

An overview of the research done using KRATOS Multiphysics

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& the Kratos team

RESEARCH PROJECTS

RESEARCH LINES



(inevitably)
DRIVEN BY FUNDING

1. PRIVATE FUNDING

- FUNDED BY COMPANIES OR OTHER INSTITUTIONS

2. PUBLIC FUNDING

LOCAL
NATIONAL
EUROPEAN
INTERNATIONAL



PRIVATE FUNDING VS PUBLIC FUNDING

- | | |
|--|---|
| <ol style="list-style-type: none">1. Innovation in terms of better results (cheaper, faster, ...) and internal knowledge build up2. BEYOND THE CURRENT PRACTICE but many “ingredients” are taken from classical procedures3. Medium to low risk4. Typically SHORT TERM results and more detailed work description5. Outcome provides benefit to the respective company such as a know-how lead or even a product.6. INDIVIDUAL | <ol style="list-style-type: none">1. Innovation in the sense of new ideas, new paradigm, new procedures2. FAR BEYOND THE CURRENT PRACTICE3. High risk of unsuccess (at least partial)4. Typically LONG TERM results sometimes with potential to establish a technology which is required by companies for privately funded projects5. Outcome is scientific advance and results benefit to the scientific community and society6. COLLABORATIVE |
|--|---|



IS IDEAL FOR BOTH SCENARIOS
(and everything in between)

List of relevant RESEARCH PROJECTS

(not comprehensive)

EUROPEAN

- **ExaQute**- EXAscale Quantification of Uncertainties for Technology and Science Simulation H2020 FET-Future & emerging technologies 2018-2021 G.A.nº 800898
- **ULITES** Ultra-lightweight structures with integrated photovoltaic solar cells: design, analysis, testing and application to an emergency shelter prototype REA Ref: Program FP7-SME-2012 –nº: 314891
- **T-MAPPP** Training in Multiscale Analysis of multi-Phase Particulate Processes FP7 PEOPLE 2013 ITN–nº607453
- **NUMEXAS** Numerical methods and tools for key exascale computing challenges in engineering and applied sciences 2013-16
- **FORTISSIMO** HPC-enabled System for enHanced sEakeeping and stAtion-Keeping design 2015-16



INTERNATIONAL

- **TCAiNMaND** - Tri Continental Alliance in Numerical Methods applied to Natural Disasters FP7-PEOPLE-2013-IRSES



List of relevant RESEARCH PROJECTS (not comprehensive)

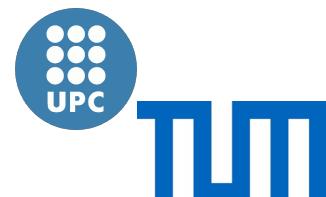
NATIONAL

- **PRECISE** - Numerical methods for PREdicting the behaviour of Civil StructurEs under water natural hazards – 2018-20
- **HIRMA** – Development and validation of a tool for defining the failure hydrogram in embankment dams considering the specific geomechanics 2016-20
- **PITON** - Particle-fluid-structure-InTeractiOn in Natural hazards – MIUR (Rita Levi Montalcini Project) 2018-21
- **COFRE** Diseño Industrial de una COmpuerta Fusible REcuperable para la mejora de la Seguridad Hidrológica de las Presas 2018-21
- **PABLO** Prototype for wedge-shaped blocks spillways 2018-21
-

PAST: XPRES, EDAMS, HIRMA, ACOMBO, NUMA, CALA, ACUÑA, DIABLO, AIDA, POLILAB, BALAMED, MONICAB, RESILTRACK,.....

LOCAL

- University SCHOLARSHIPS



AIM OF THE TALK

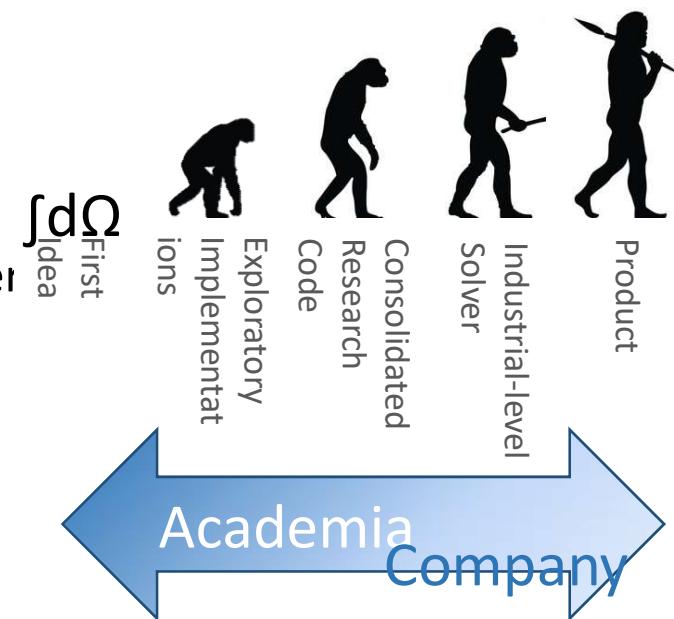
**THIS PRESENTATION WILL GIVE AN OVERVIEW OF A SELECTION
OF THE ACTIVE RESEARCH LINES in KRATOS**

Just keep in mind:

- Applications with different level of maturity
- Not all the features shown are usable by an end user just clicking the buttons of an interface (FOR THIS ->THE AFTERNOON SESSION!)

BUT

- You will see KRATOS potential





KRATOS IS HPC



1 HIGH PERFORMANCE COMPUTING

1.1 Parallel computing

1.2 Adaptive mesh refinement

1.3 Embedded Solvers

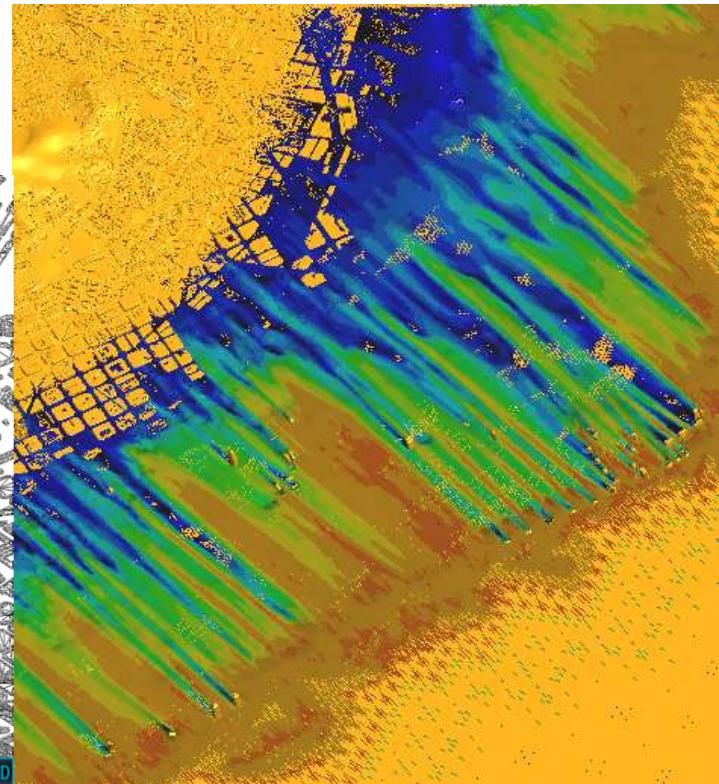
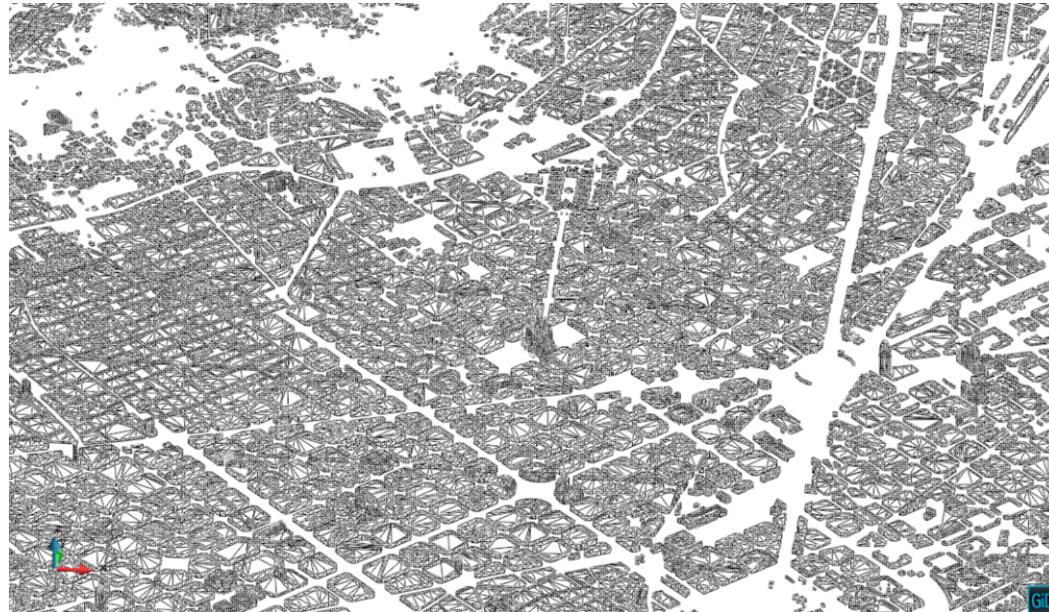
1.4 Uncertainty Quantification

