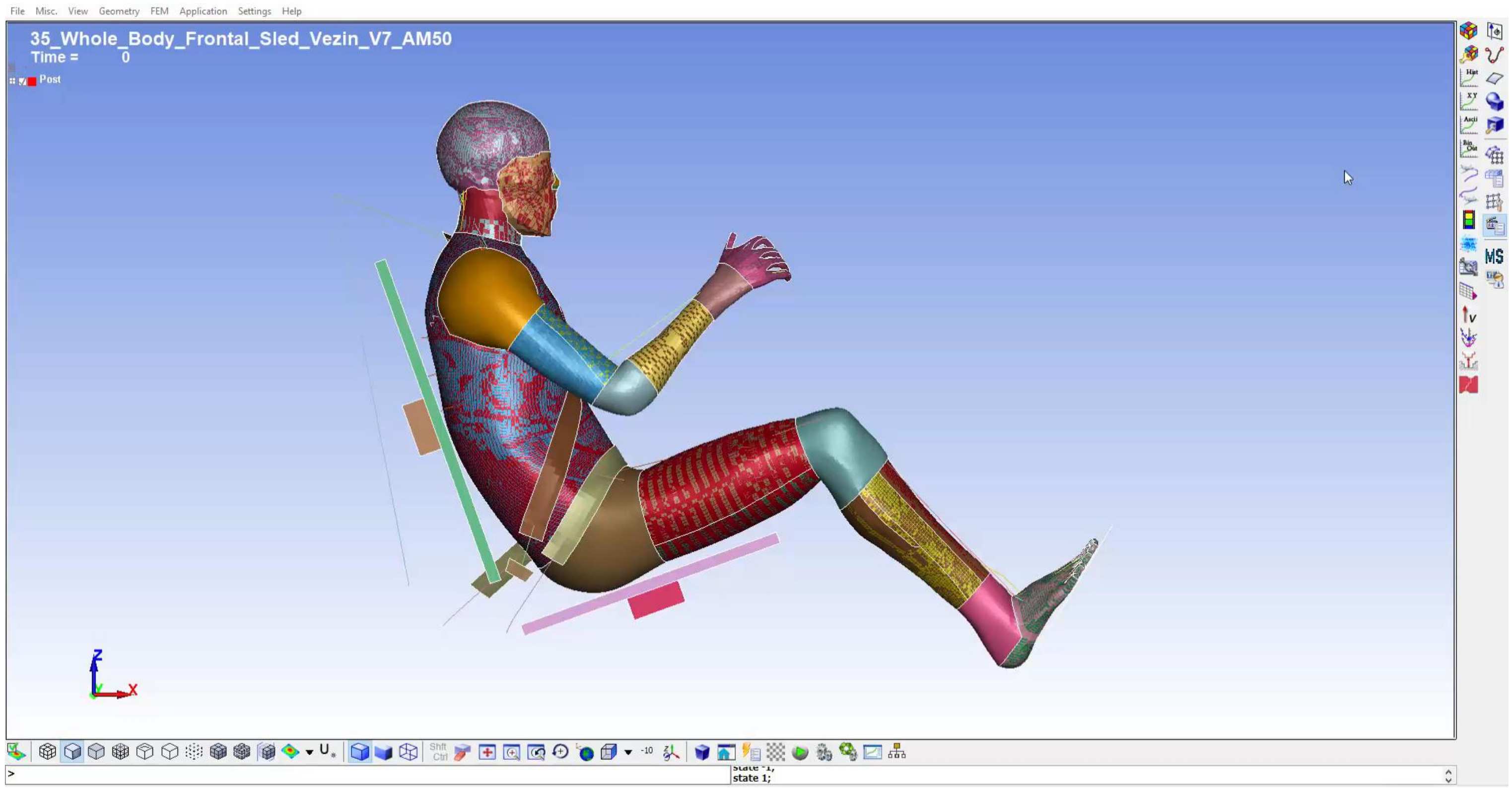
Parametric THUMS – Sled test

- The parametric THUMS is validated through **sled test simulations**
- Morphing is driven by skin and bone landmarks
- Morphed model is also verified for intermediate and smaller occupant sizes



