TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Human Body Models customization by advanced mesh morphing: parametric THUMS

Master's degree in Mechanical Engineering A.Y. 2022/2023

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STUDENT GRADUATING
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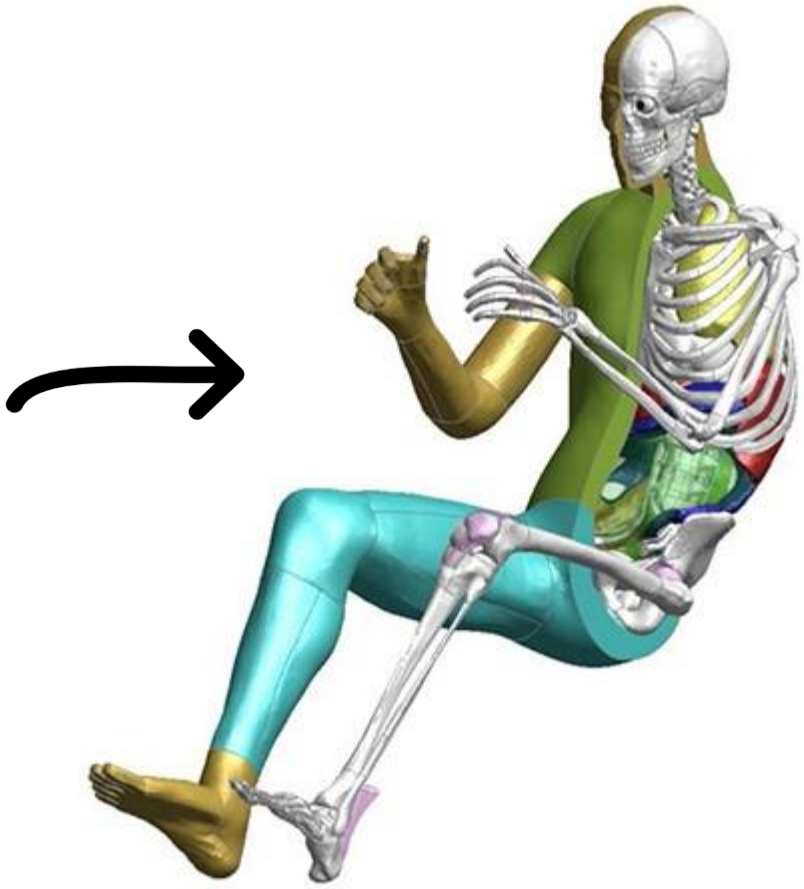
Introduction

- Vehicle safety: injury predictions
- Injury prediction tools
- Crash tests: **ATDs** (Anthropometric test devices)

Introduction

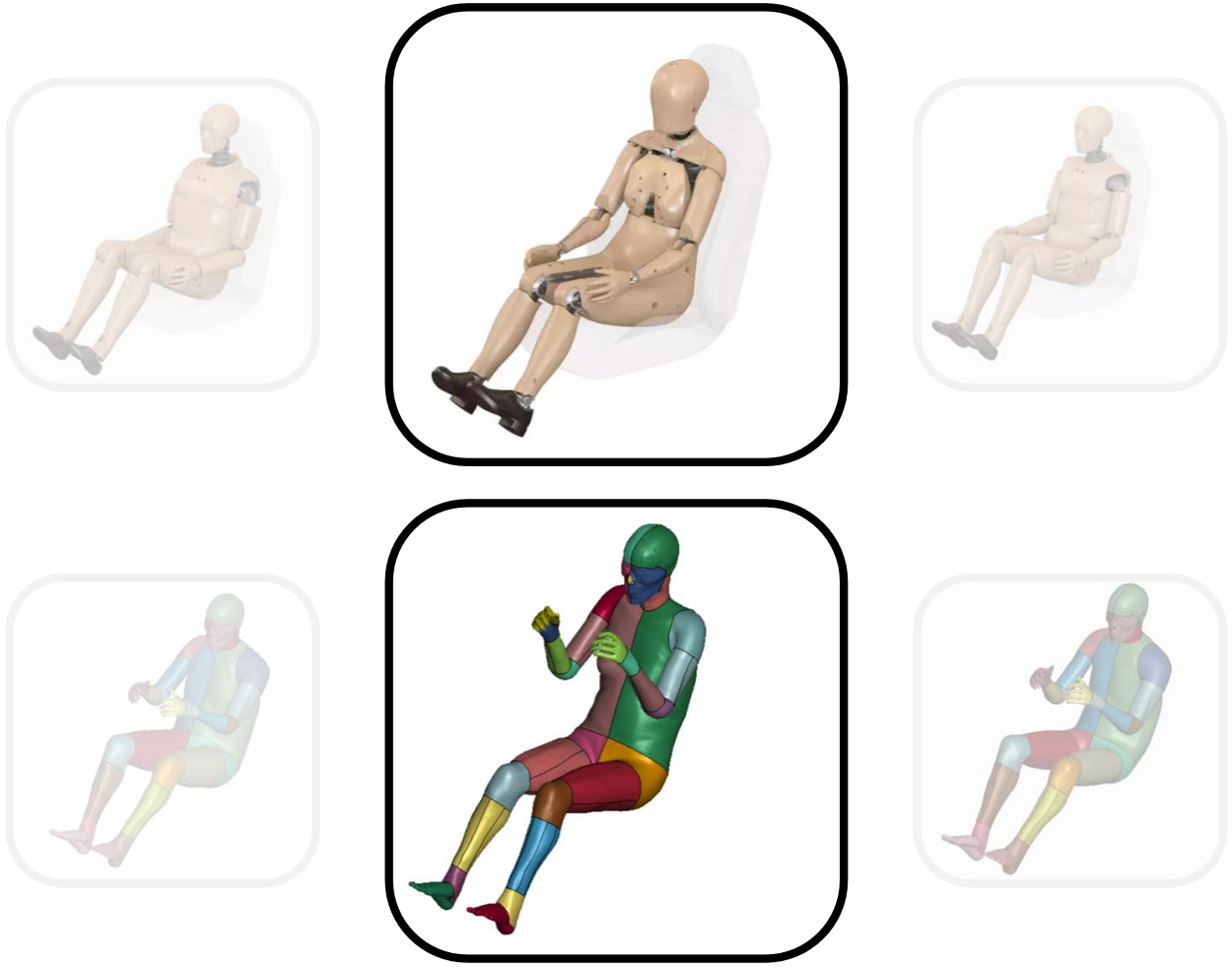
- Vehicle safety: injury predictions
- Injury prediction tools
- Crash tests: **HBMs** (Human body Models)



HBMs vs ATDs

- ✓ Complete Anatomy→ accuracy
- ✓ Omnidirectionality → Flexible usage
- ⚠ Small number of shape avaiable