1 HIGH PERFORMANCE COMPUTING

1.1 Parallel computing

- Prepared for large scale simulations

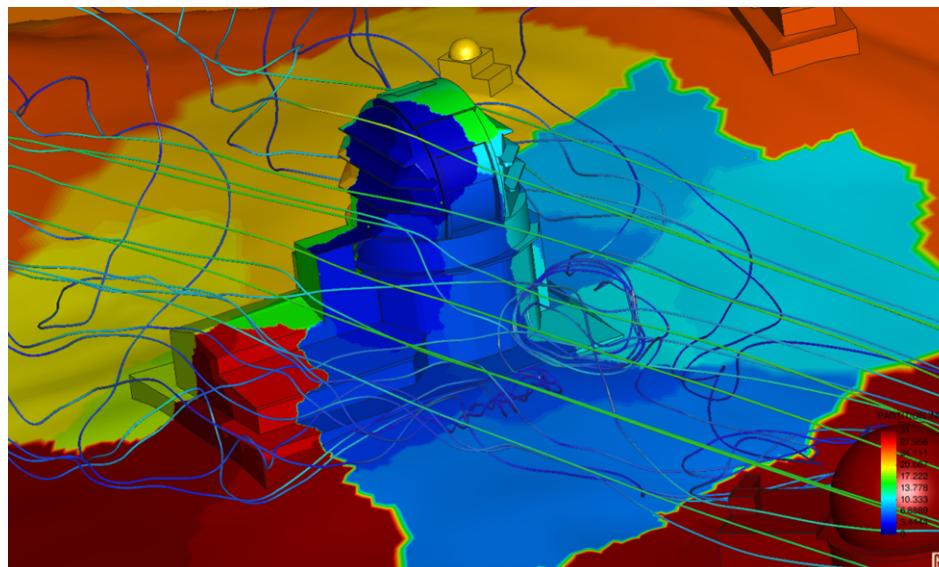
380M unstructured elements



1 HIGH PERFORMANCE COMPUTING

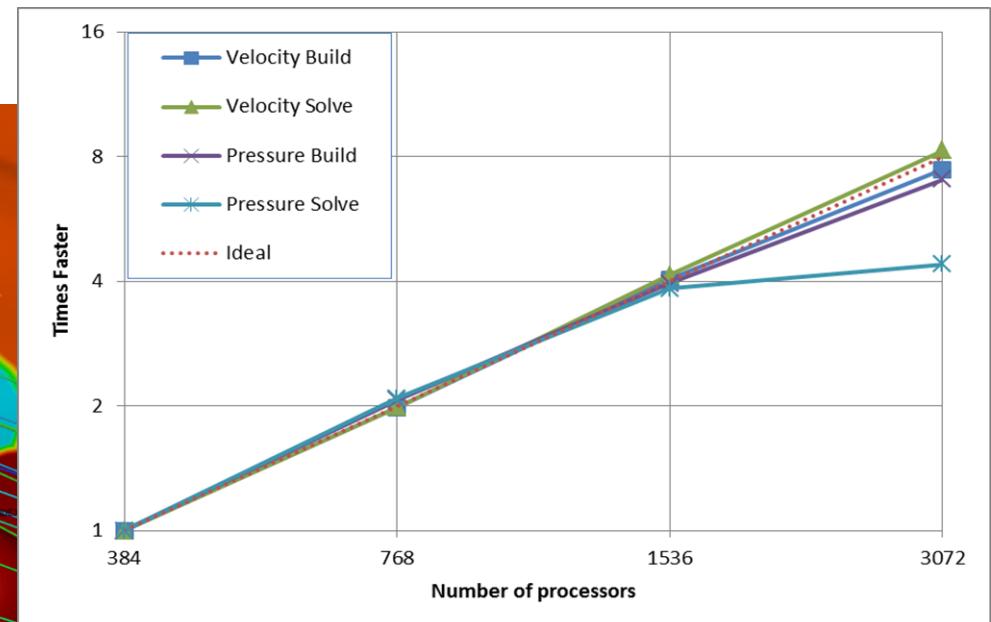
1.1 Parallel computing

- Prepared for large scale simulations
- Shared Memory Parallelization
- Some Applications are migrated to MPI
- Few GPU support