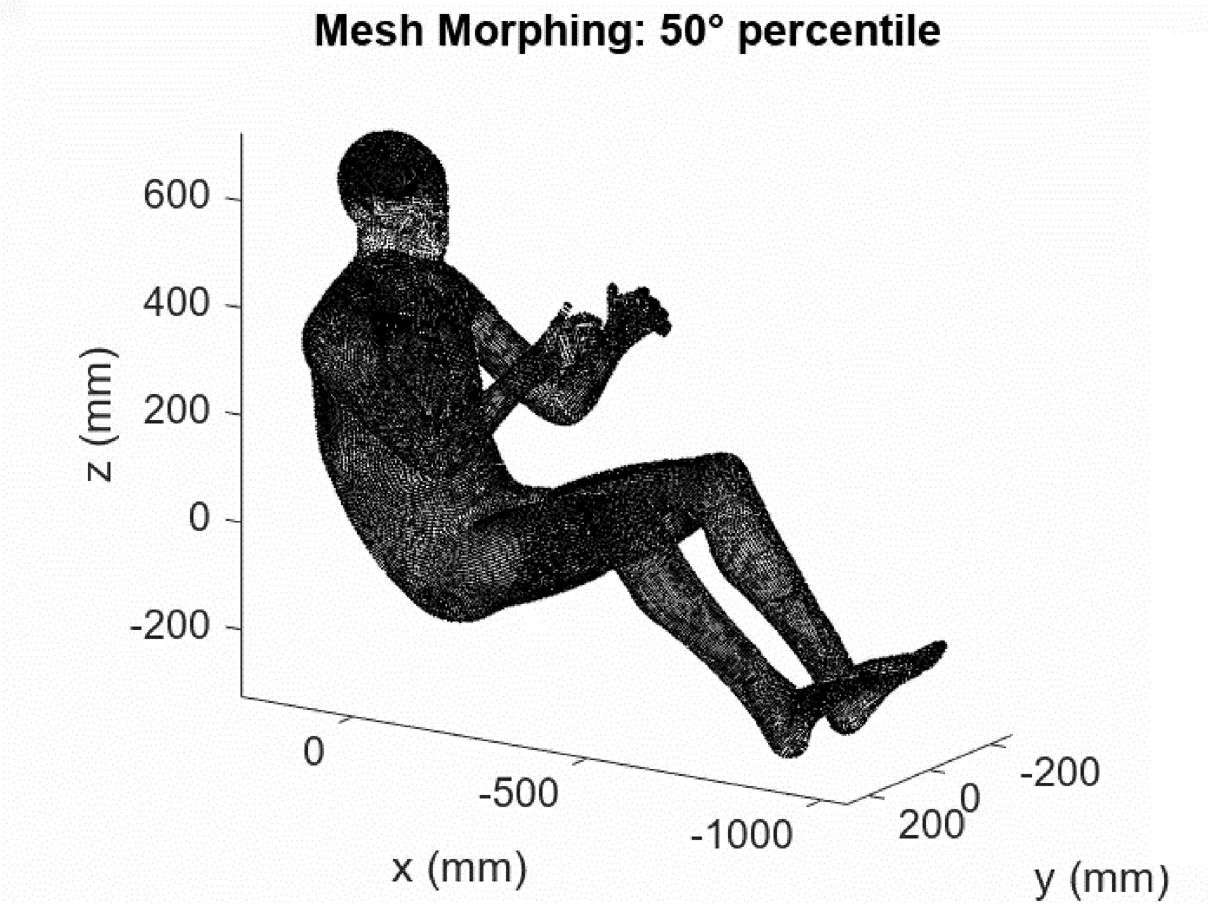
Parametric THUMS – Sled test

- AM50m95: mesh morphing to 95th percentile → 100 kg
- AM50m75: mesh morphing to 75th percentile → 89 kg
- AM50m35: mesh morphing to 35th percentile → 65 kg