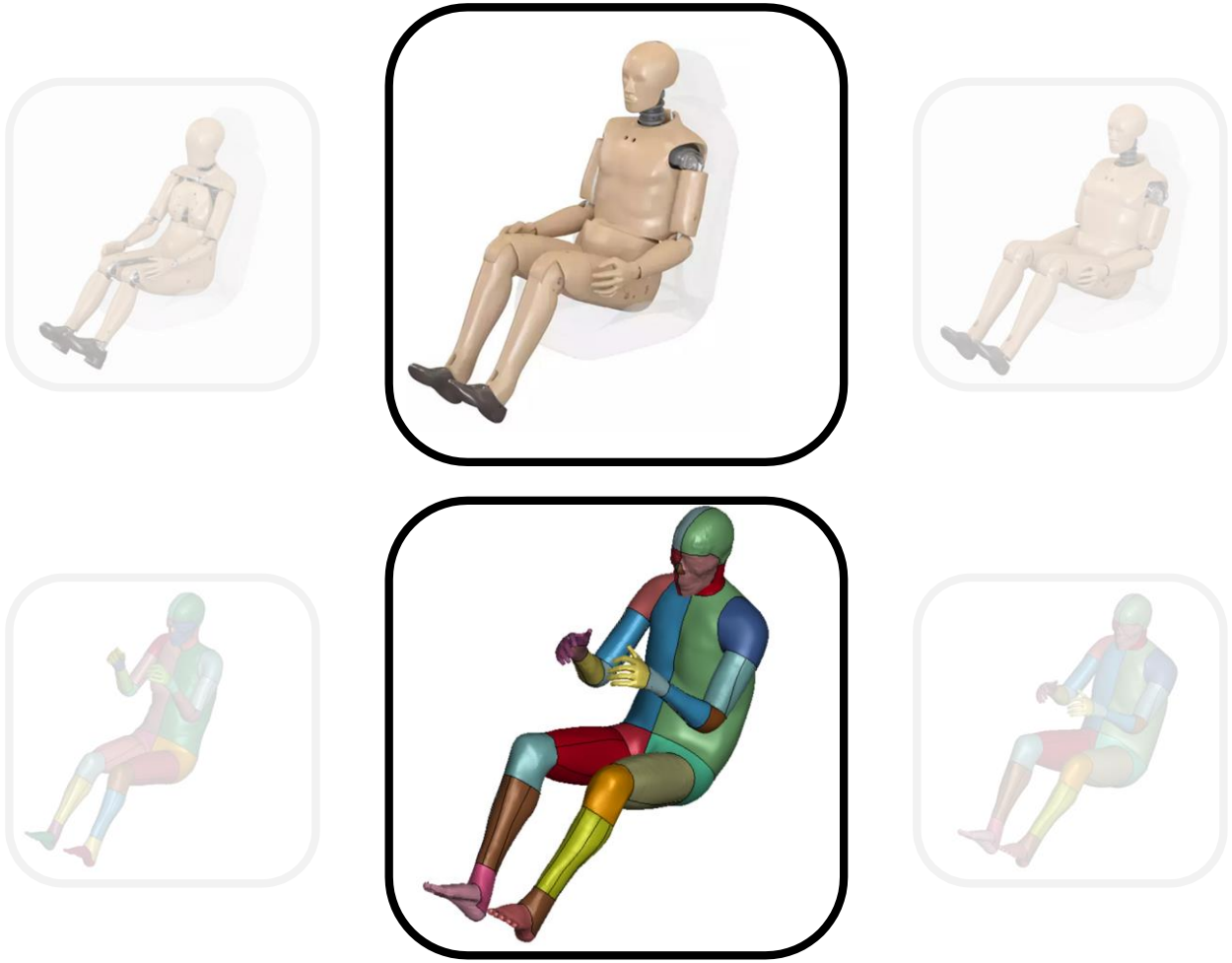
Small number of shape



Small size adult female

- Shape corresponding to the 5^{th} statistical anthropometric percentile

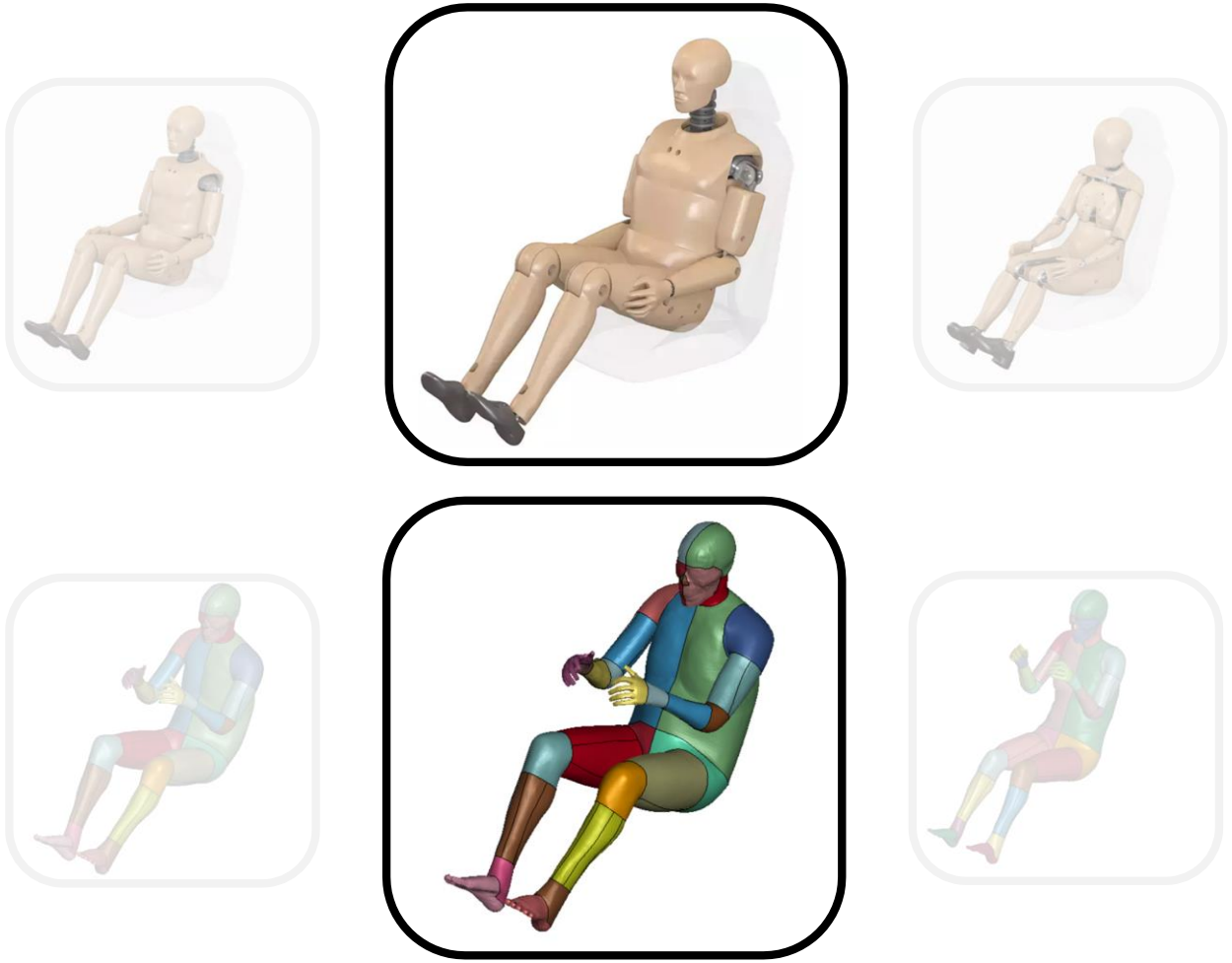
Small number of shape



Middle size adult male

- Shape corresponding to the 50^{th} statistical anthropometric percentile

Small number of shape

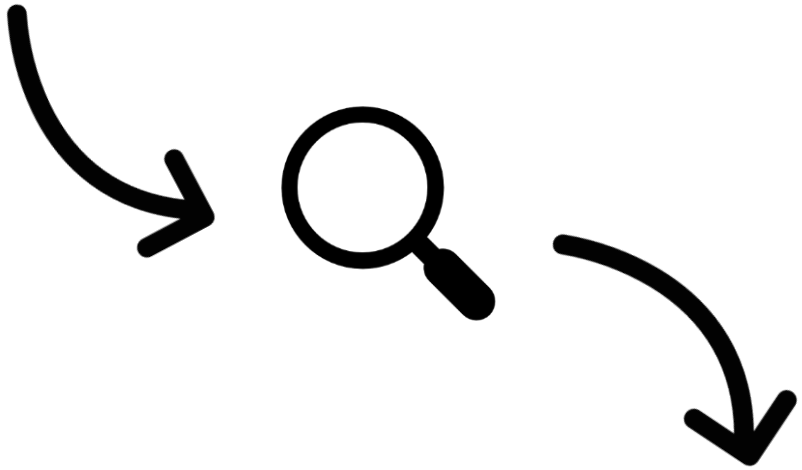


Large size adult male

- Shape corresponding to the 95^{th} statistical anthropometric percentile

Small range of shape

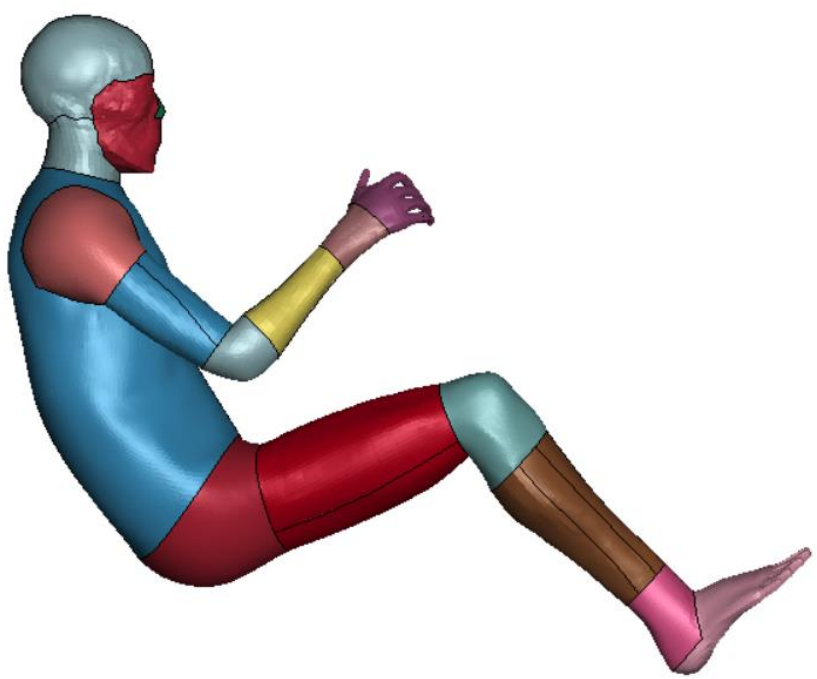
- In the development of HBMs, most antrhopometric shapes have ramained inexplored

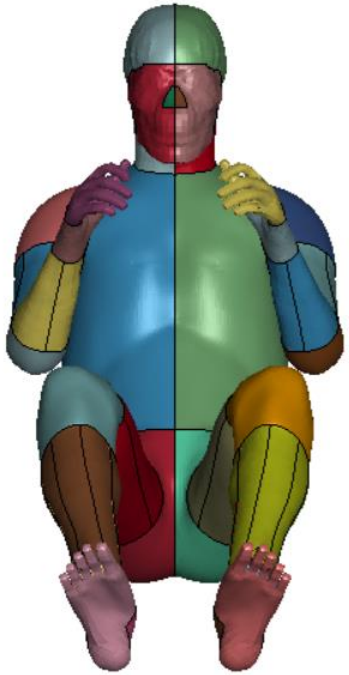


Human Body Models customization

Total Human Model for Safety: THUMS™

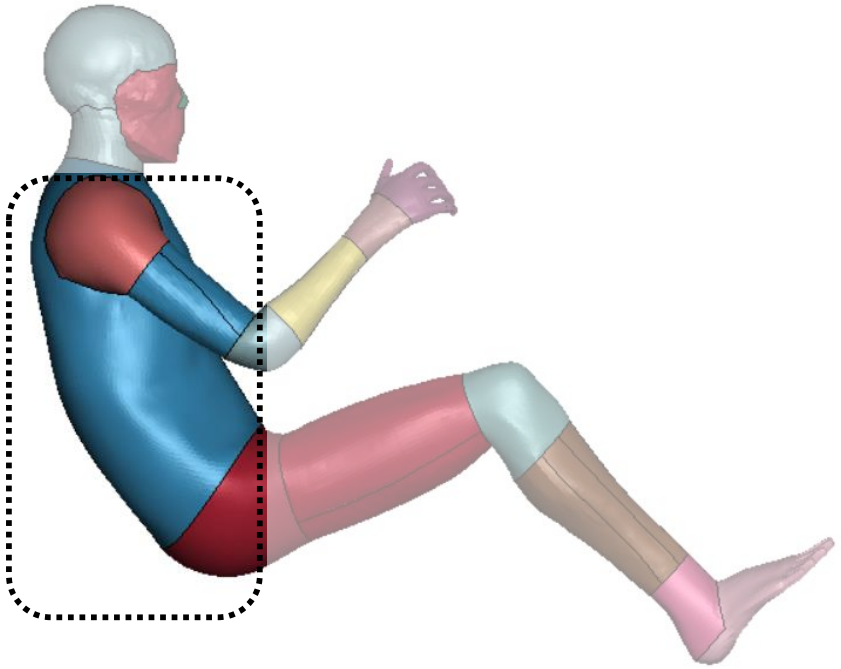
- Developed by TOYOTA → open source since 2021
- Advanced features

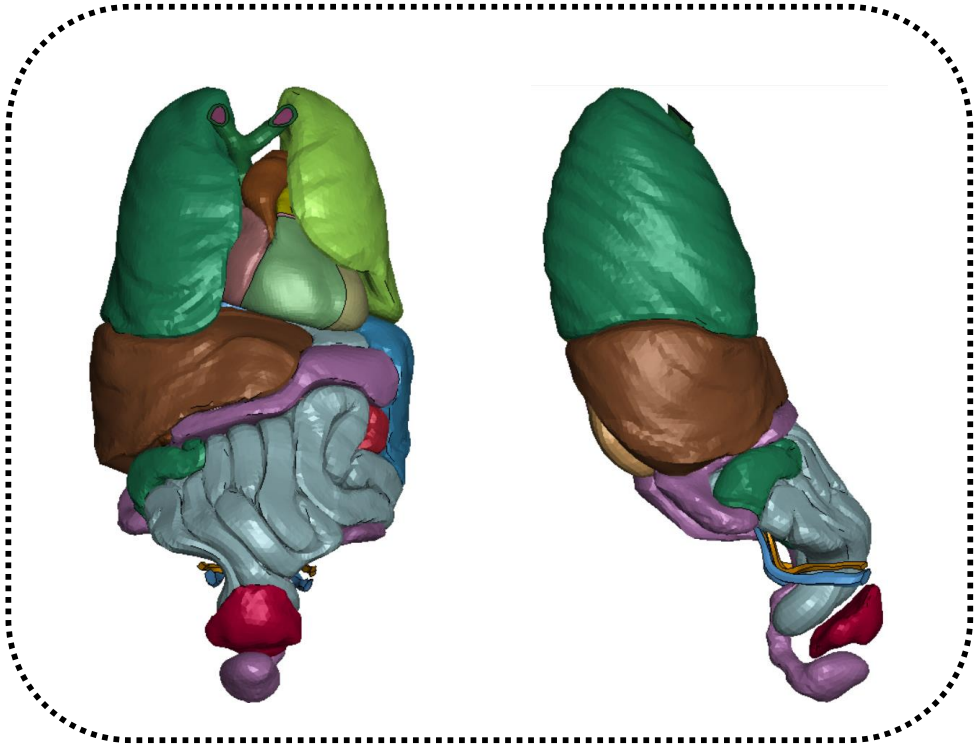




Total Human Model for Safety: THUMS™

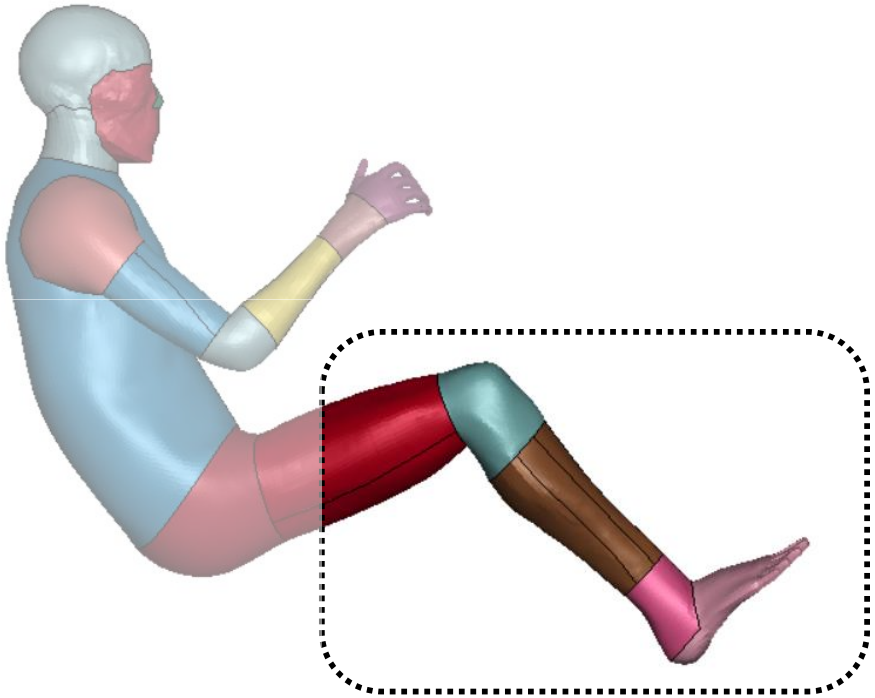
- **Internal organs** geometry extremely detailed