10

V KRATOS WORKSHOP - 25-27 March 2019 - TUM Munich, Germany



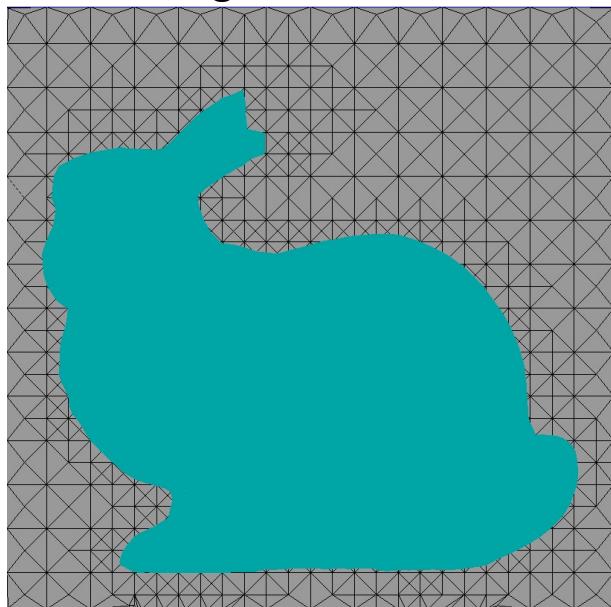
KRATOS
MULTI-PHYSICS

1 HIGH PERFORMANCE COMPUTING

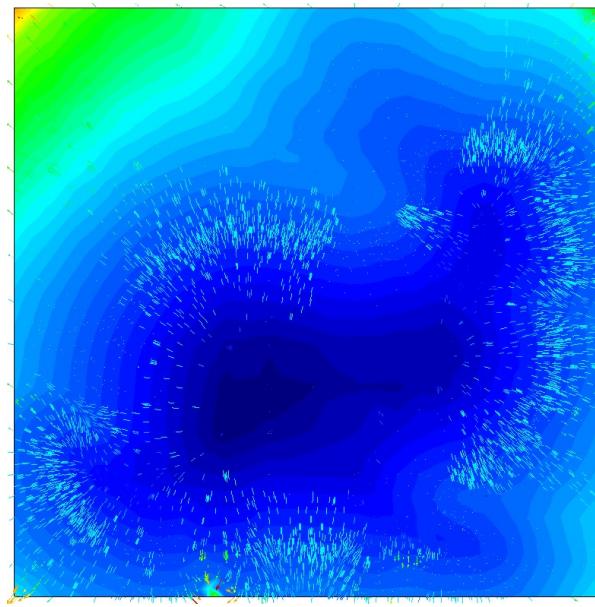
1.2 Adaptive mesh refinement

LEVEL SET REMESHING

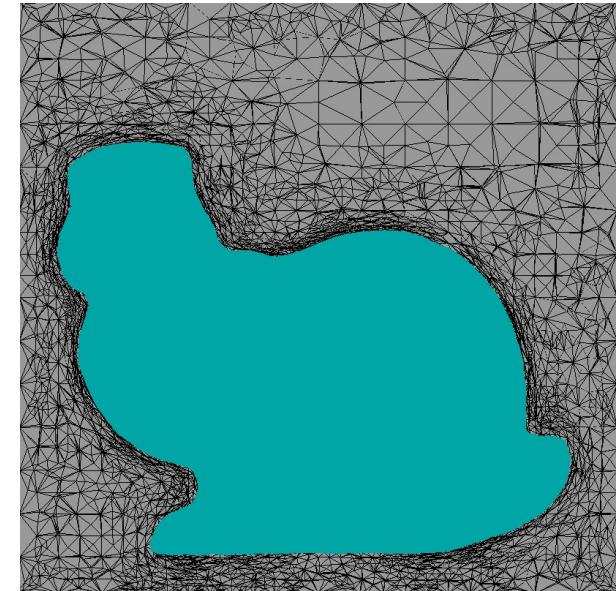
Original mesh



Gradient of distance

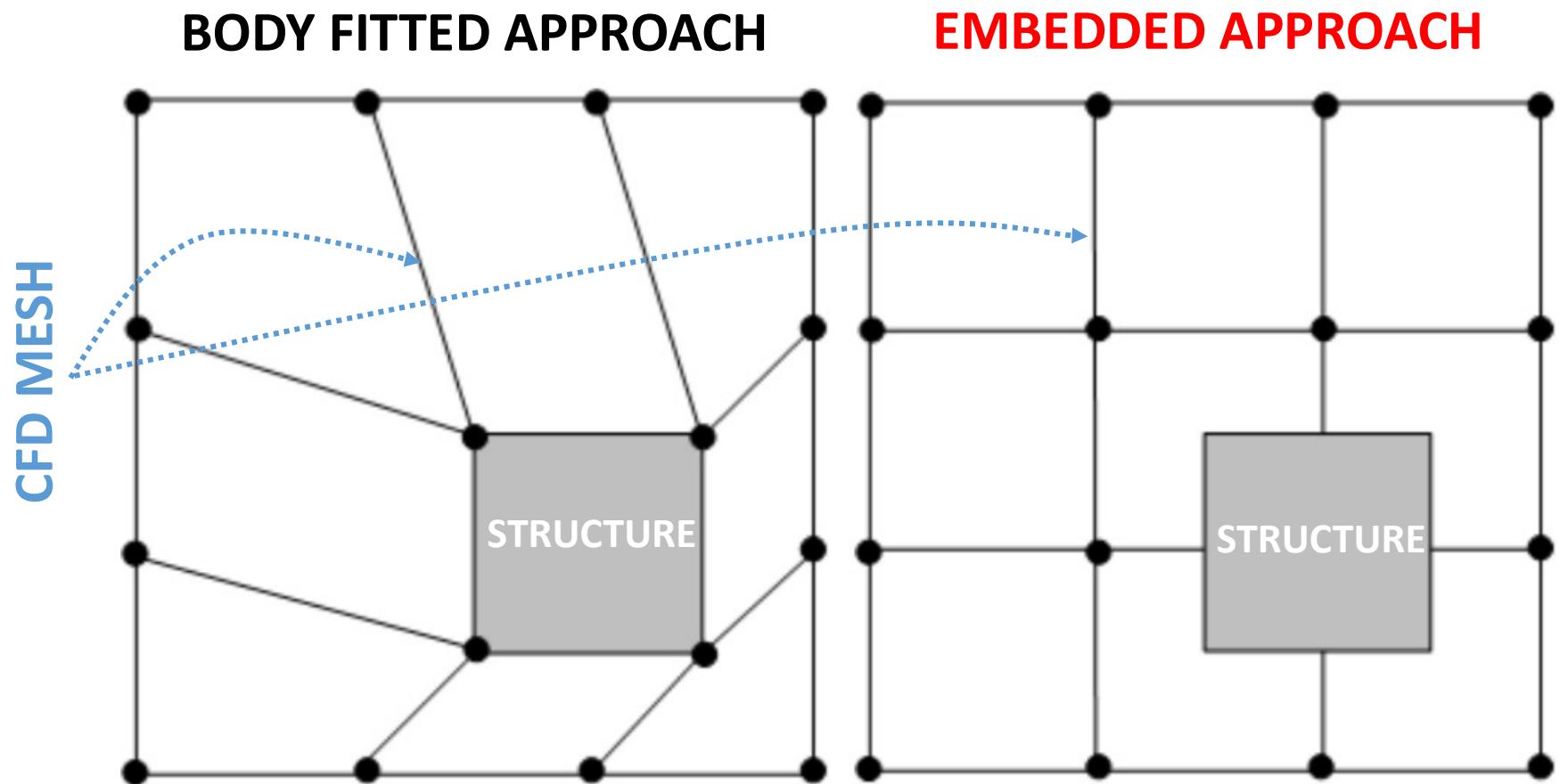


Final mesh



1 HIGH PERFORMANCE COMPUTING

1.3 Embedded techniques

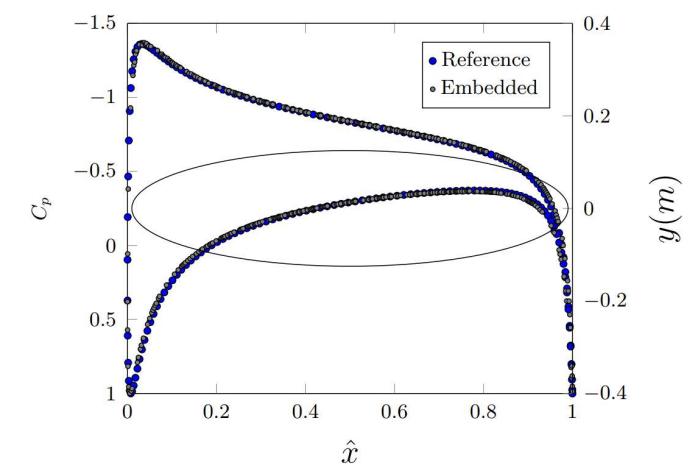
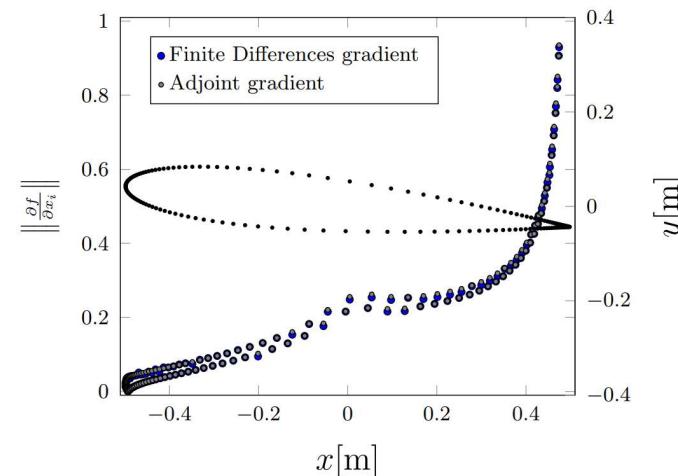
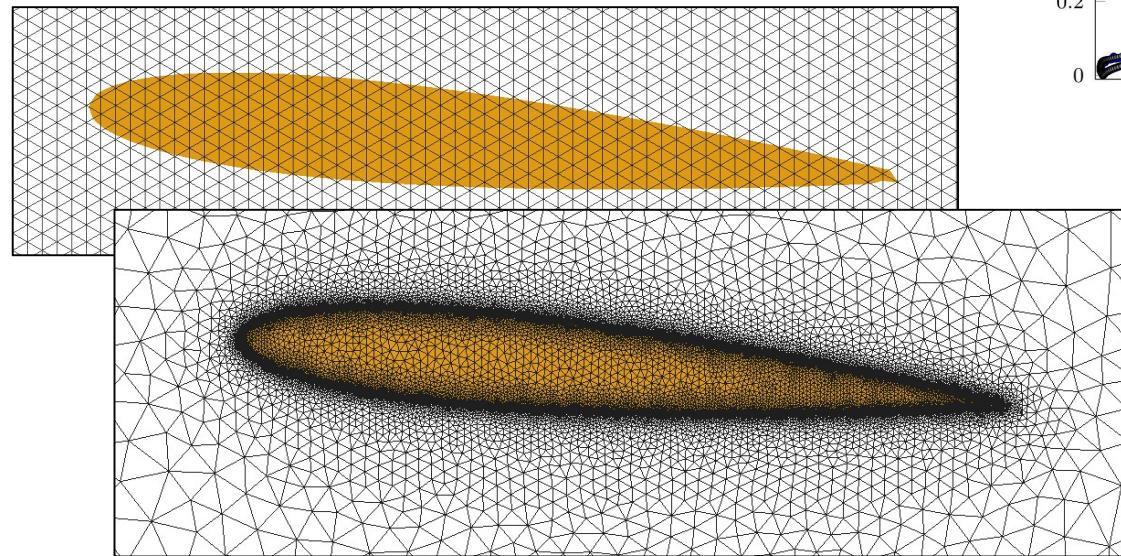


1 HIGH PERFORMANCE COMPUTING

1.2 Adaptive mesh refinement

1.3 Embedded techniques

Integration of [MMG library \(INRIA\)](#) in KRATOS for Embedding geometries in the CFD mesh



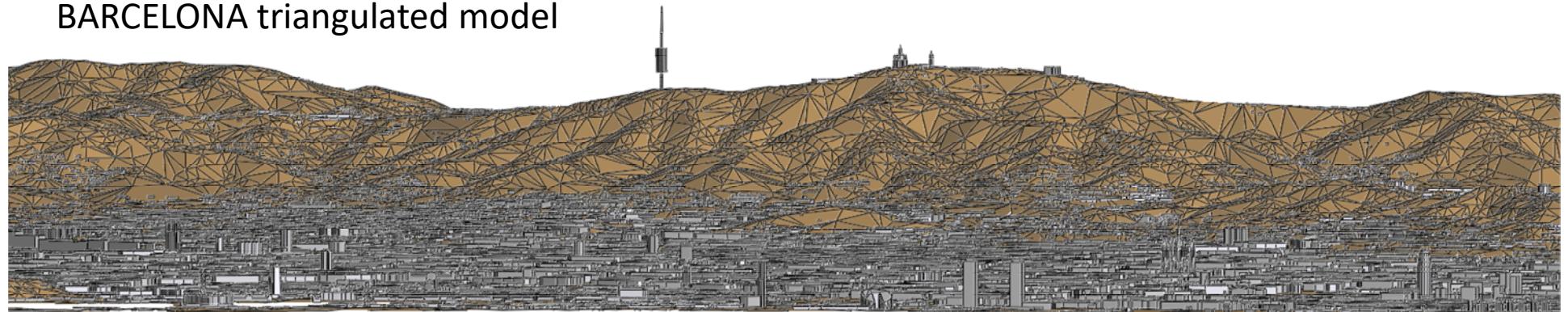
1 HIGH PERFORMANCE COMPUTING

1.2 Adaptive mesh refinement

1.3 Embedded techniques

Extremely large model
Extremely dirty information

BARCELONA triangulated model

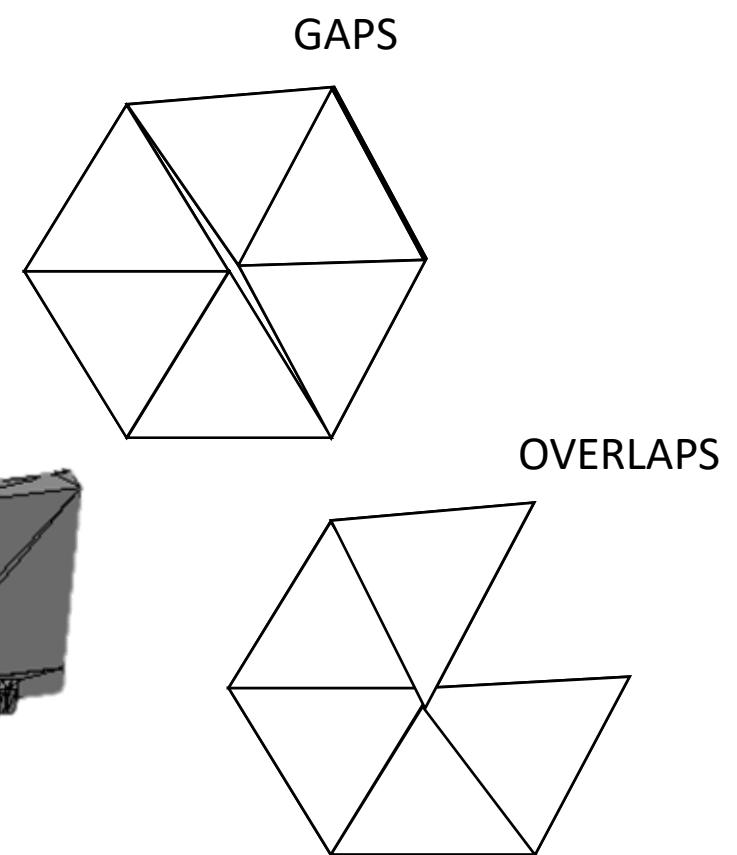
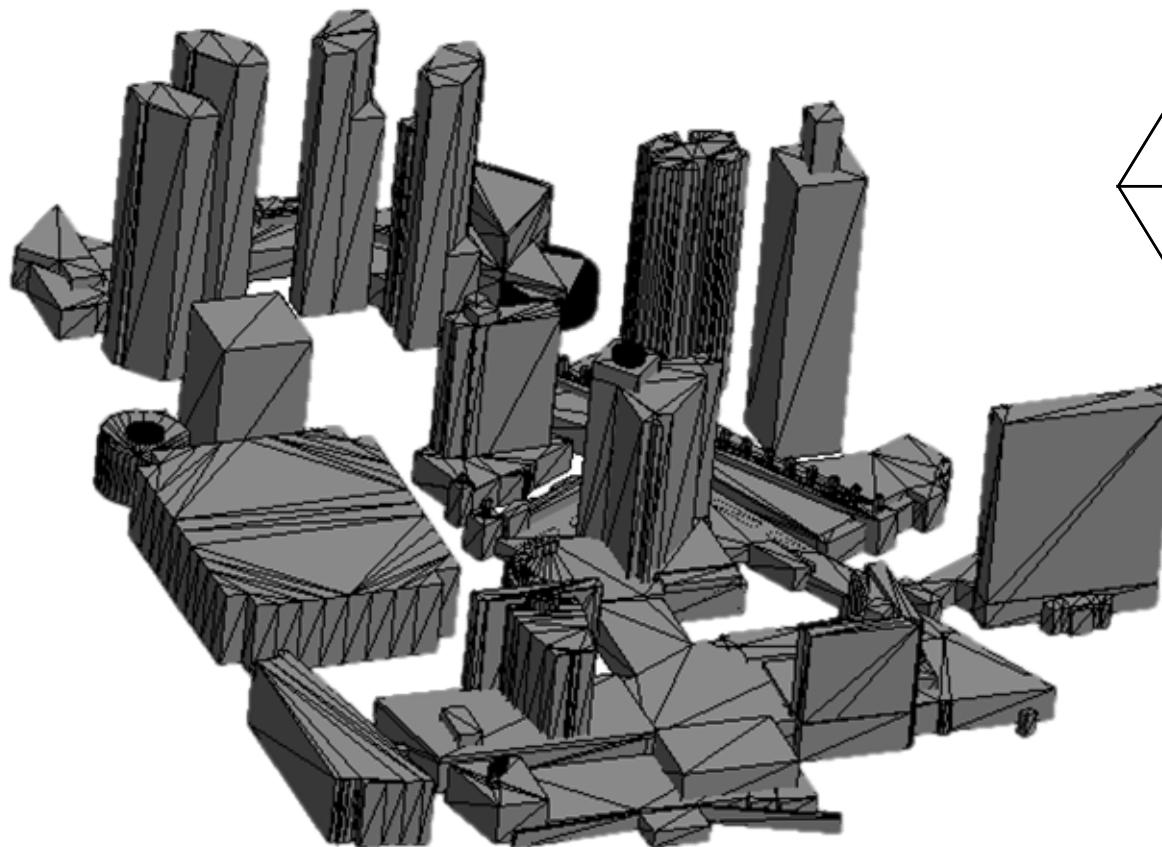