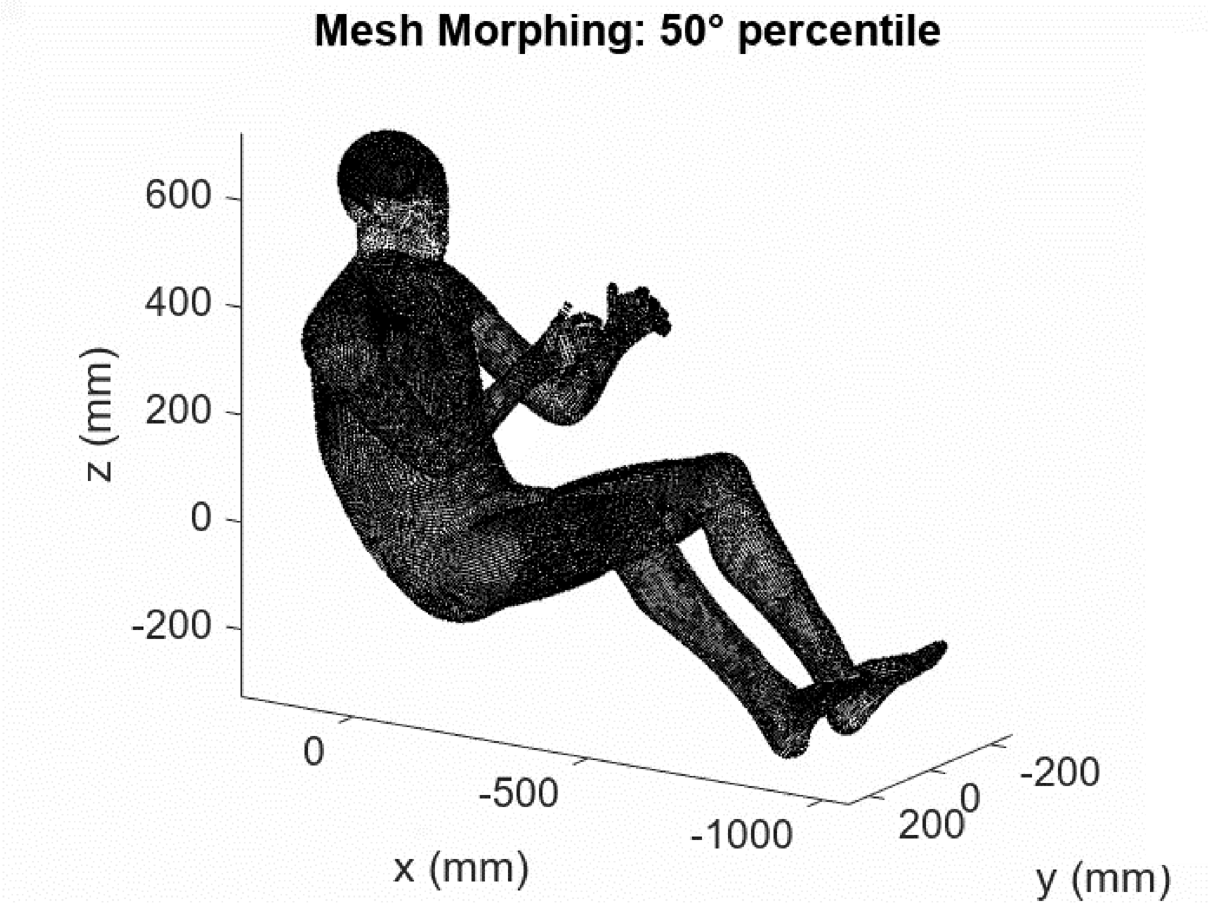


- In the video mesh morphing from AM50 to AM95 is represented

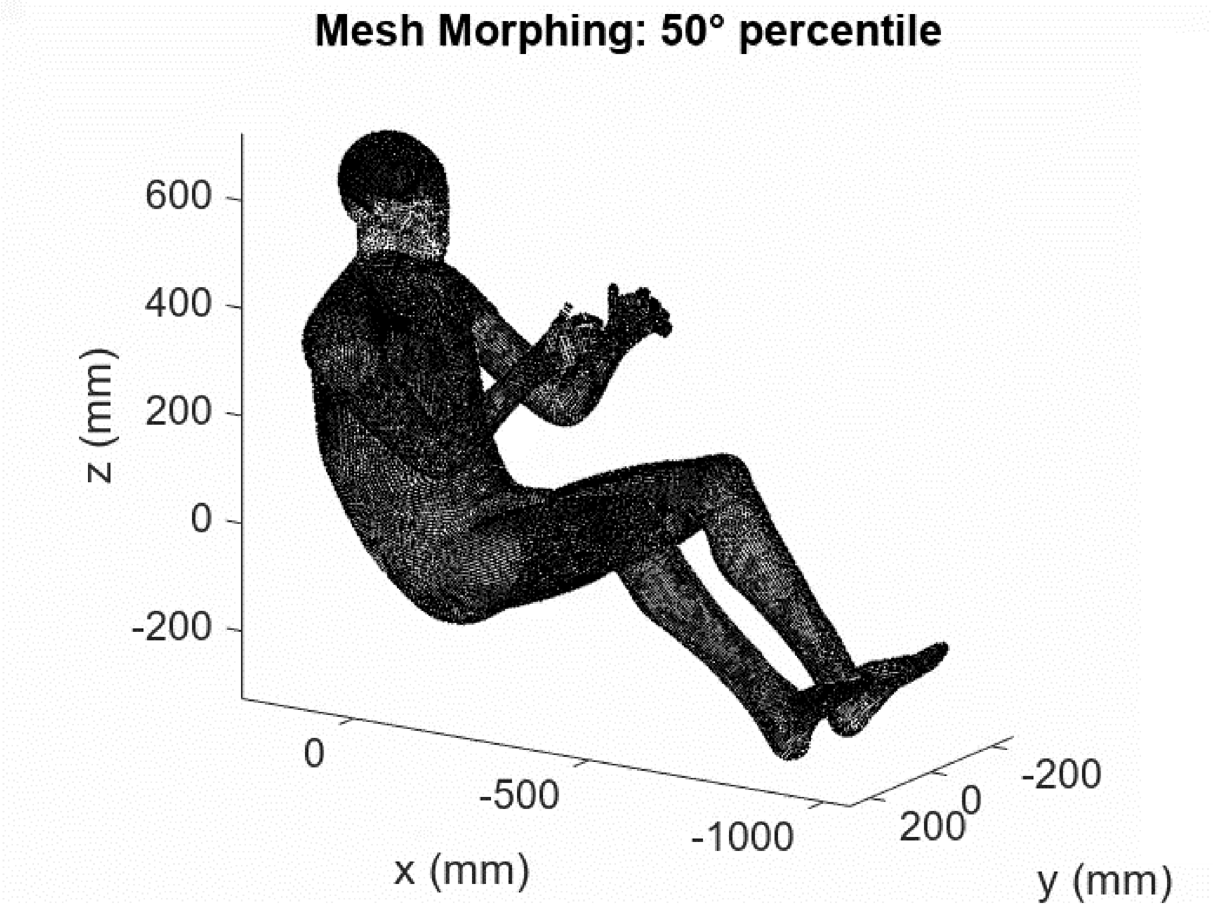
Parametric THUMS – Sled test – AM50m95