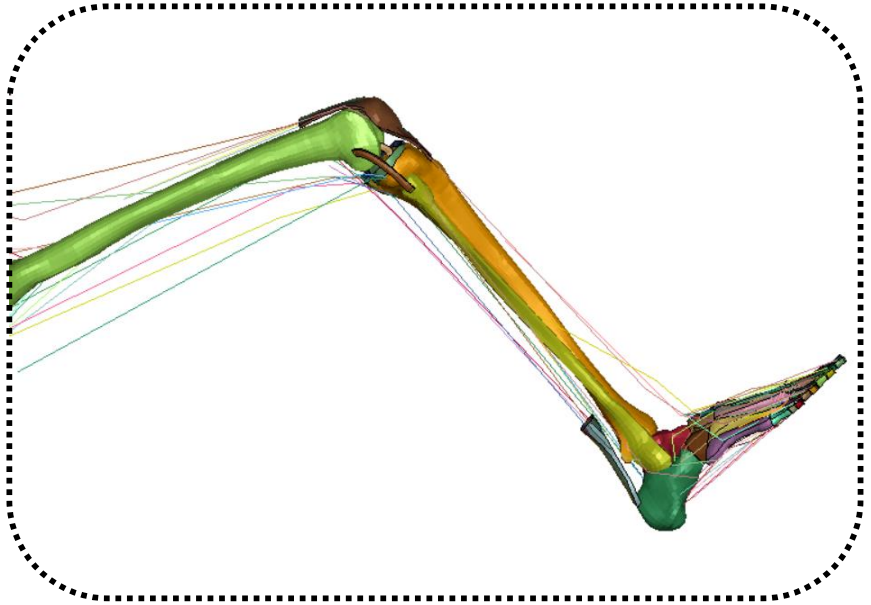




Total Human Model for Safety: THUMS™

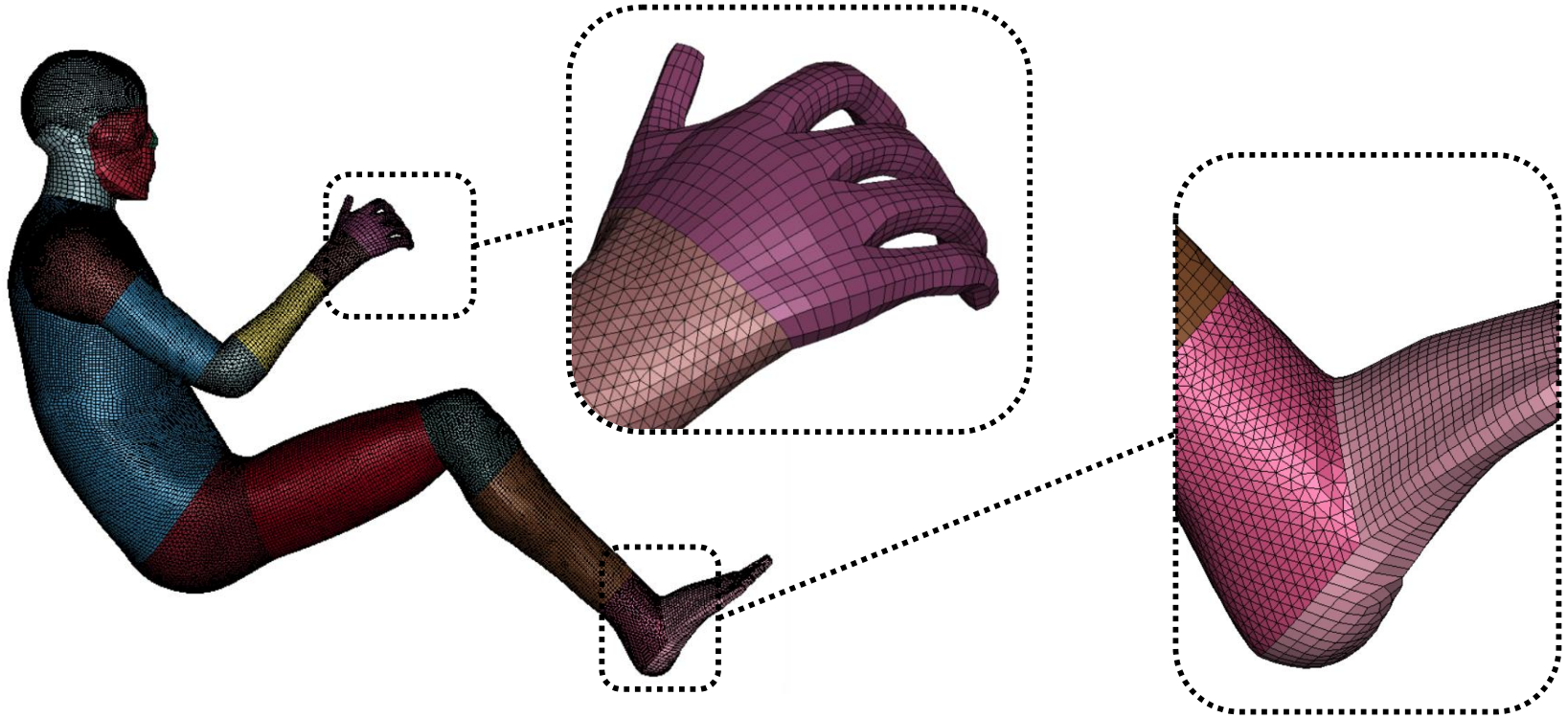
- **Complete modeling of muscolar function** through one-dimensional elements activated by feedback controllers





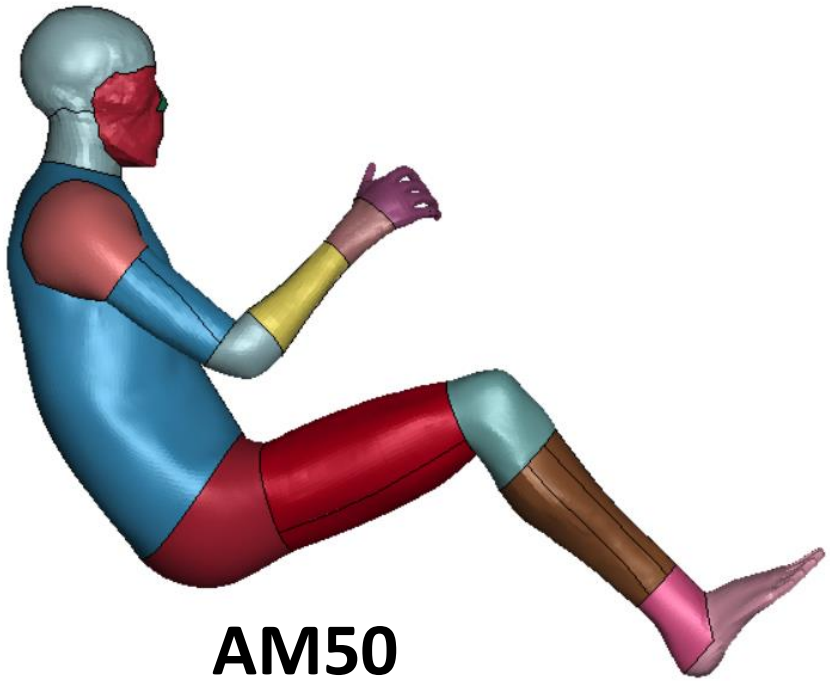
Total Human Model for Safety: THUMS™

- **Mesh** composed of over **2 milion elements**

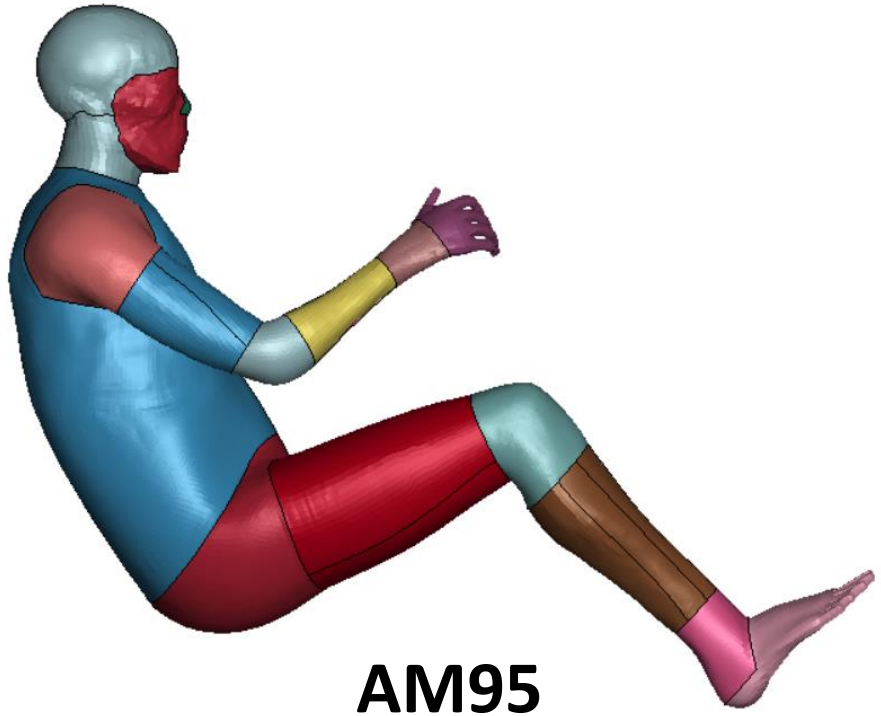


Total Human Model for Safety: THUMS™

- Unique shapes avaiable for male models: 50^{th} e 95^{th} statistical anthopometric percentile



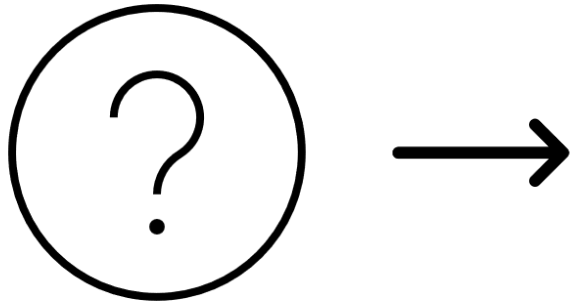
AM50



AM95

Objective

- **Define** a method to create **THUMS** corresponding to the **generic percentile**