1 HIGH PERFORMANCE COMPUTING

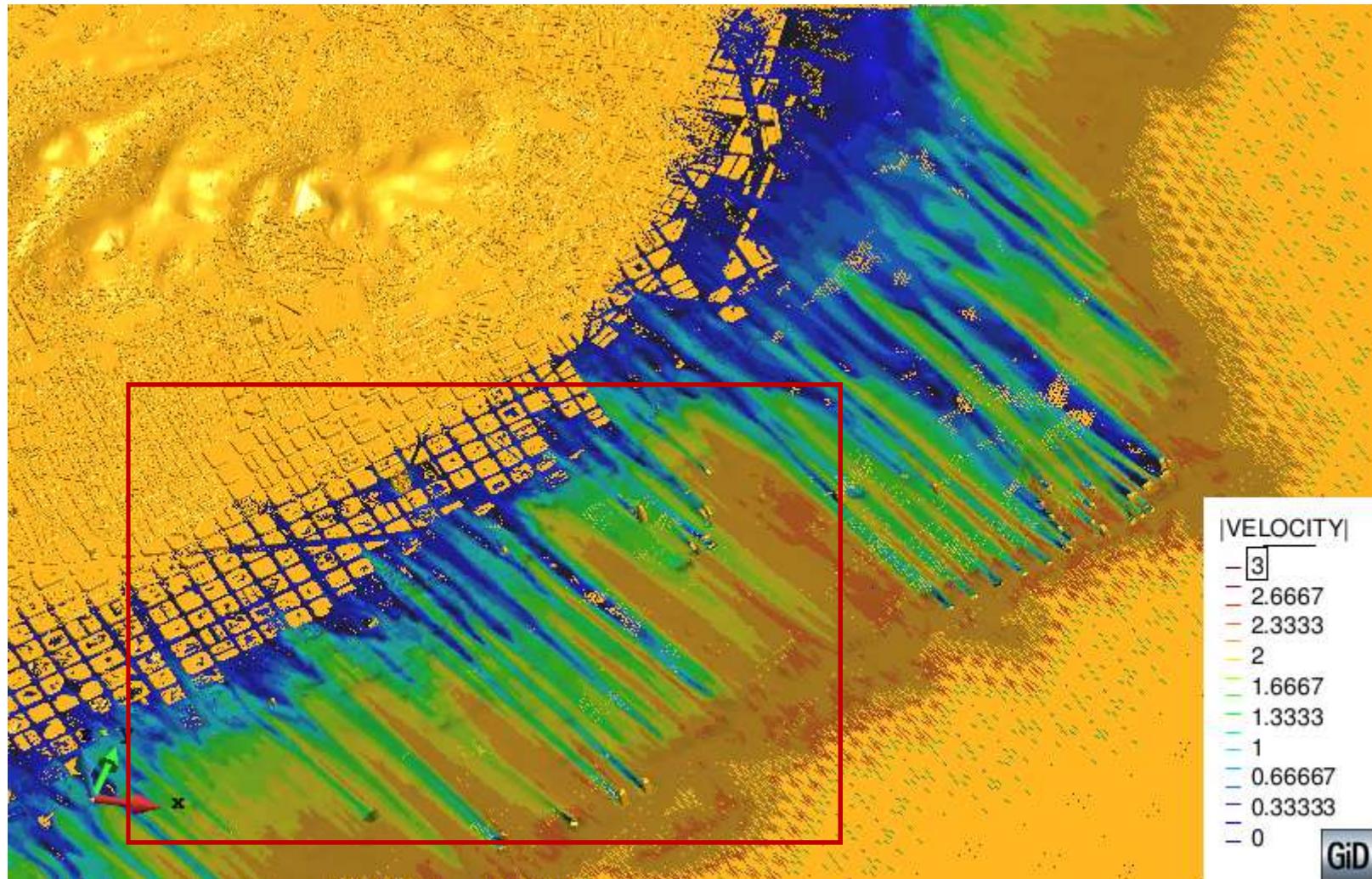
1.2 Adaptive mesh refinement

1.3 Embedded techniques

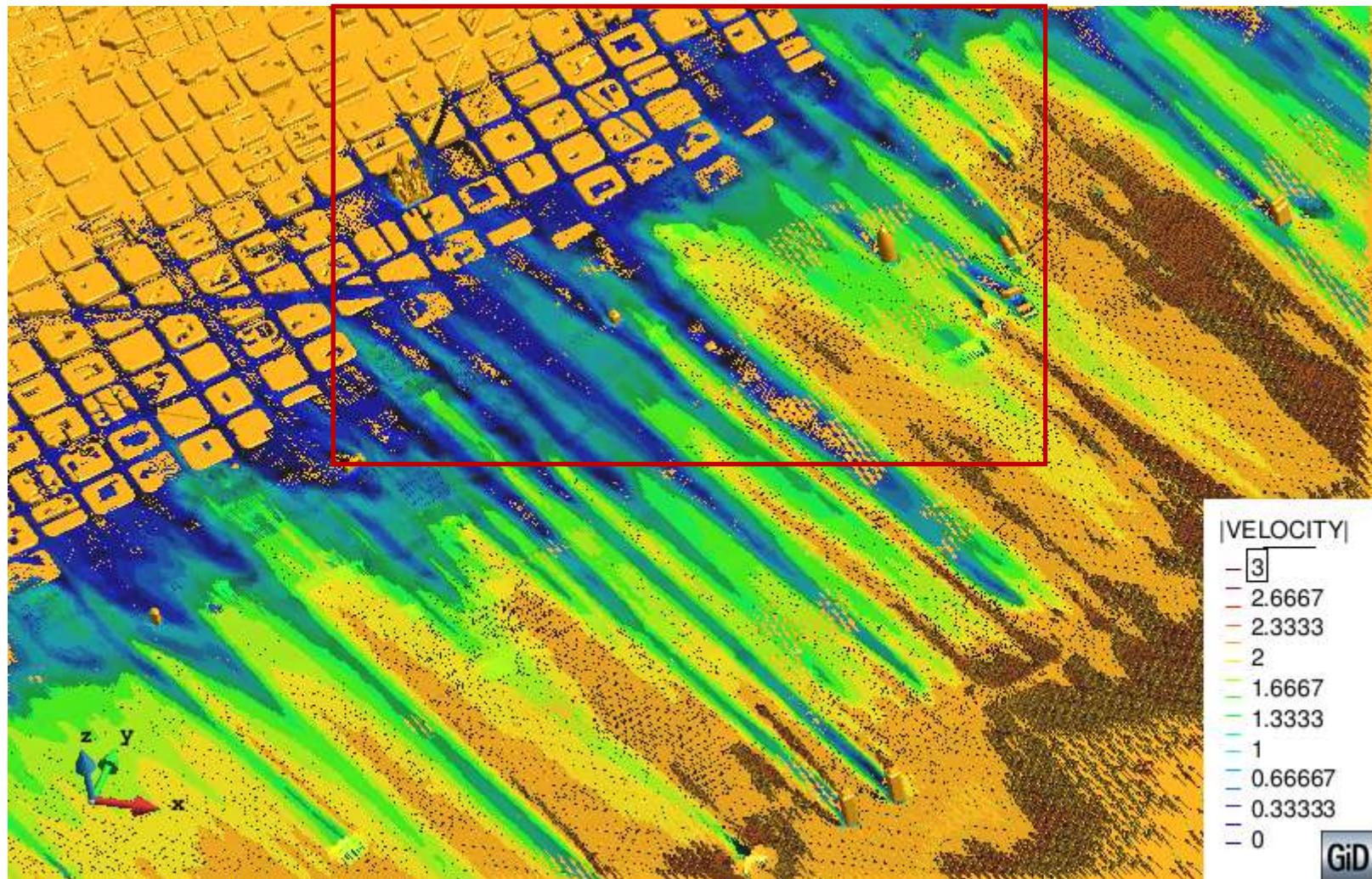
- STL-like non conforming meshes are a standard
- Not suitable for calculation