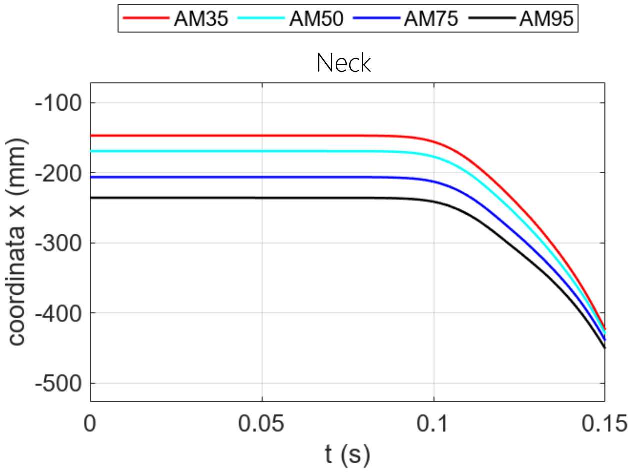
Parametric THUMS – Sled test – AM50m75

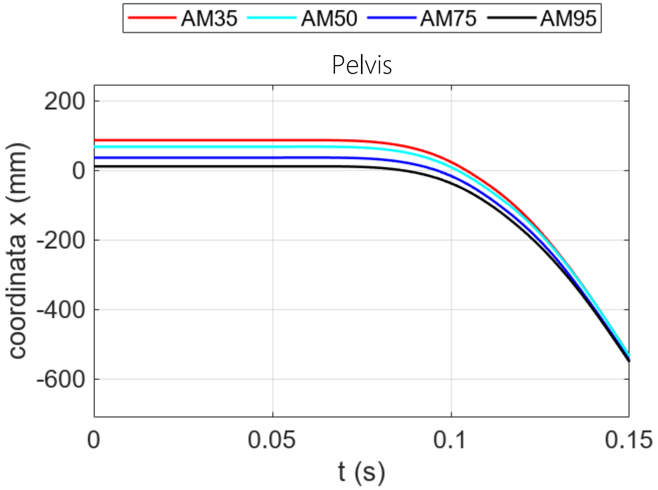


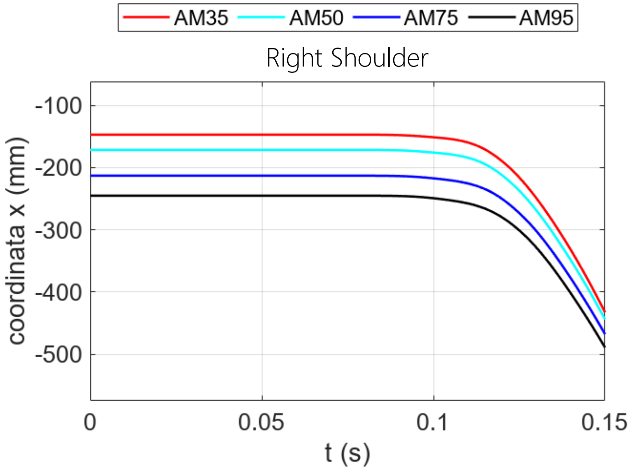