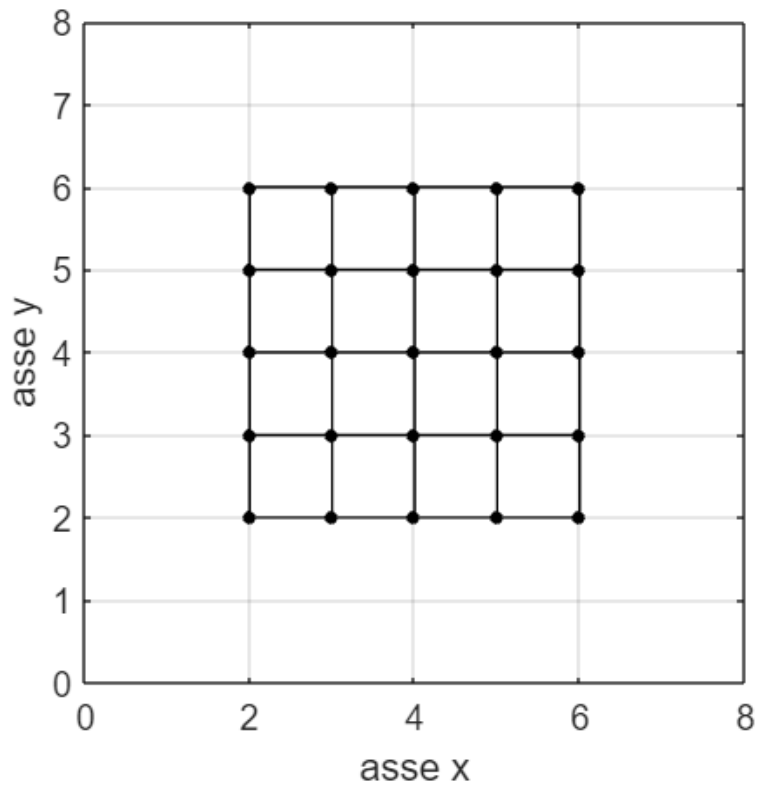


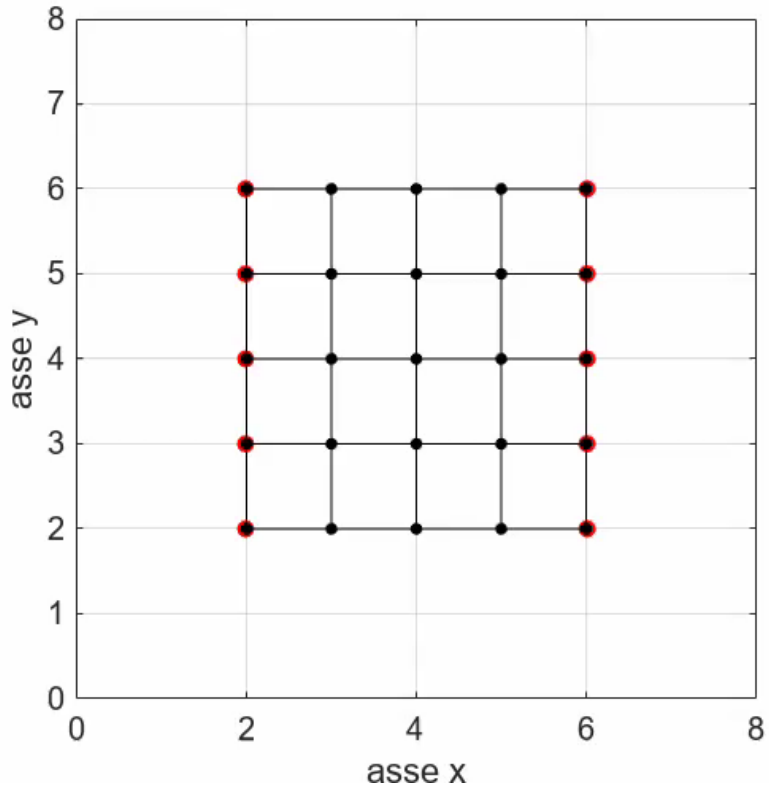
RBF mesh morphing

Through RBF mesh morphing, it is possible to modify a discretized geometry by imposing the displacement of a certain number of its nodes

Mesh Morphing driven by RBF

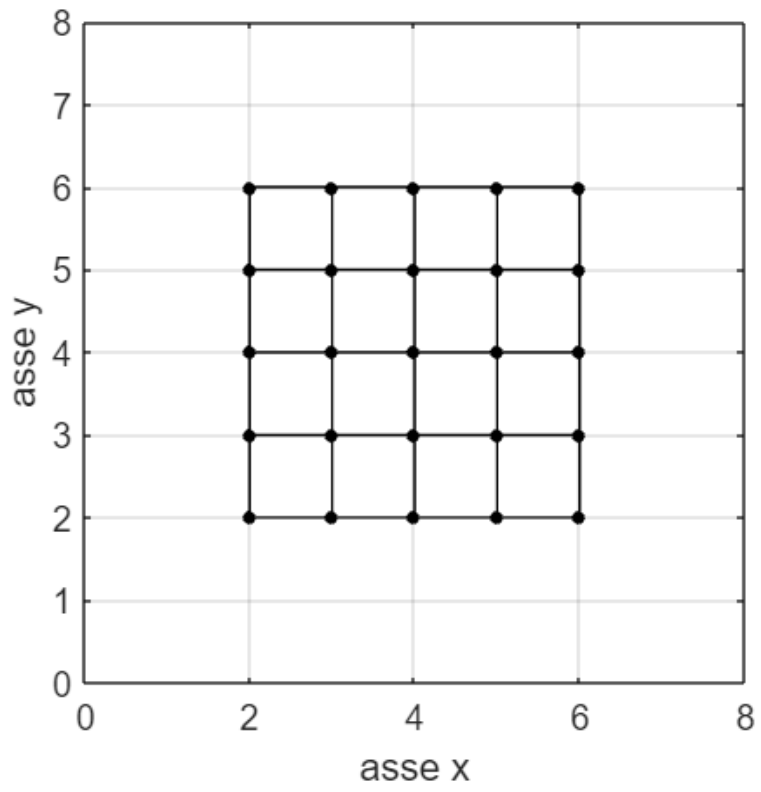
Example:



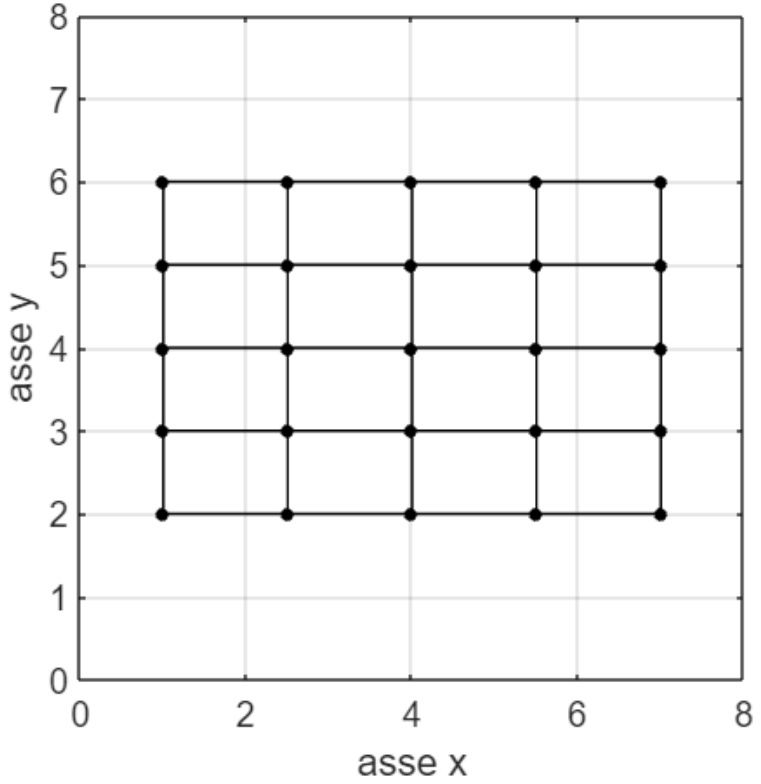


Mesh Morphing driven by RBF

Example:

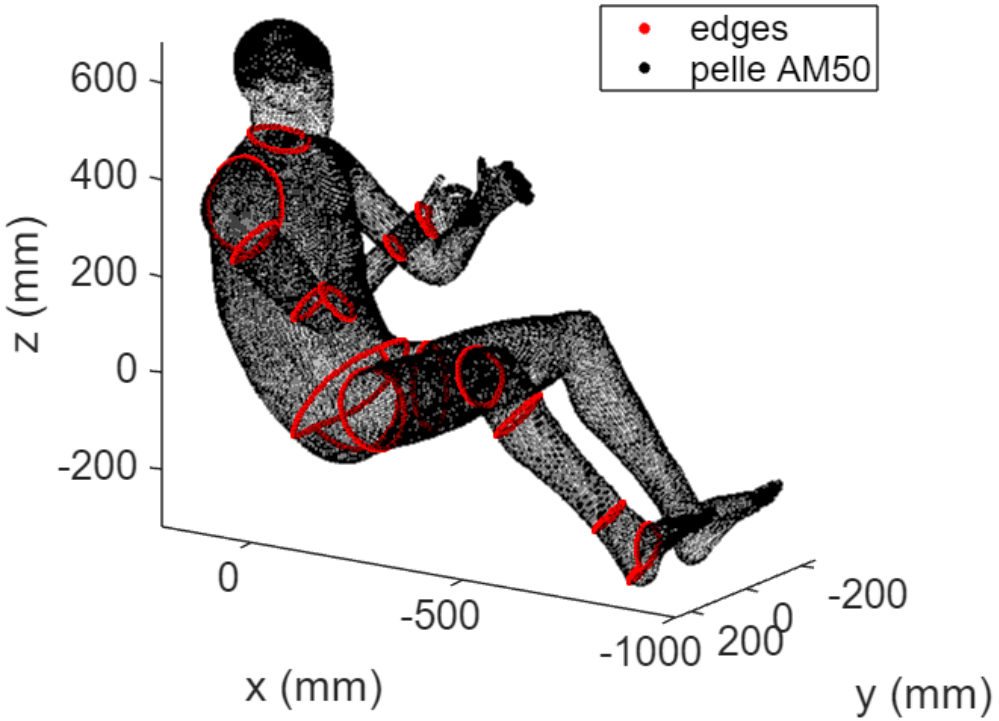


RBF

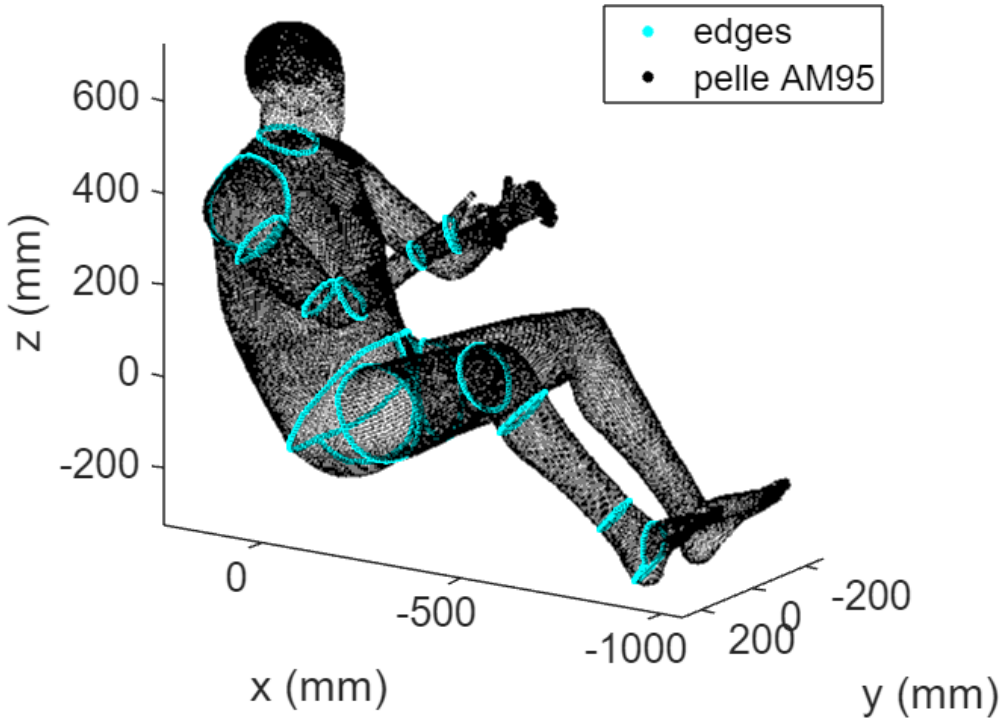


Source points selection

- Source points in AM50

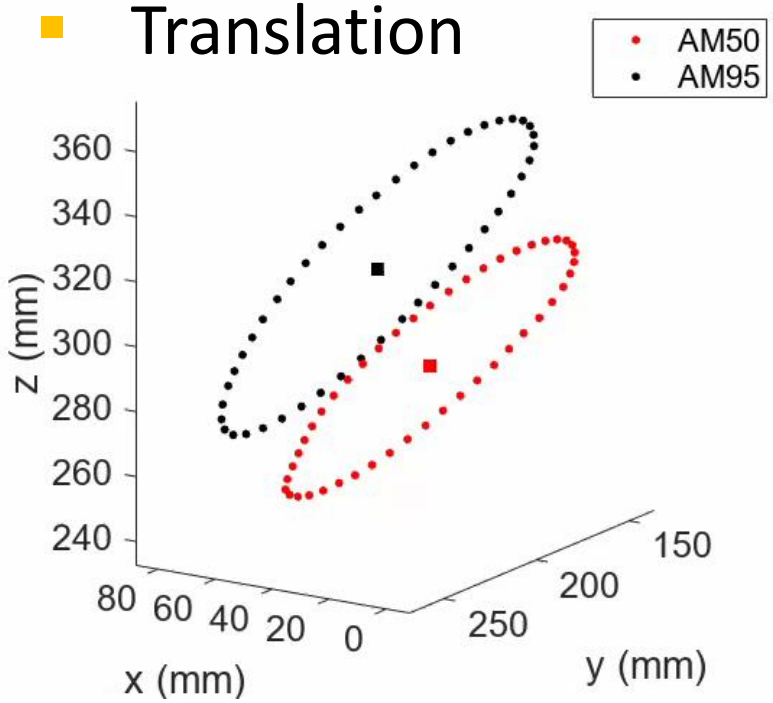


- Homologous edges in AM95

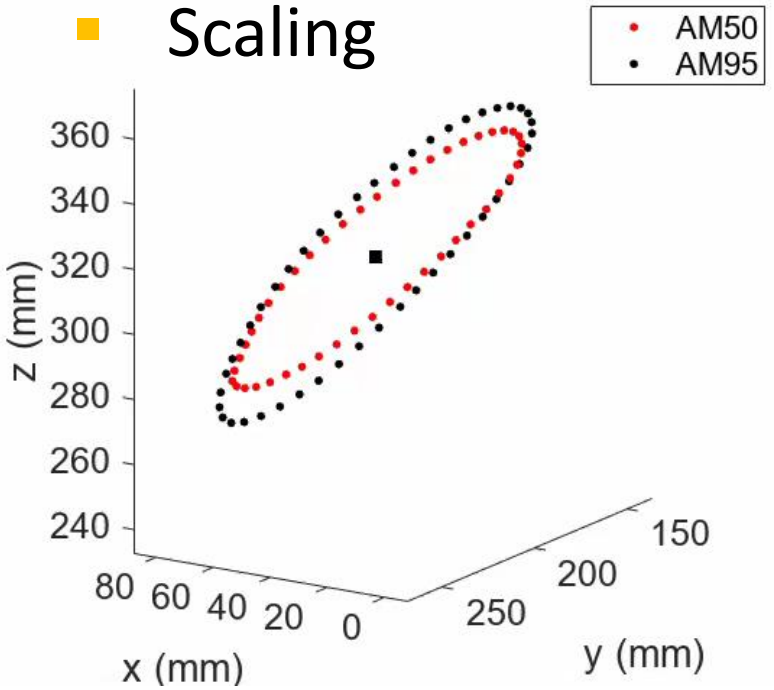


RBF displacements

- Translation



- Scaling



Combining the 2 operations $\longrightarrow$ Displacements: $\boldsymbol{D_{50-95}}$

Parametric mesh morphing

- δ: modulation parameter
- $\boldsymbol{D_{50-P}}$: source points displacement in the mesh morphing to the generic percentile

$$\boldsymbol{D_{50-P}} = \delta * \boldsymbol{D_{50-95}}$$

With δ varying linearly between 0 and 1 from the 50^{th} to the 95^{th} statistical anthropometric percentile

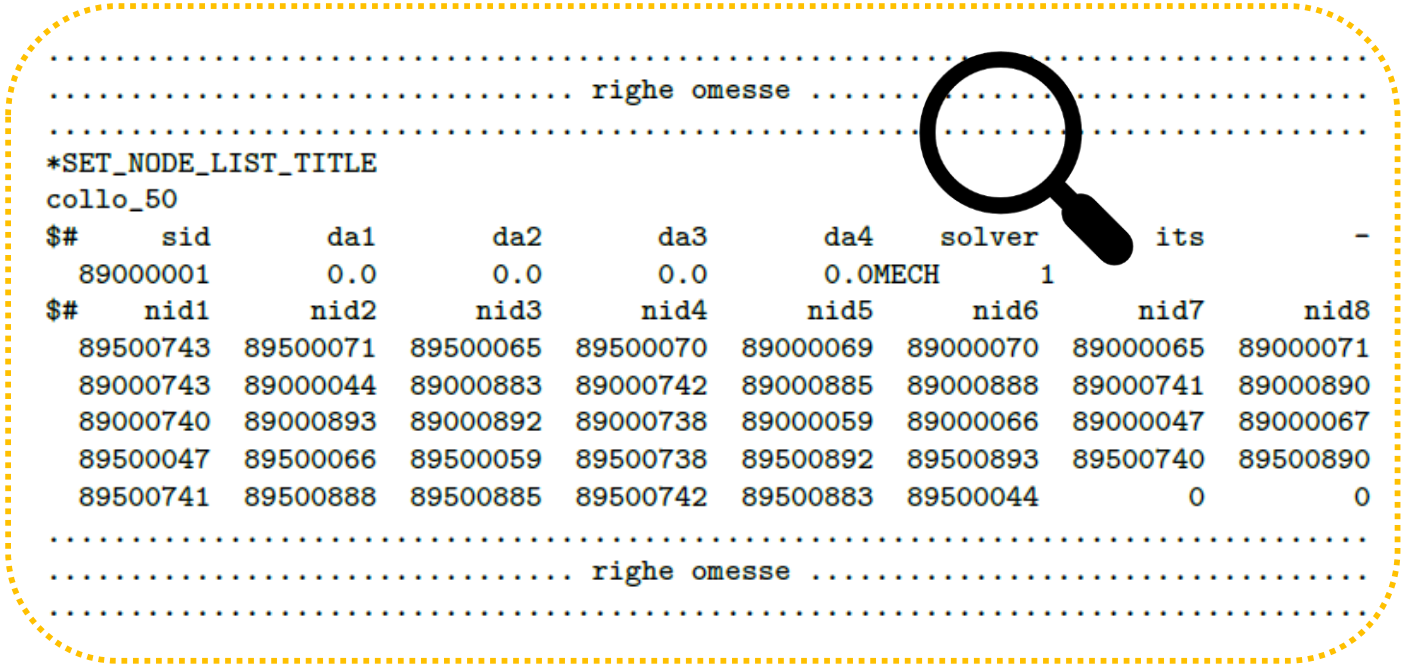
Mesh morphing implementation

Automatic procedure in 4 phases:

1. Setting
2. Definition
3. Esecution ← rbf
4. Writing

Setting

- Reading the LS-DYNA simulation K-FILE relative to THUMS AM50

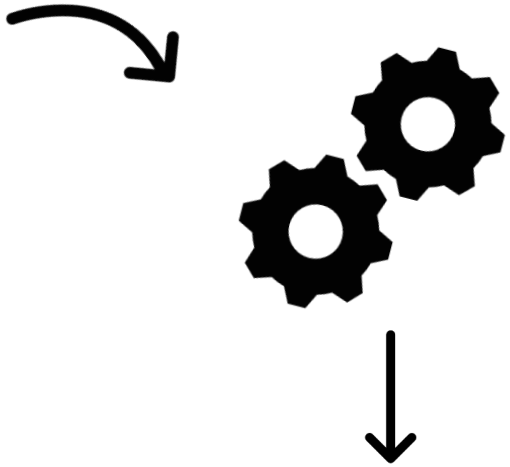


```
.....
..... righe omesse .....
.....
*SET_NODE_LIST_TITLE
collo_50
$#     sid       da1       da2       da3       da4    solver       its         -
  89000001       0.0       0.0       0.0       0.0MECH      1
$#    nid1      nid2      nid3      nid4      nid5      nid6      nid7      nid8
  89500743  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
.....
..... righe omesse .....
.....
```