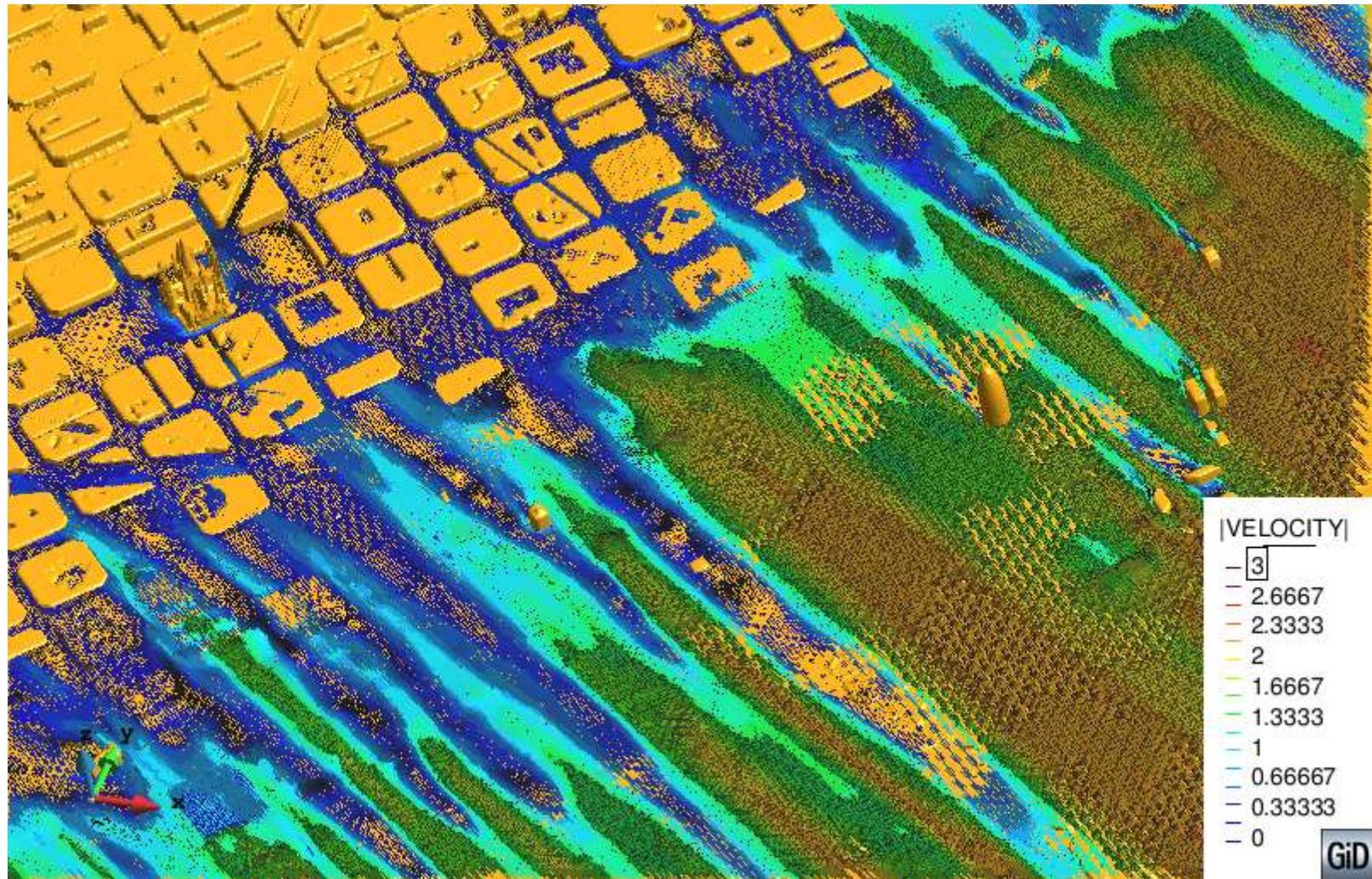
Wind over Barcelona city



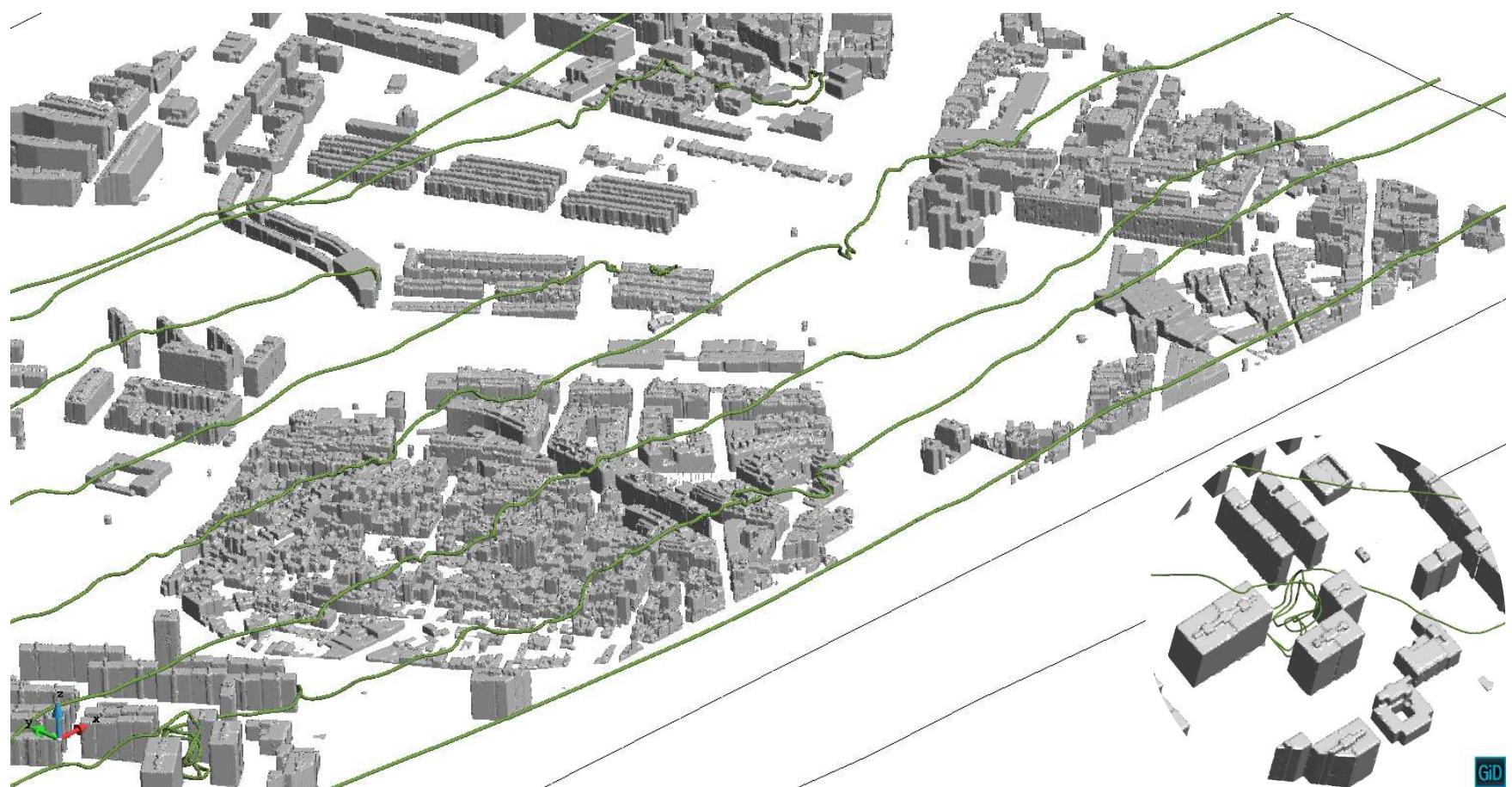
Wind over Barcelona city



Wind over Barcelona city

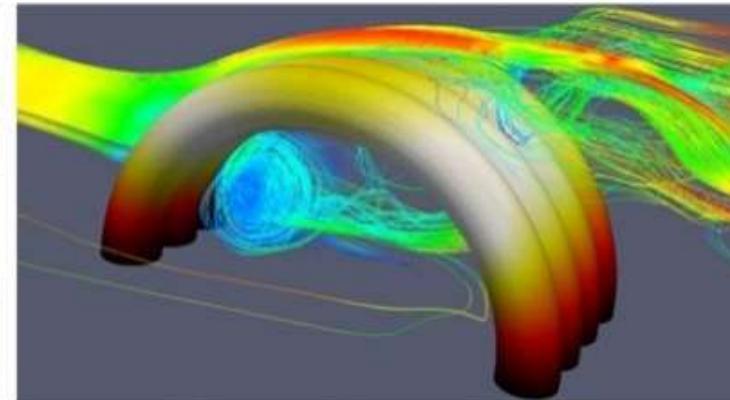


Example: 2.5 x 1.5 km CFD from topographical data (60M elements)

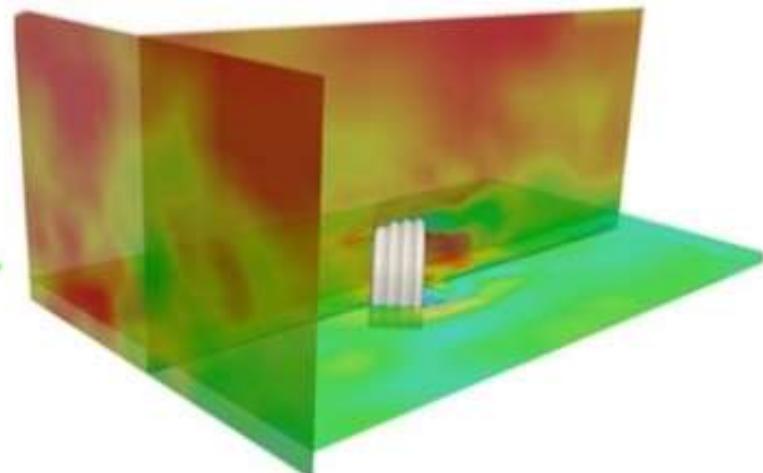
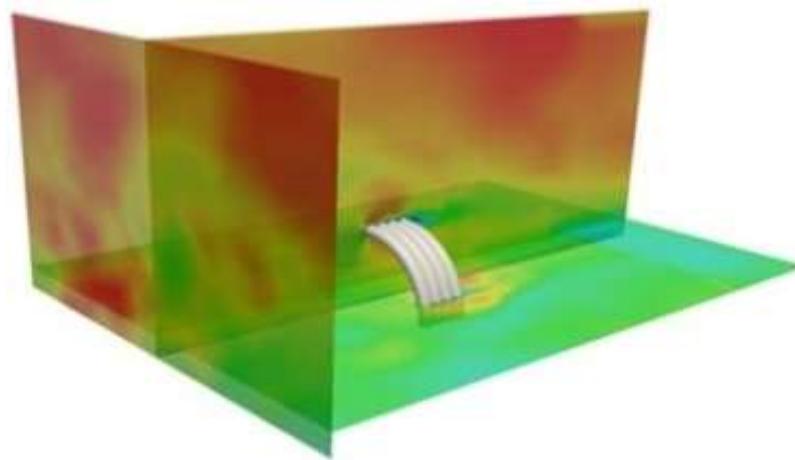


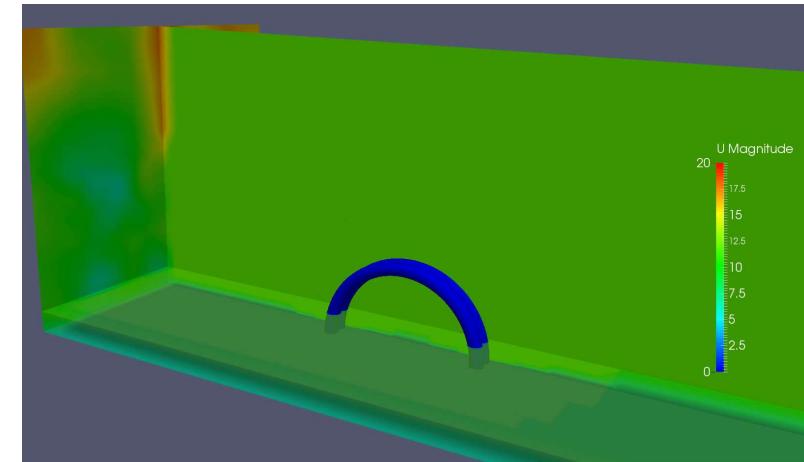
The ULITES project and the first steps towards the VIRTUAL WIND TUNNEL

ULITES

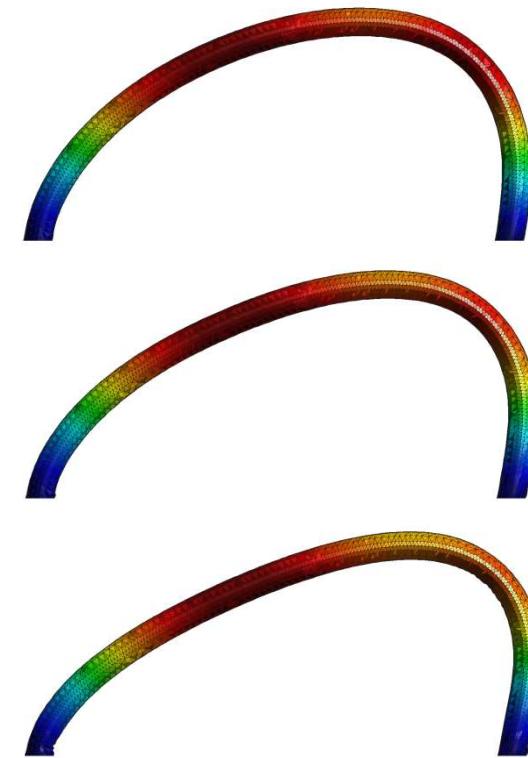


© Buildair





ULITES

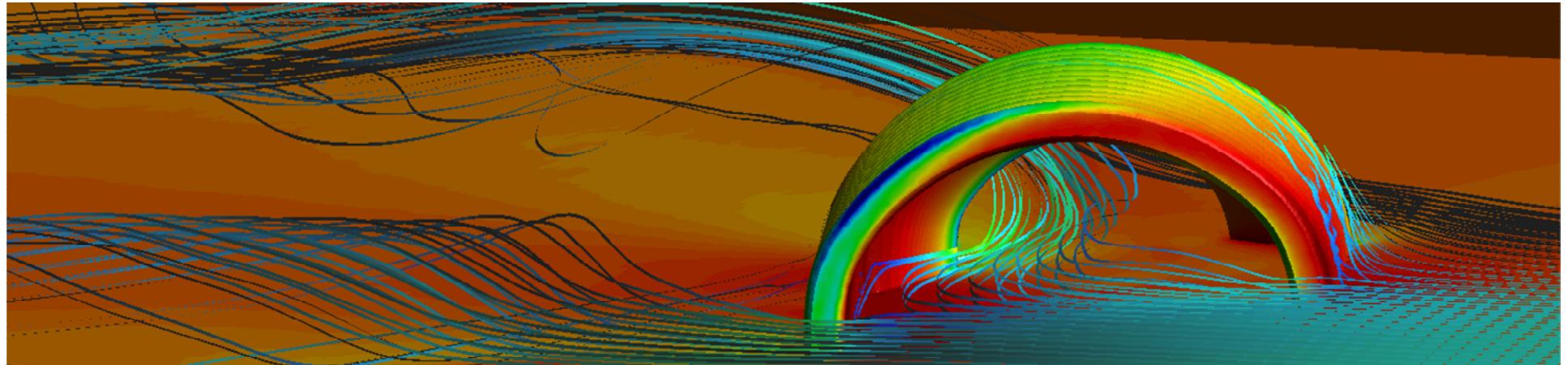


Generated synthetic wind at inlet and CFD:
wind field around prototype

- ⇒ Potential local wrinkling
- ⇒ Nonlinear structural behavior
- ⇒ Large deformations
- ⇒ Simulation of fluid-structure interaction

The logo for ULITES, featuring the word "ULITES" in a bold, blue, sans-serif font.