Parametric THUMS – Sled test – AM50m35

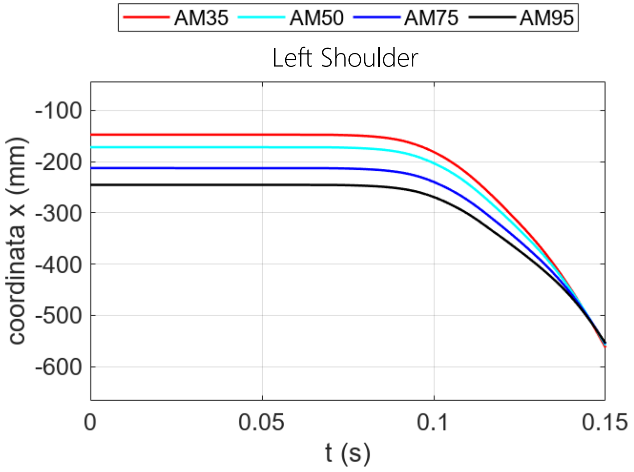


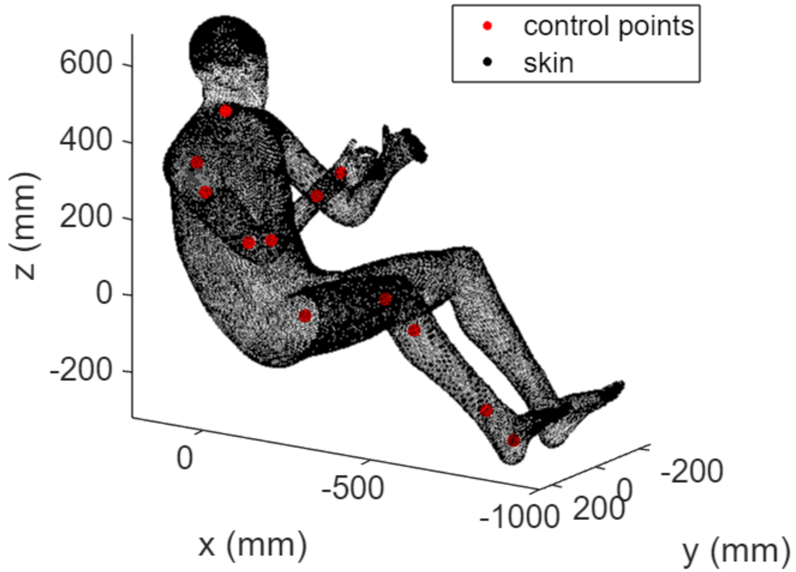
Parametric THUMS – Sled test – Kinematics