Source points coordinates

Definition

Source points coordinates

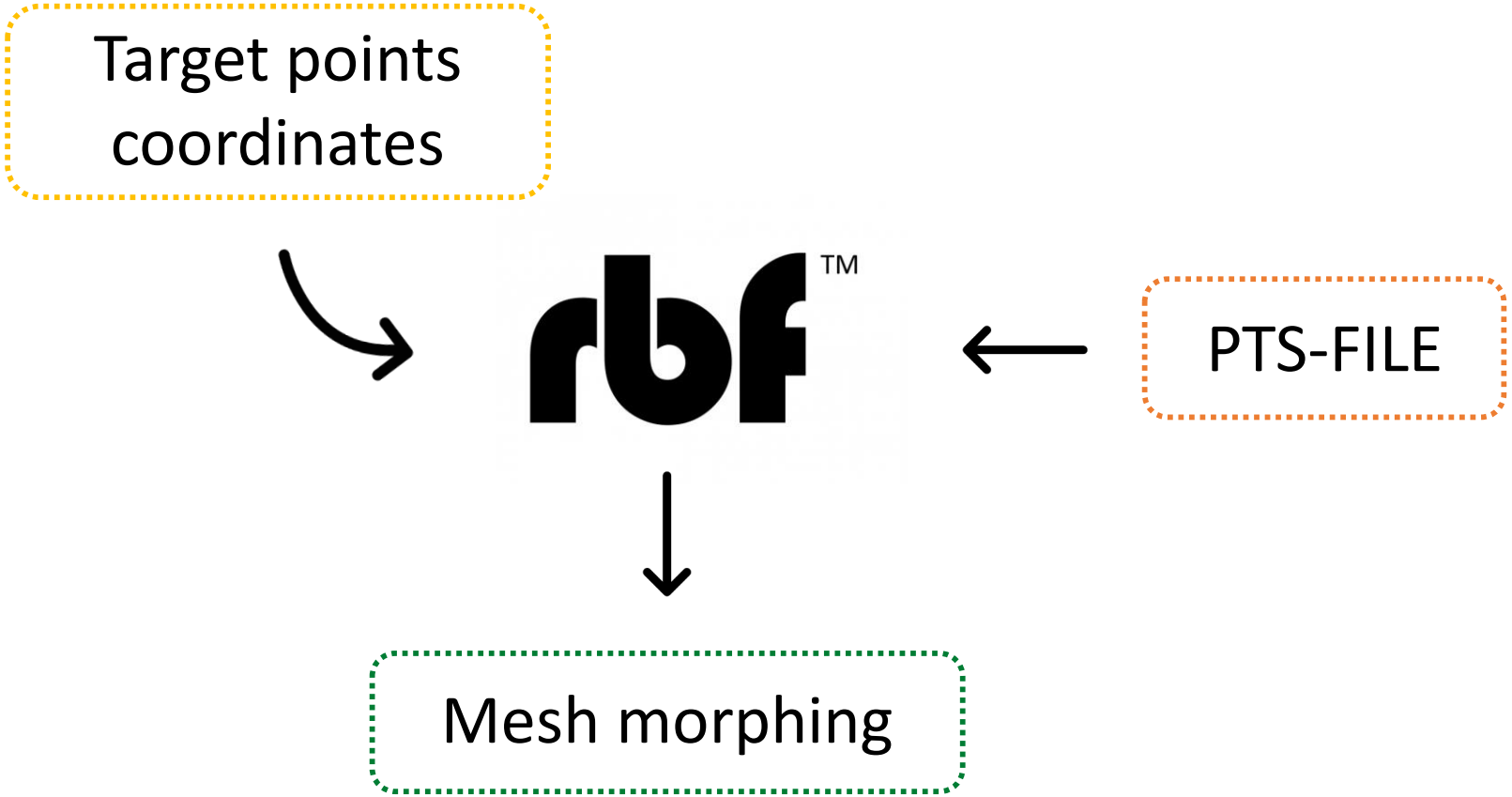


Percentile

PTS-FILE

```
1522
-811.018 67.19753 -288.0066 -38.177466141229516 3.1974164850510567 -6.893923740617389 81000774 0 s p
-807.6782 68.16429 -292.2721 -37.94366307172289 3.2650942954424296 -7.192525414021546 81000775 0 s p
-804.5713 69.83803 -296.3405 -37.72616419255343 3.3822640773577533 -7.4773293169819155 81000776 0 s p
.....
..... righe omesse .....
.....
109.8944 100.7405 423.7275 13.755605995039172 8.026604098779977 32.901360113398766 89589508 0 s p
150.0275 106.0441 408.1986 18.249523776210857 8.581565927666018 32.121853233288185 89589563 0 s p
27.22313 111.8411 378.0515 4.498461885936079 9.188156492952311 30.608554038536354 89589795 0 s p
```

Esecution



Writing

- Writing the new simulation K-FILE

```
*NODE
 7121101        132.9127        17.49752        150.8569       0       0
 7121109       -163.0202        96.61806       -48.35065       0       0
 7121152        118.2001        21.74364         156.744       0       0
 ..............................................................................
 ............................ righe omesse.....................................
 ..............................................................................
```

THUMS AM50

```
*NODE
 7121101    150.37798102     19.41371560    166.42936123       0       0
 7121109   -171.12580417    119.26328861    -44.33608968       0       0
 7121152    133.95643805     24.15646037    173.18246829       0       0
 ..............................................................................
 ............................ righe omesse.....................................
 ..............................................................................
```

THUMS AM50mP

Simulation

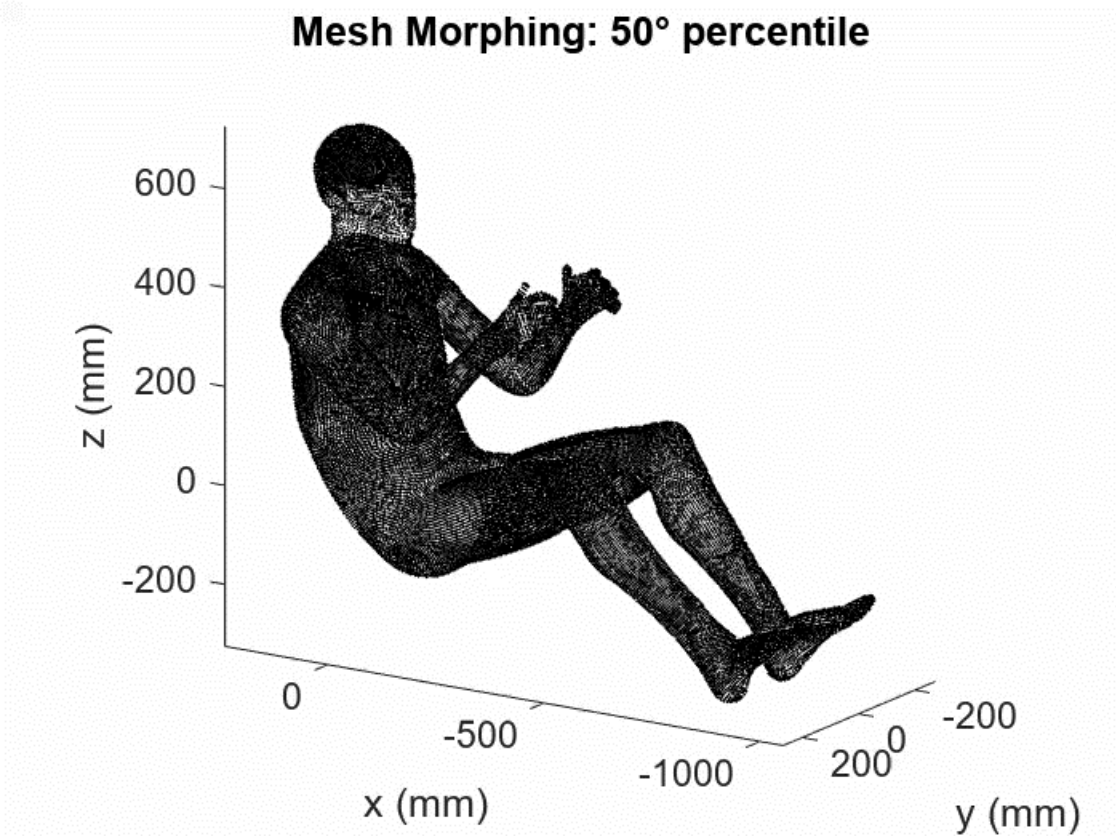
- **AM50m95:** mesh morphing to 95^{th} percentile → 100 kg
- **AM50m75:** mesh morphing to 75^{th} percentile → 89 kg
- **AM50m35:** mesh morphing to 35^{th} percentile → 65 kg