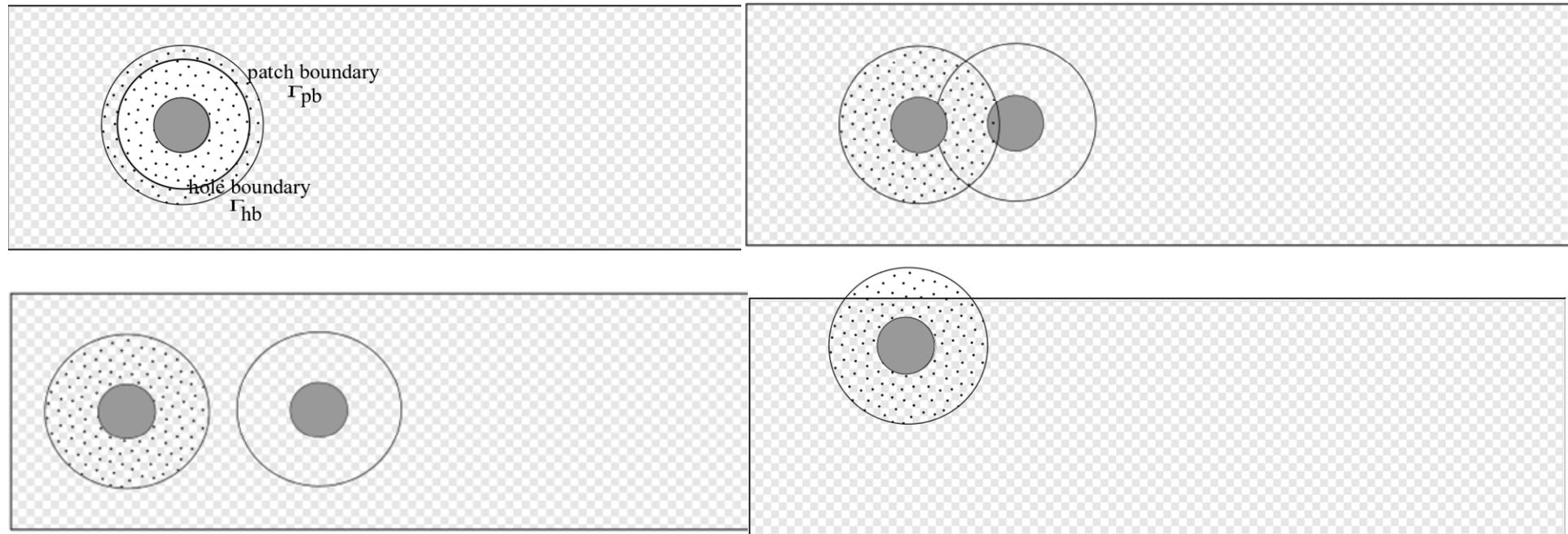
Ulites represented the opportunity to set up the basis of the **VIRTUAL WIND TUNNEL**



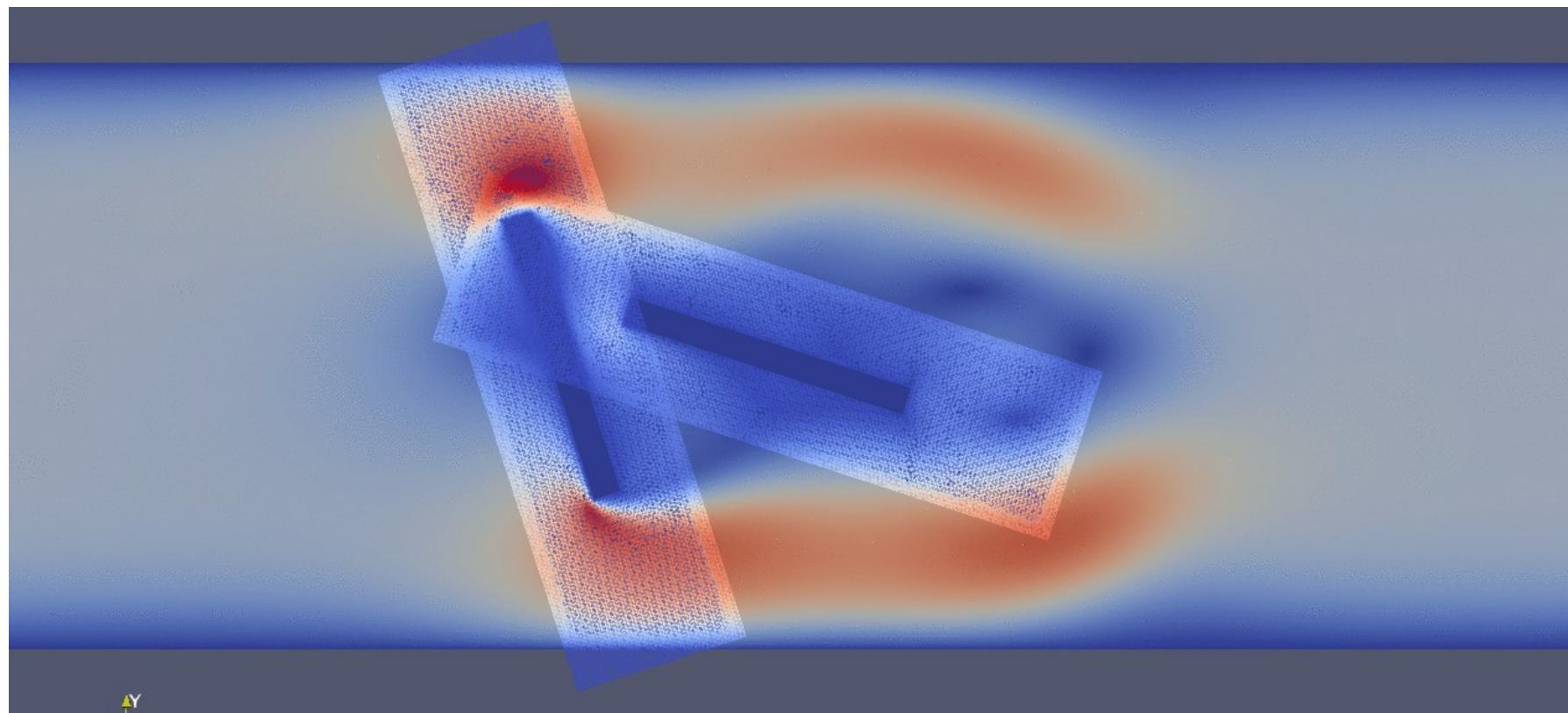
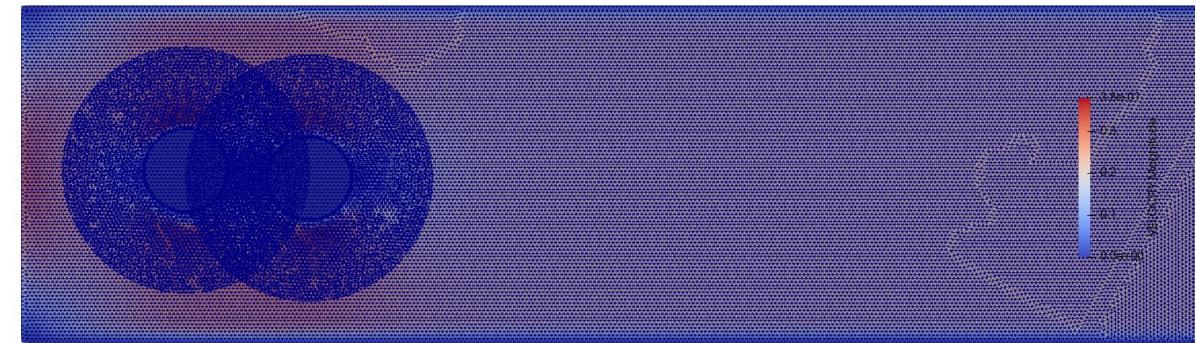
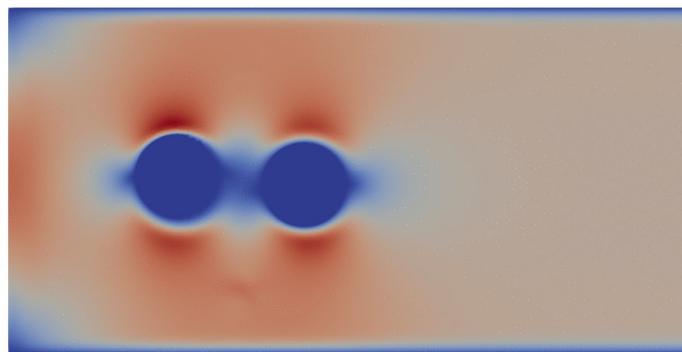


OTHER FEM FEATURES

CHIMERA METHOD



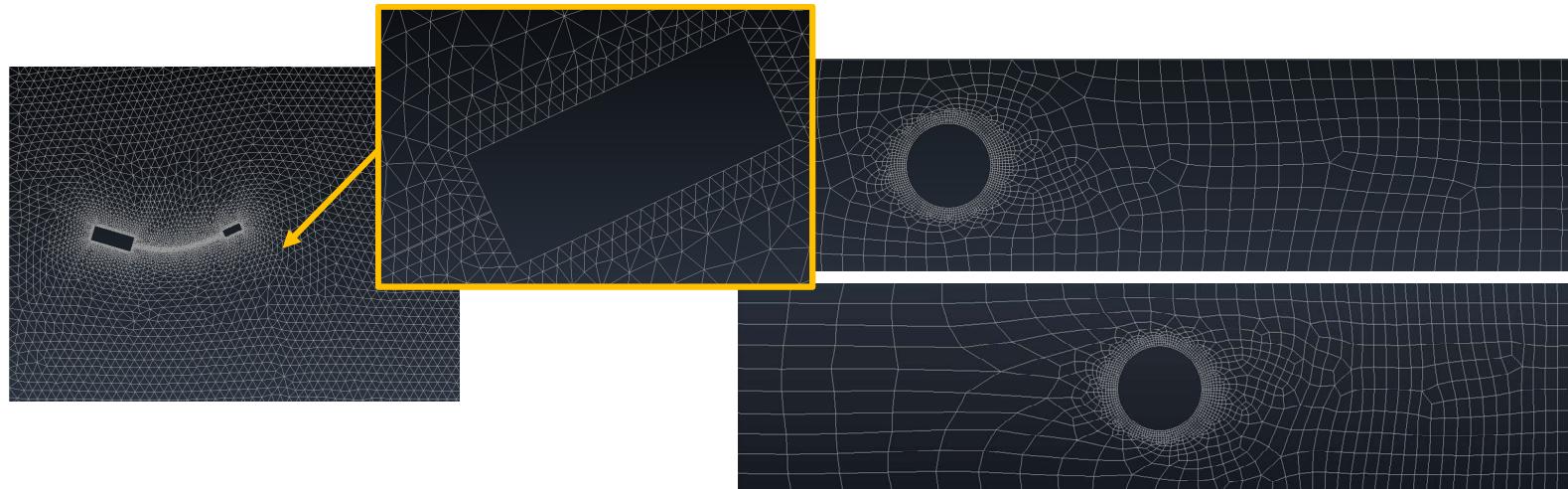
background Ω_b patch Ω_{p1} patch Ω_{p2} structure patches overlaps