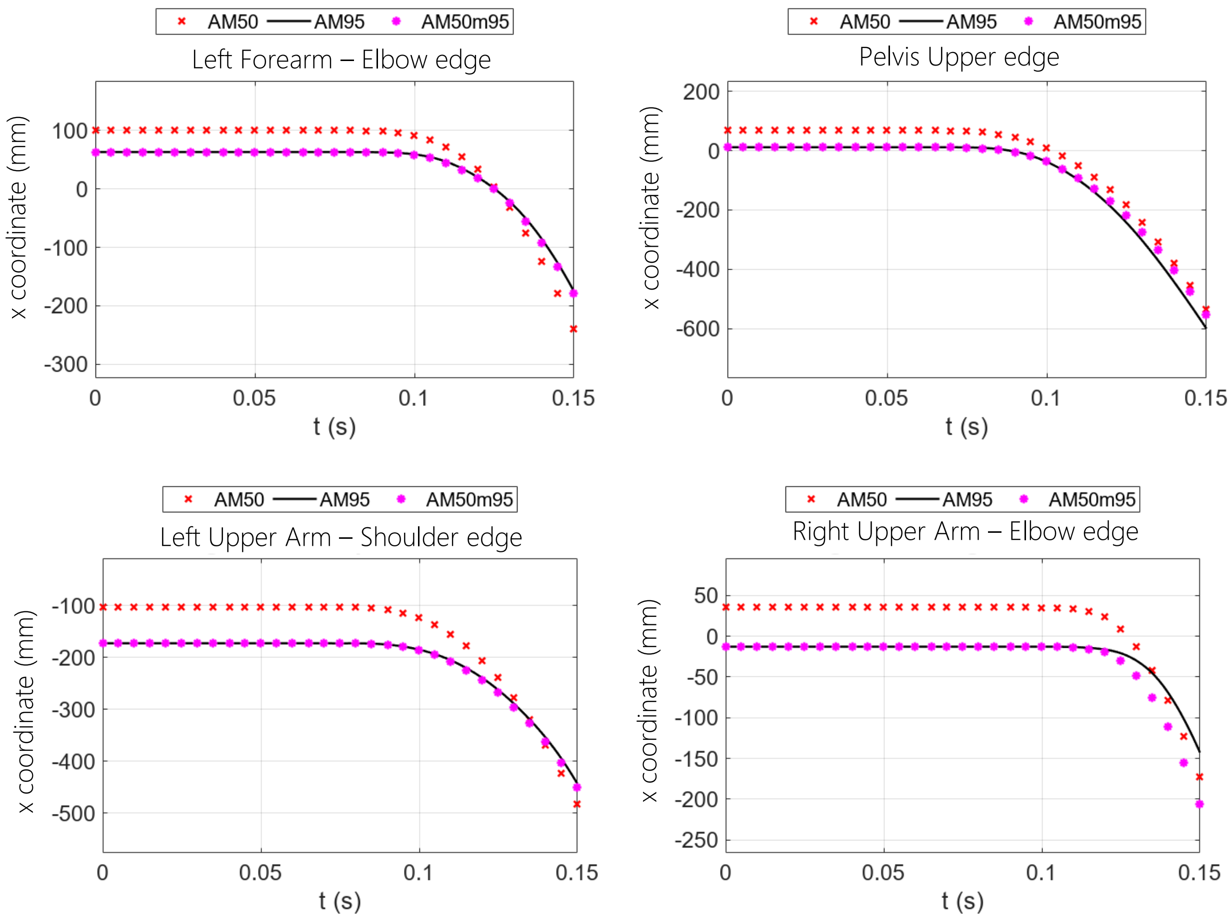


- Linear influence of morphing
- Differences introduced by the mesh morphing

0.8 mm/percentile

Parametric THUMS – Sled test – Kinematics

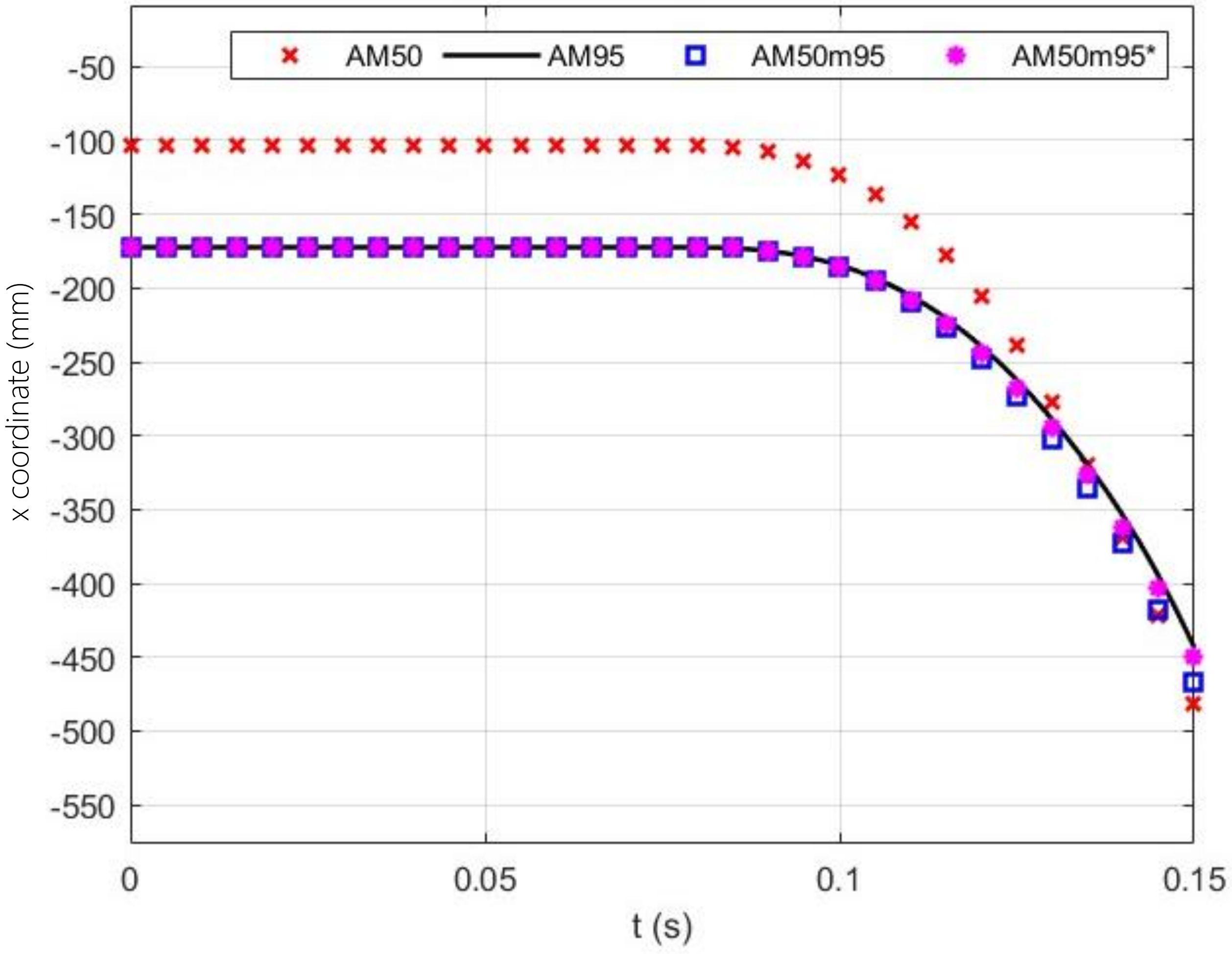
s_{mean} related to the AM95 *[mm]*		
Control points	*AM50*	*AM50m95*
Pelvis	55.89	8.57
Neck	54.71	6.67
Chest – Right Shoulder	61.72	9.87
Chest – Left Shoulder	58.36	4.34
…	…	…
Shin – Right Ankle	17.31	13.91
Shin – Left Ankle	17.84	14.70
Right Foot	18.97	19.62
Left Foot	18.99	19.62
Average	34.42	7.84