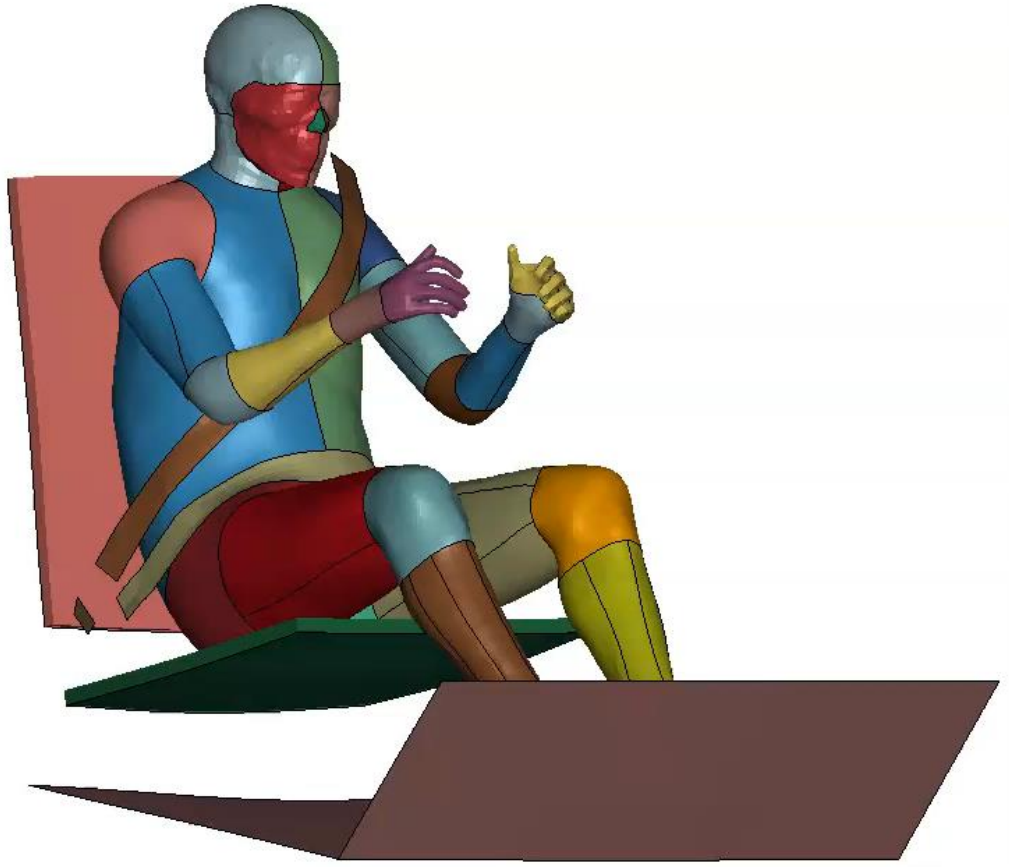
Ansys / LS-DYNA

Frontal impact kinematic analysis

Simulation

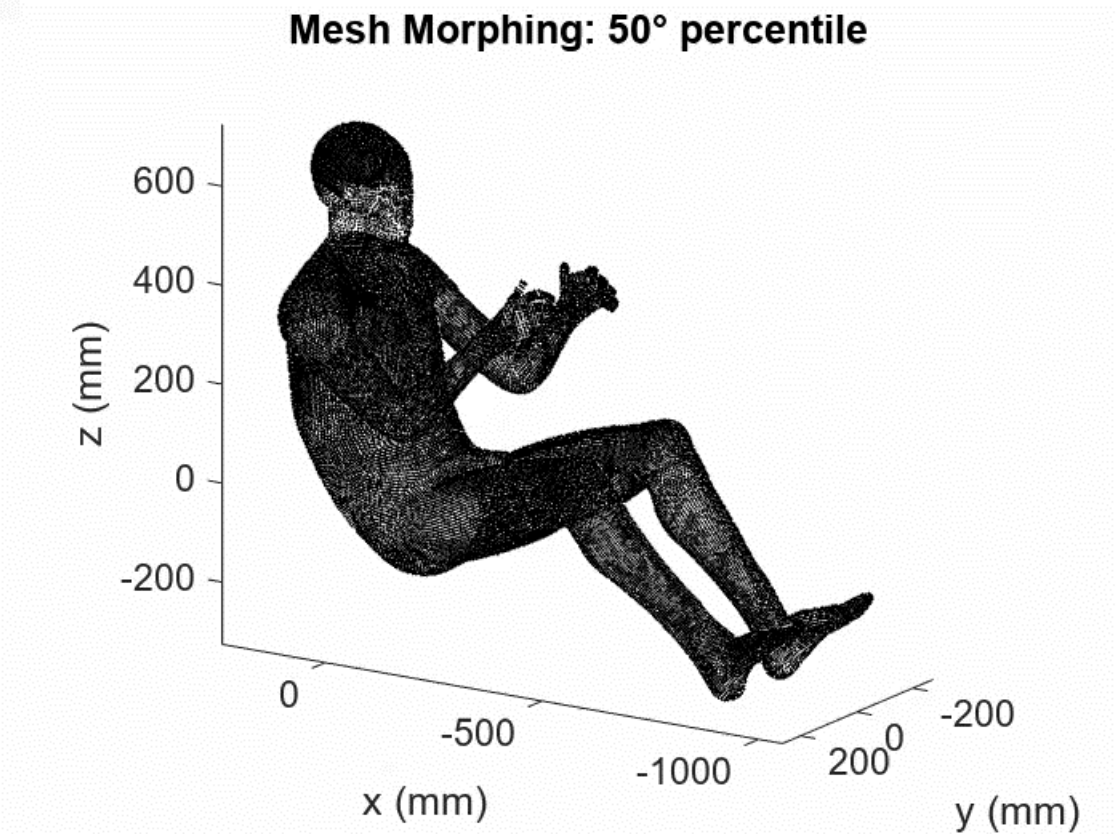
Ansys / LS-DYNA

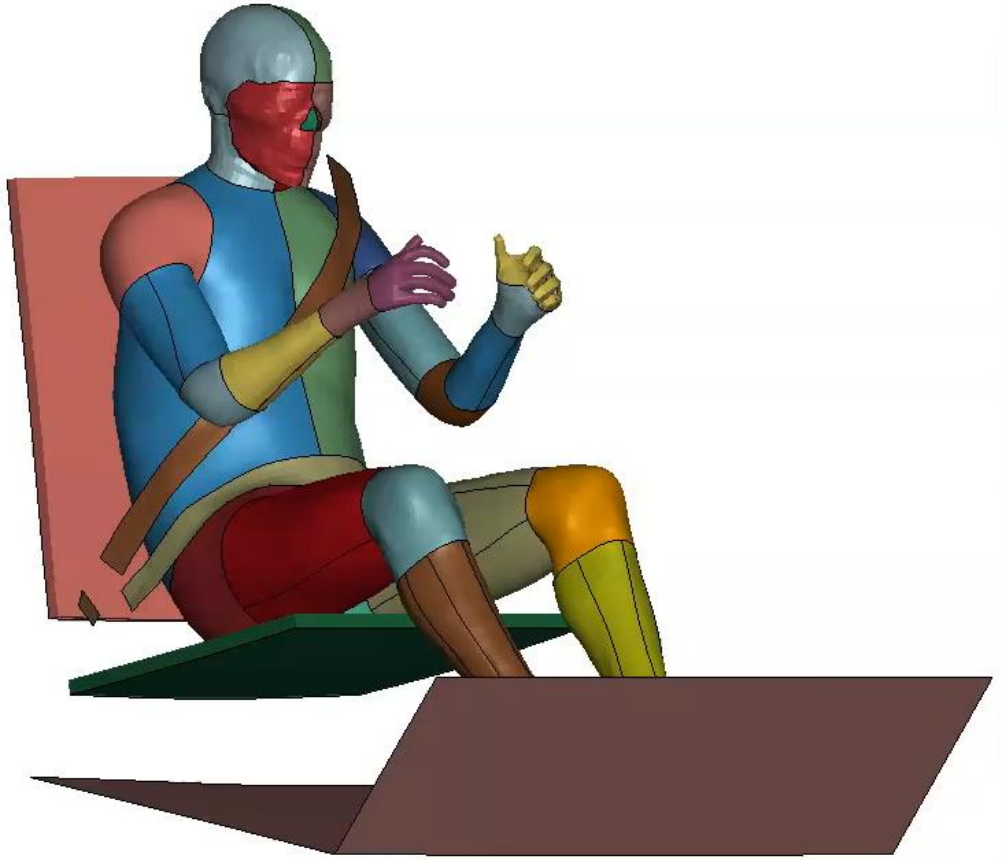




Simulation

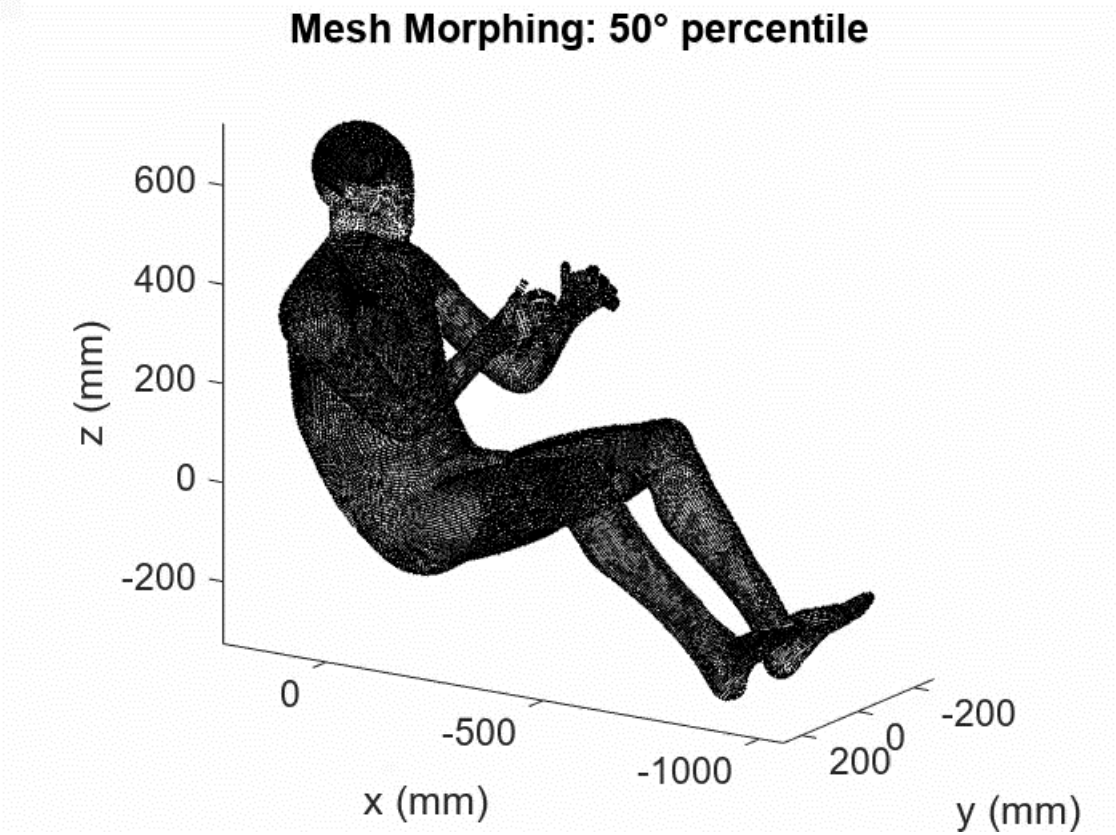
Ansys / LS-DYNA





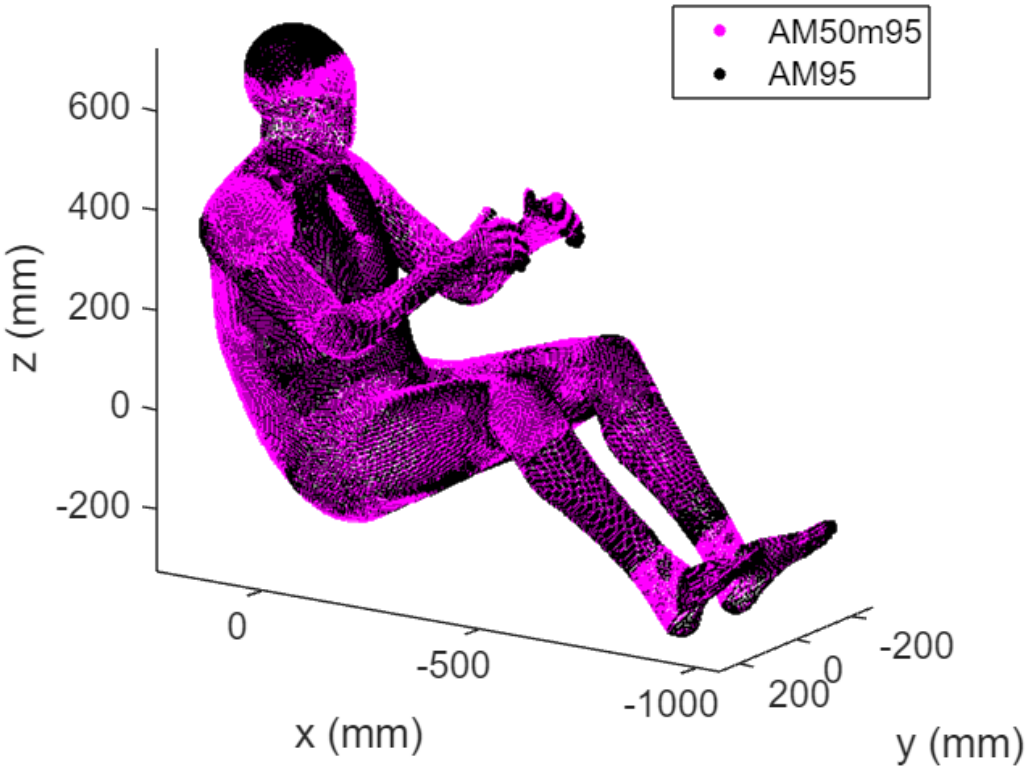
Simulation

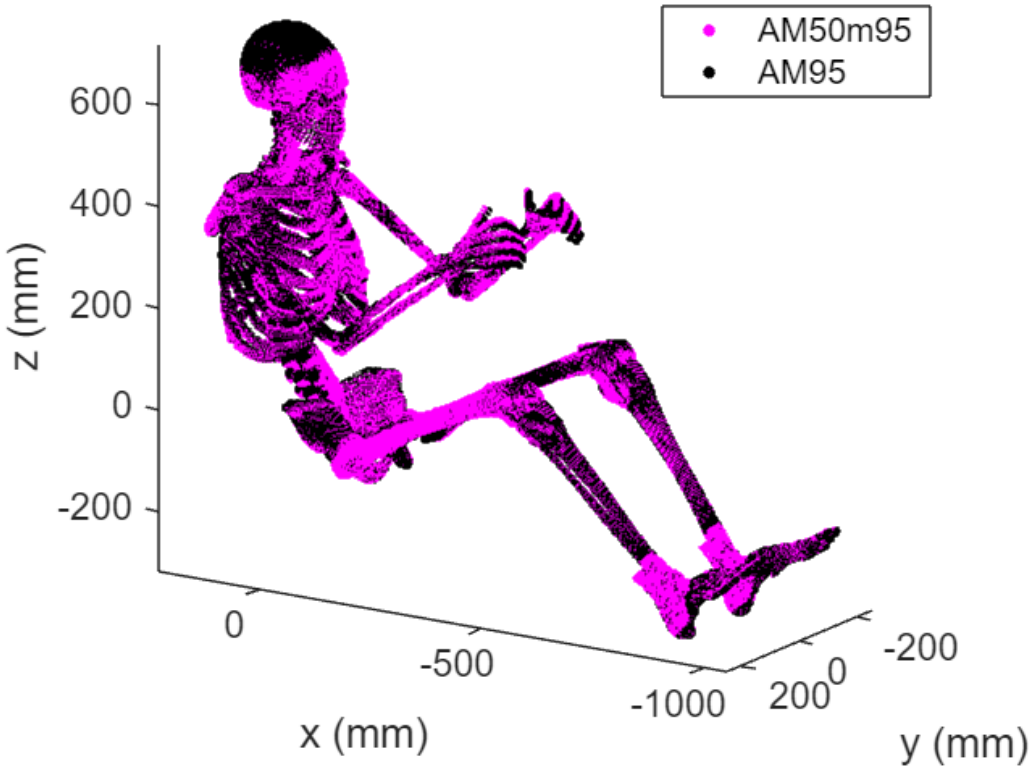
Ansys / LS-DYNA



Results

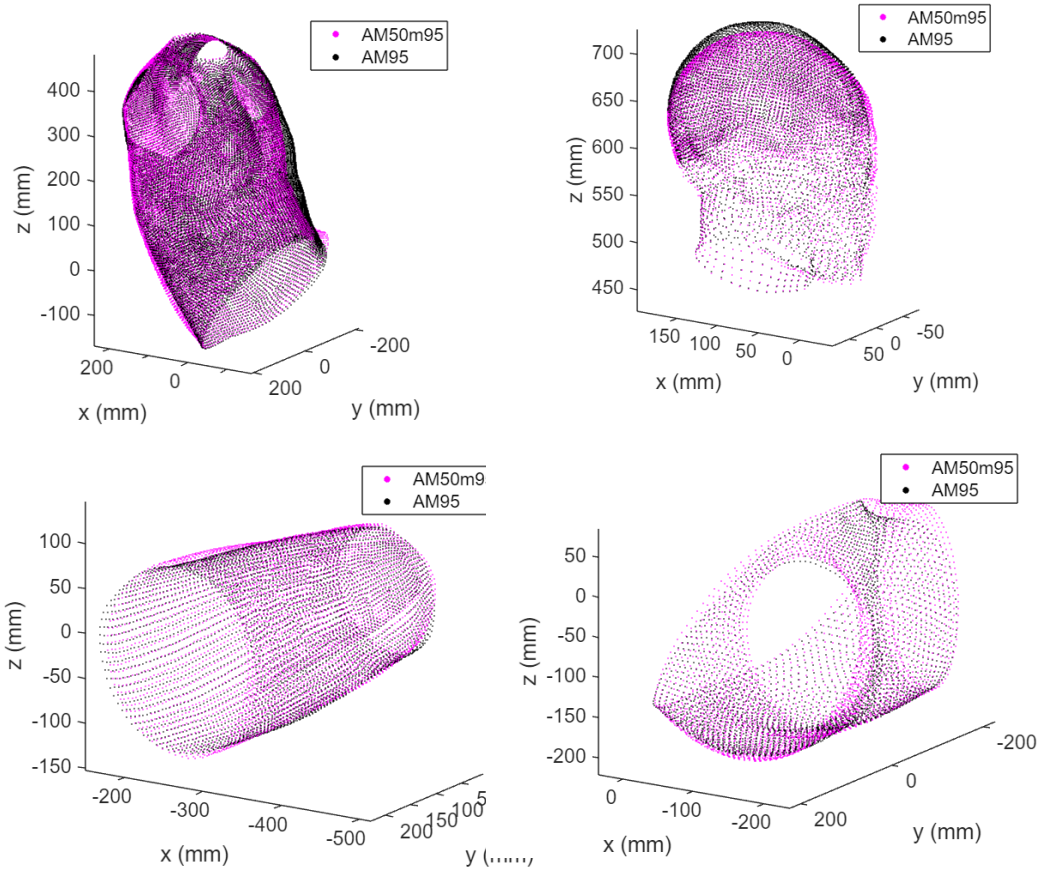
- Geometry quality: AM50m95 vs AM95



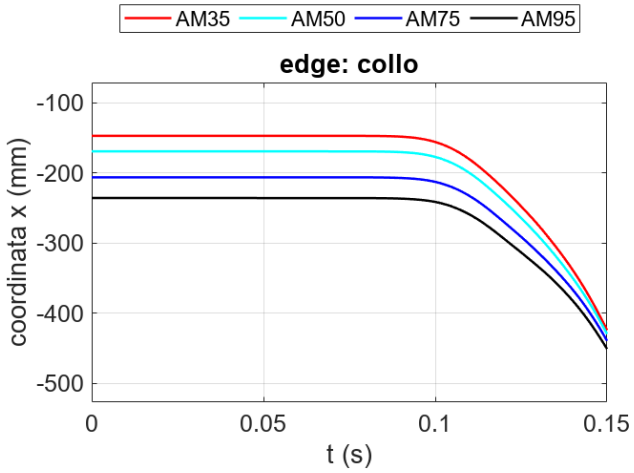


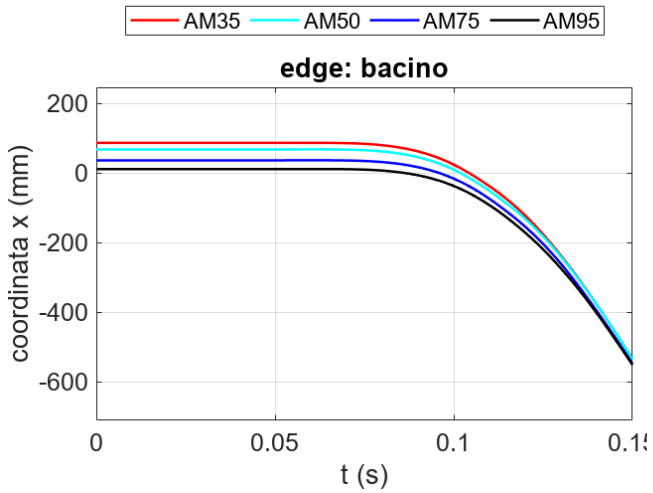
Results: MDA and MDM

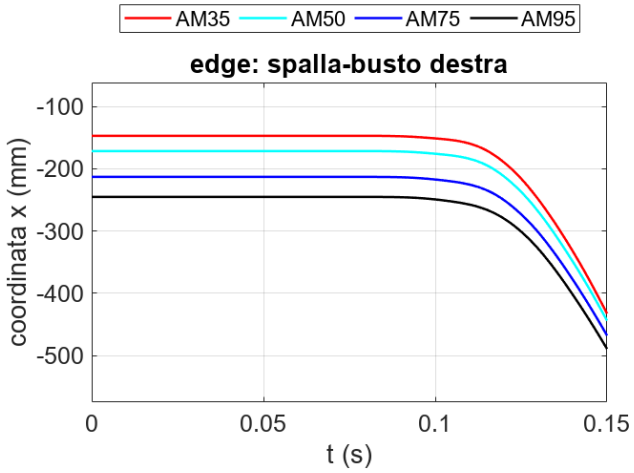
Body areas comparison			
area	**MDA *[mm]***	**MDM *[mm]***	**MDA/MDM**
Busto	7.10	24.36	29%
Viso	4.05	11.45	35%
Spalla	3.42	9.06	37%
…	…	…	…
Stinco	1.68	3.14	53%
Cassa toracica	1.97	6.31	31%
Ossa pelviche	2.48	7.52	32%