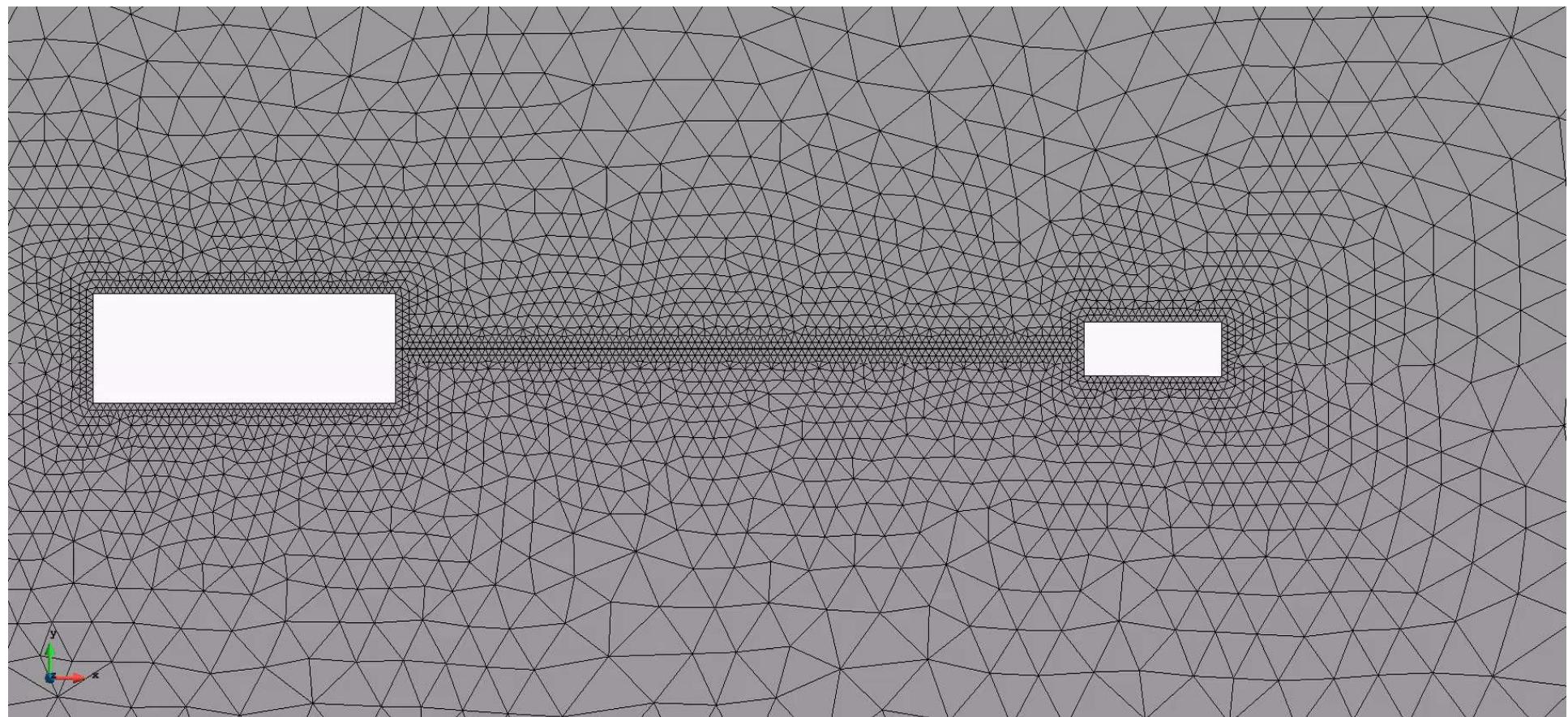
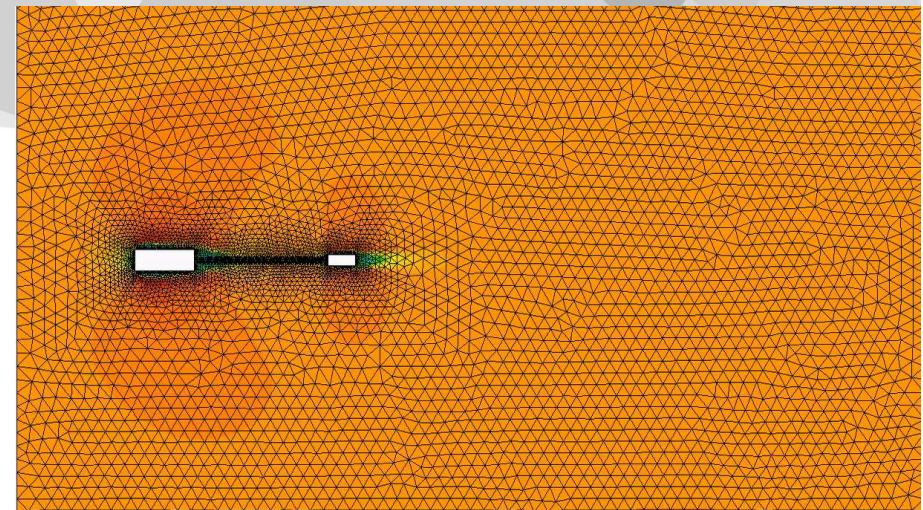
MESH MOVING TECHNIQUE for FSI and ALE CALCULATIONS



- Laplacian equation or „structural similarity“ approach
- 2D and 3D with different types of elements
- Used in **FSI and structural optimization**

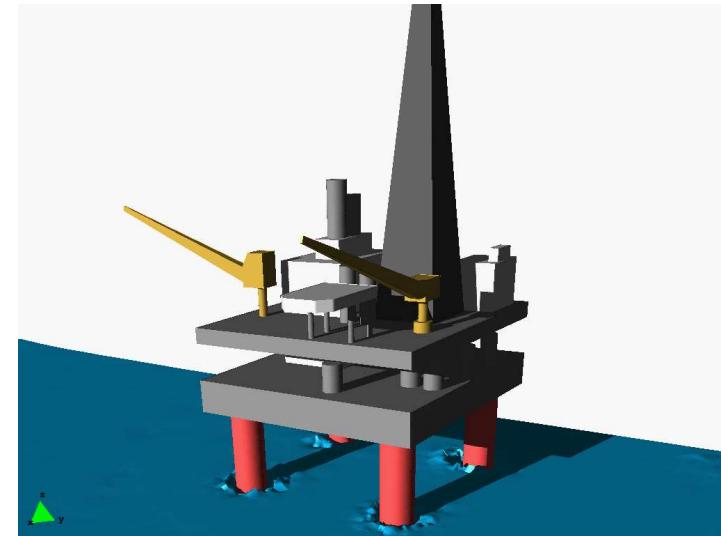
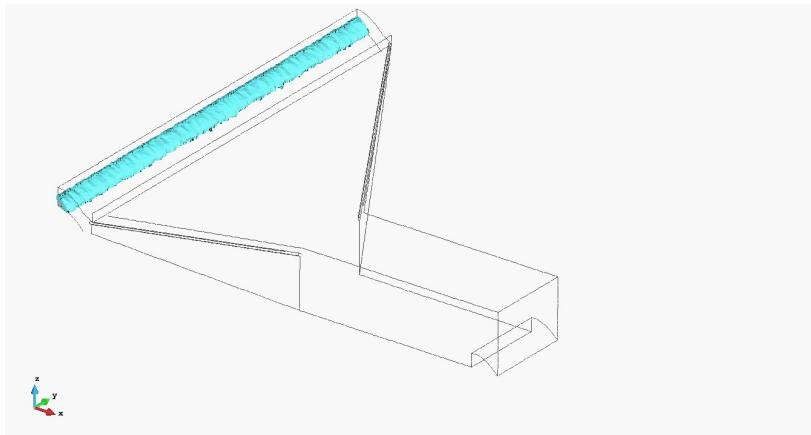


ALE METHODS

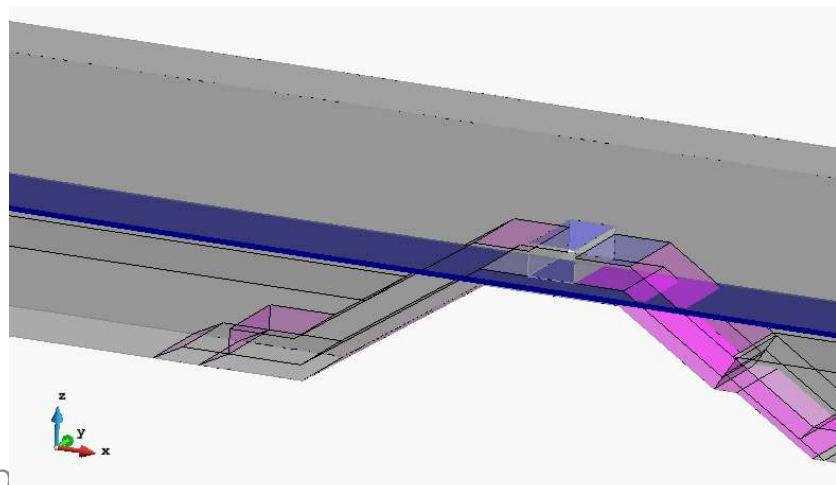


LEVEL SET TECHNIQUES for single and multifluid

DAM SPILLWAYS



- Navier-Stokes Eulerian Solver
- Level set technique for tracking the free surface

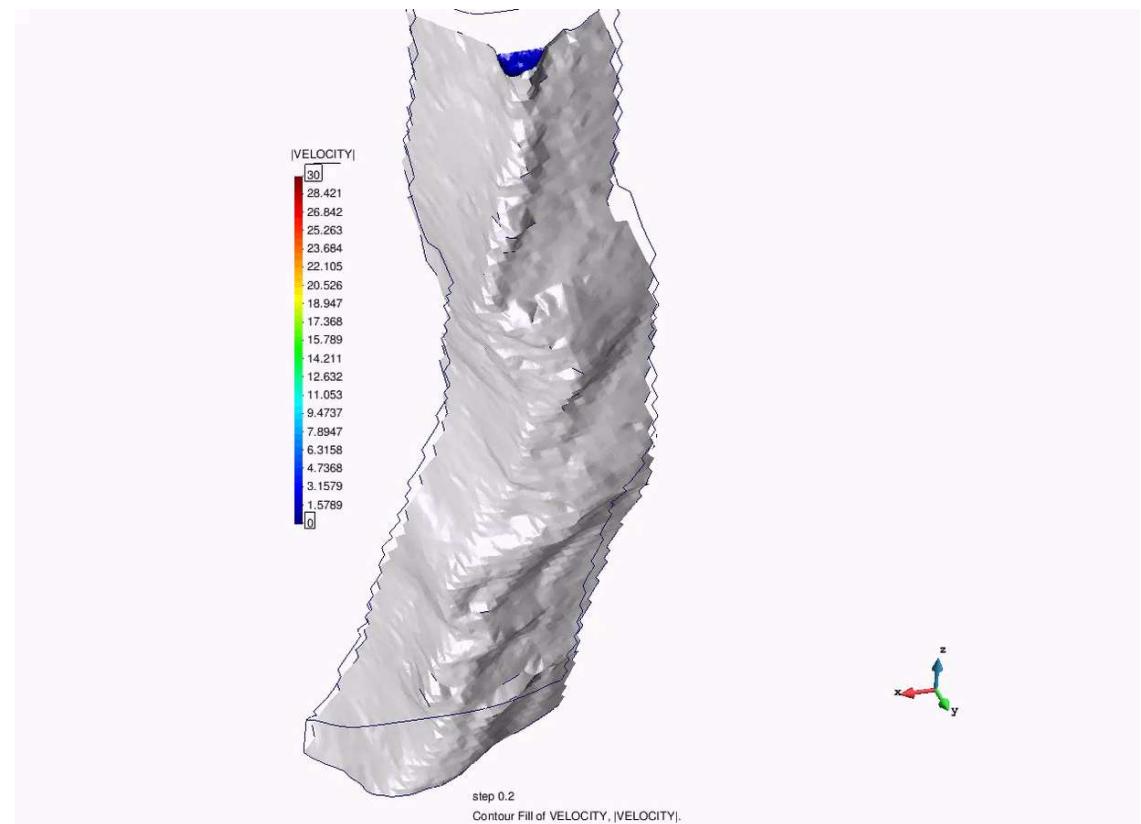


WAVES ON HARBOUR PROTECTION DIKES

LEVEL SET TECHNIQUES for single and multifluid

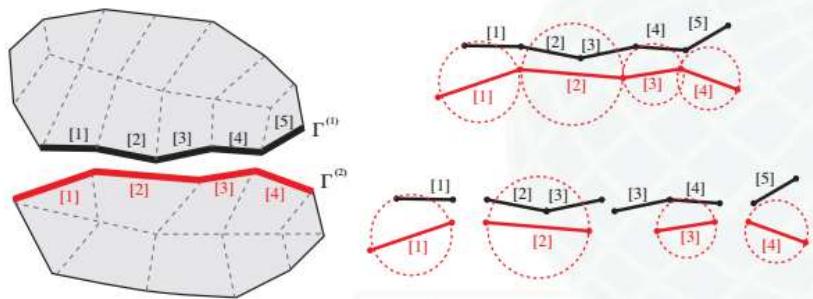
Computation data

- 84 processors
- computation time of 2 hours
- 700 000 elements
- 900 time steps