Parametric THUMS – Sled test

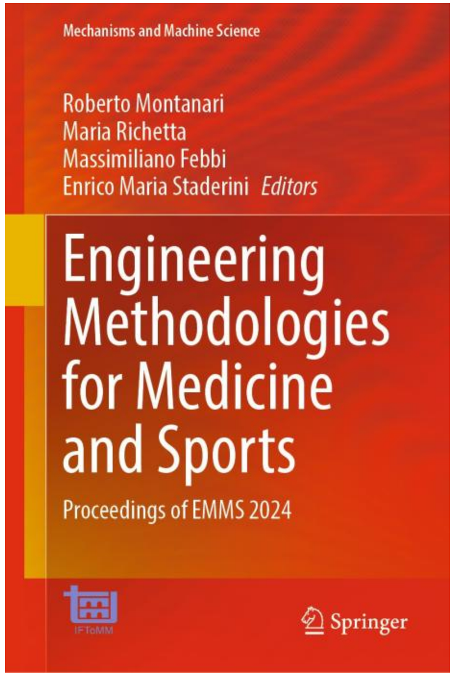
- Displacements were evaluated across different THUMS models.
- The parametric THUMS, morphed from AM50 to AM95 using skin and bones control points (AM50m95*), shows an excellent agreement with the original AM95 response.

Left Shoulder – Arm edge



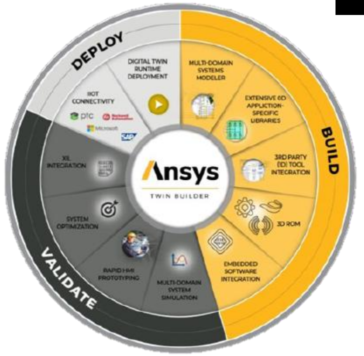
Conclusions

- We developed **parametric THUMS** extending its use beyond the six predefined models available
- The morphing process, driven by skin and bone landmarks, generates accurate intermediate and scaled models in just **a few seconds**, maintaining **mesh quality** and numerical **stability**
- **Validation** through sled test simulations confirmed that the morphed models reproduce the kinematic response of the reference THUMS with high fidelity
- A detailed description of this work is available in the EMMS 2024 Proceedings at: https://link.springer.com/book/10.1007/978-3-031-63755-1

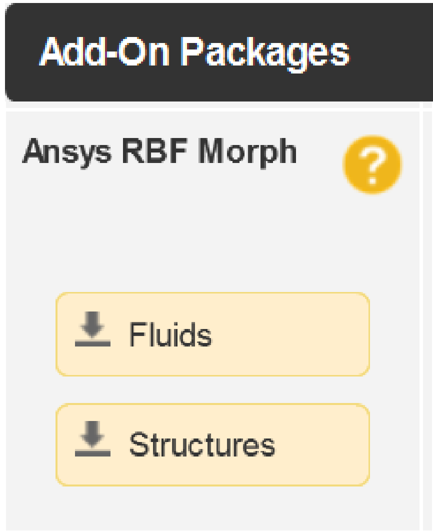


The advanced morphing solution selected by Ansys

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



Ansys OPTISLANG



Ansys part of Synopsys

Many thanks for your attention!

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