Average	**3.65**	**8.46**	**34%**

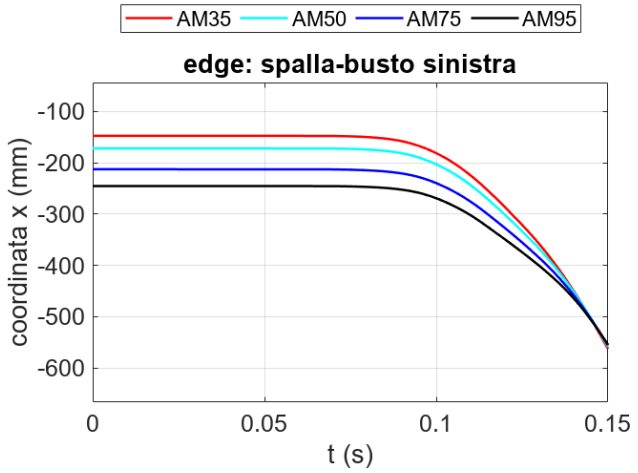


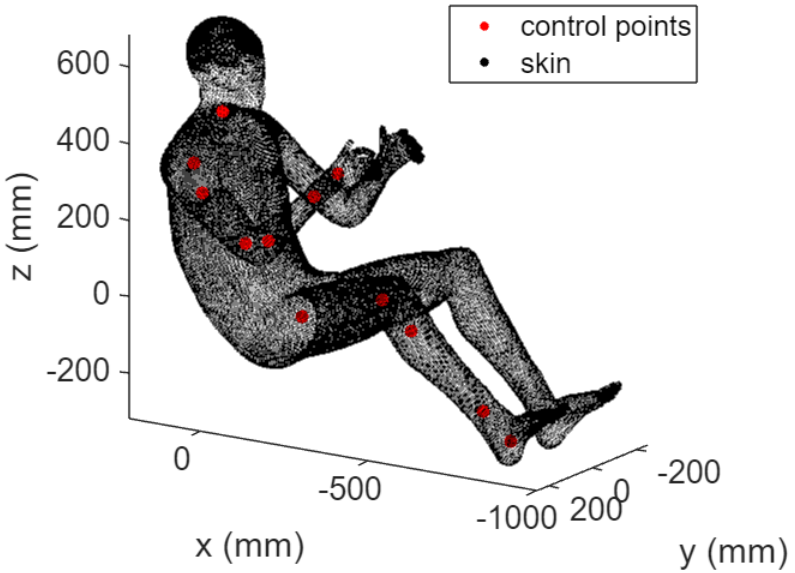
Results: kinematic analysis







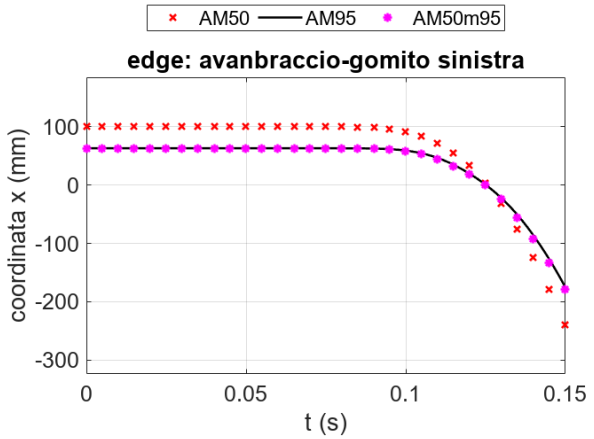


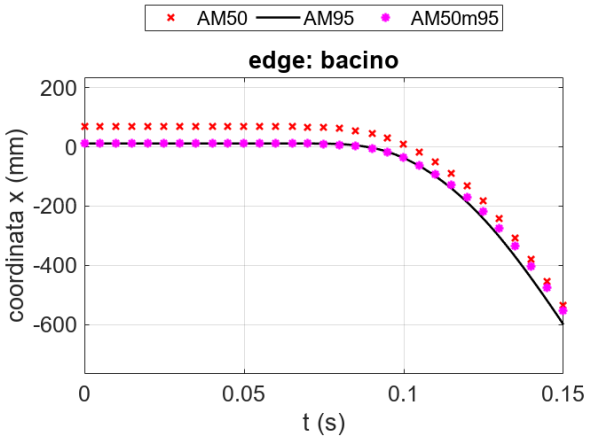


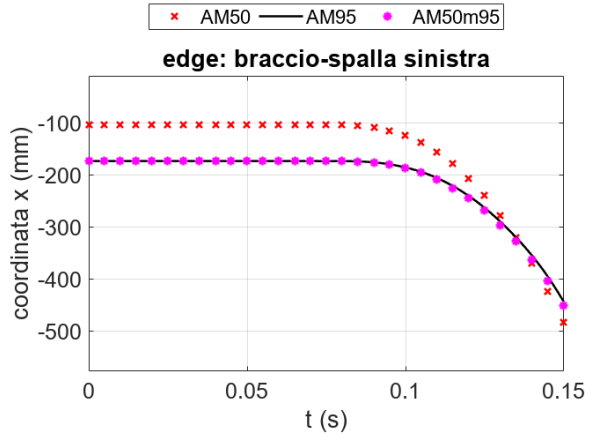
- Linear influence
- Differences introduced by the mesh morphing **0.8 mm/percentile**

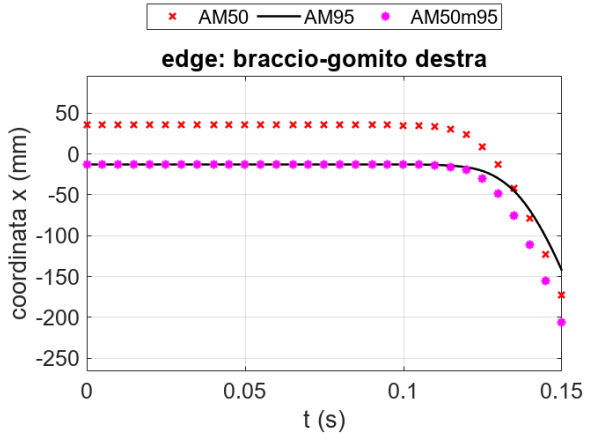
Results: kinematic analysis

S_{mean} related to the AM95 *[mm]*		
Control points	***AM50***	***AM50m95***
Bacino	55.89	8.57
Collo	54.71	6.67
Busto-spalla destra	61.72	9.87
Busto-spalla sinistra	58.36	4.34
…	…	…
Stinco-caviglia destra	17.31	13.91
Stinco-caviglia sinistra	17.84	14.70
Piede destra	18.97	19.62
Piede sinistra	18.99	19.62
Average	**34.42**	**7.84**









Conclusion

- Method
- Method efficiency
- Choices effectiveness

Thanks for your attention