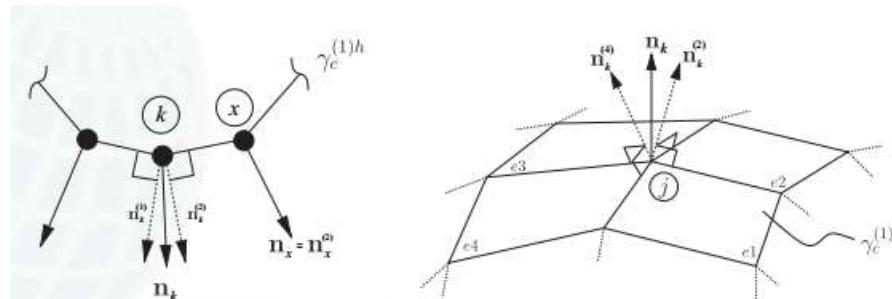


CONTACT MECHANICS

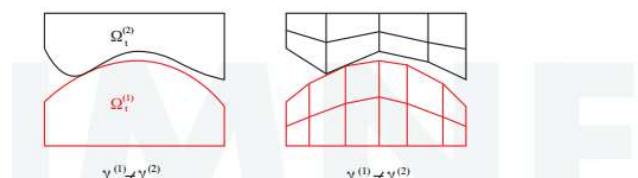
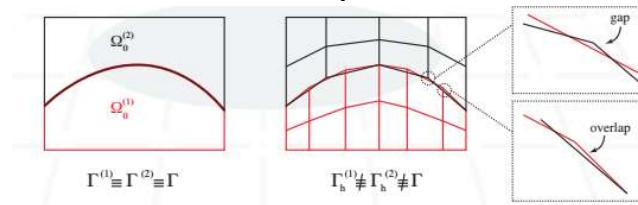
Local search



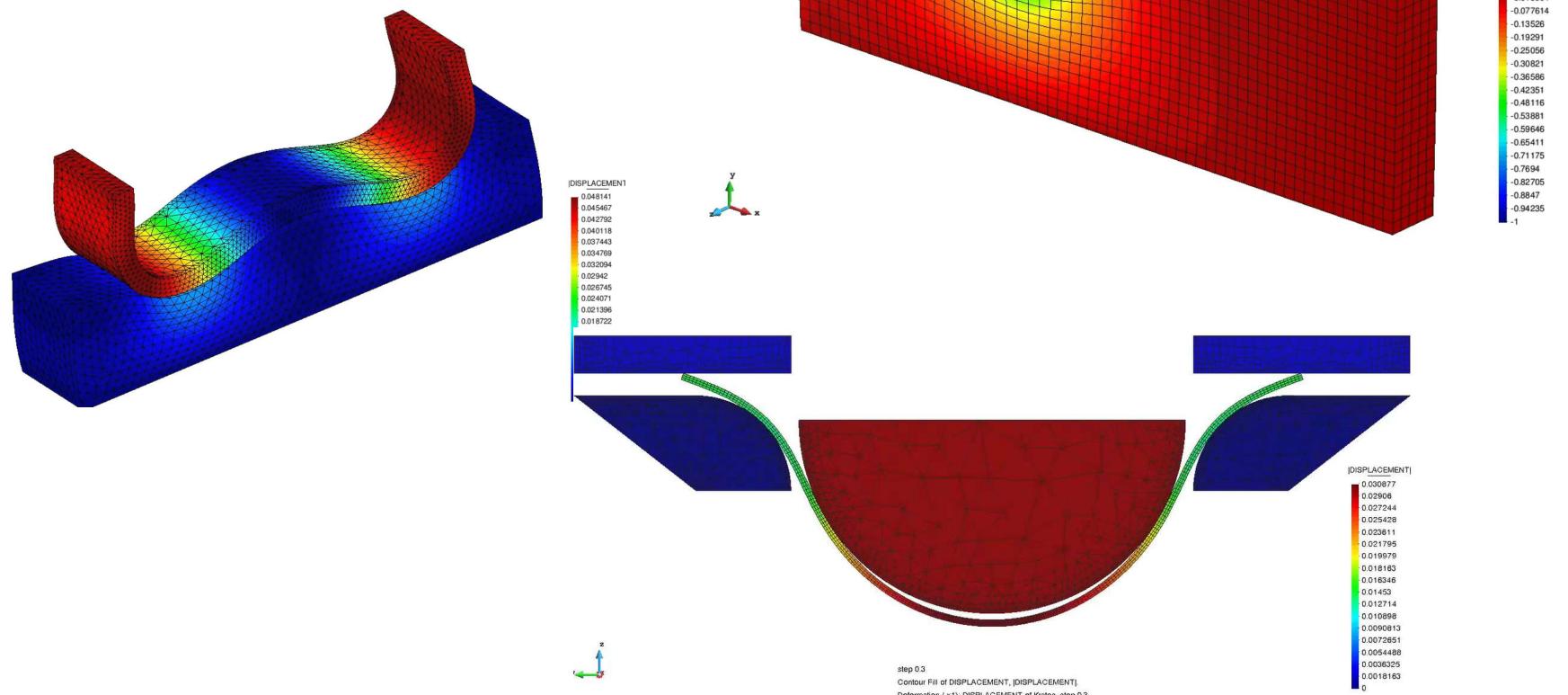
Normal averaging



Interface overlap



CONTACT MECHANICS





...IS KRATOS “JUST” A FINITE ELEMENT PLATFORM?



To be honest....this was the initial idea several years ago...

BUT

the answer is **NO**,

KRATOS IS NOT JUST FINITE ELEMENTS!



KRATOS IS ALSO A PLATFORM FOR PARTICLE METHODS

Particle methods can be divided in:

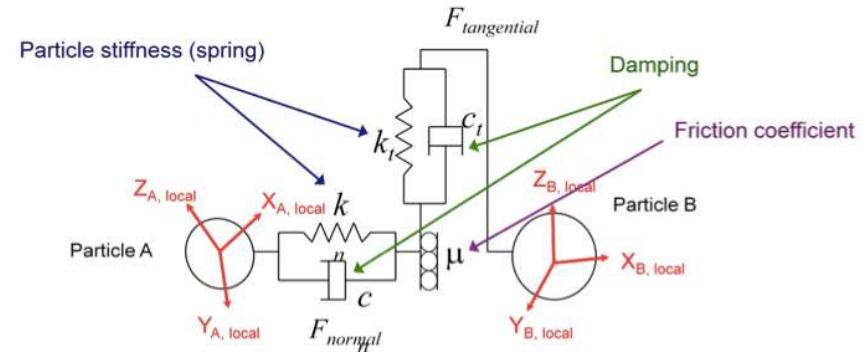
- Discrete (DEM)
- Continuum based (PFEM, MPM)
 - The **weak form** of the governing equations with suitable boundary and initial condition are solved



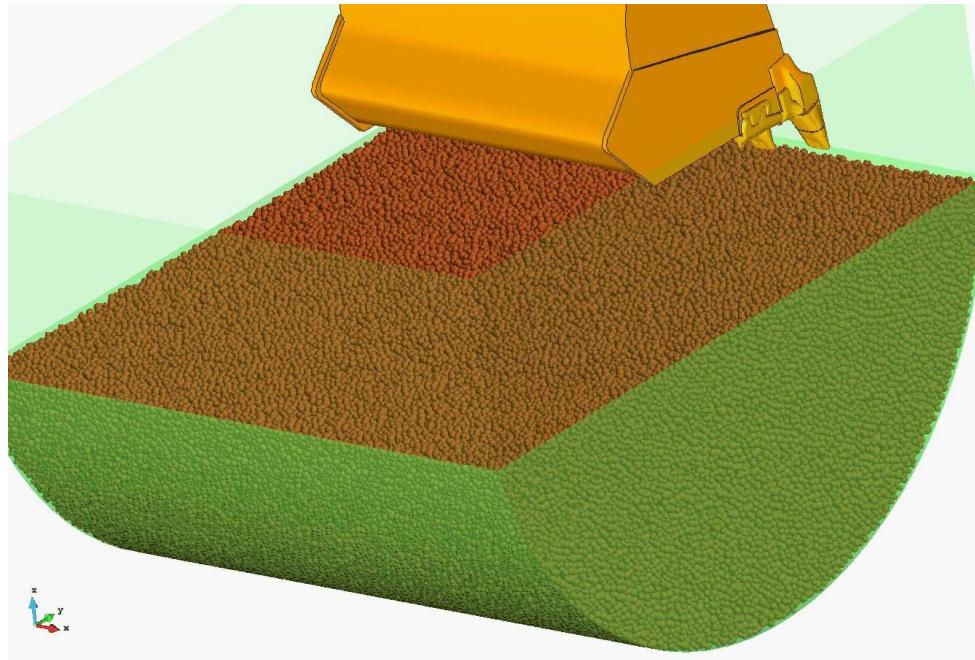
DEM IN KRATOS

DEM

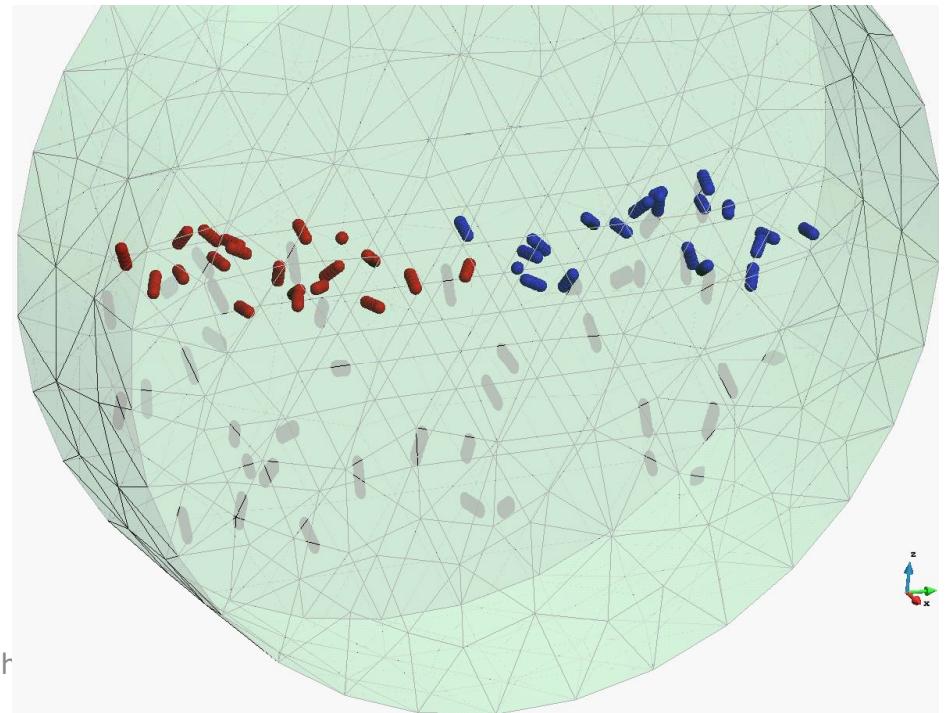
- Cohesive and non-cohesive materials
- Spherical and non-spherical particles
- Parallel computing
- Several contact laws
- Python interface
- Easy/fast coupling with other Kratos apps



Spherical particles

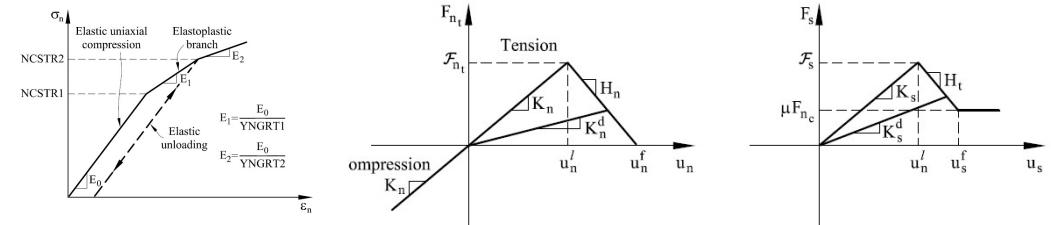


Non-spherical particles

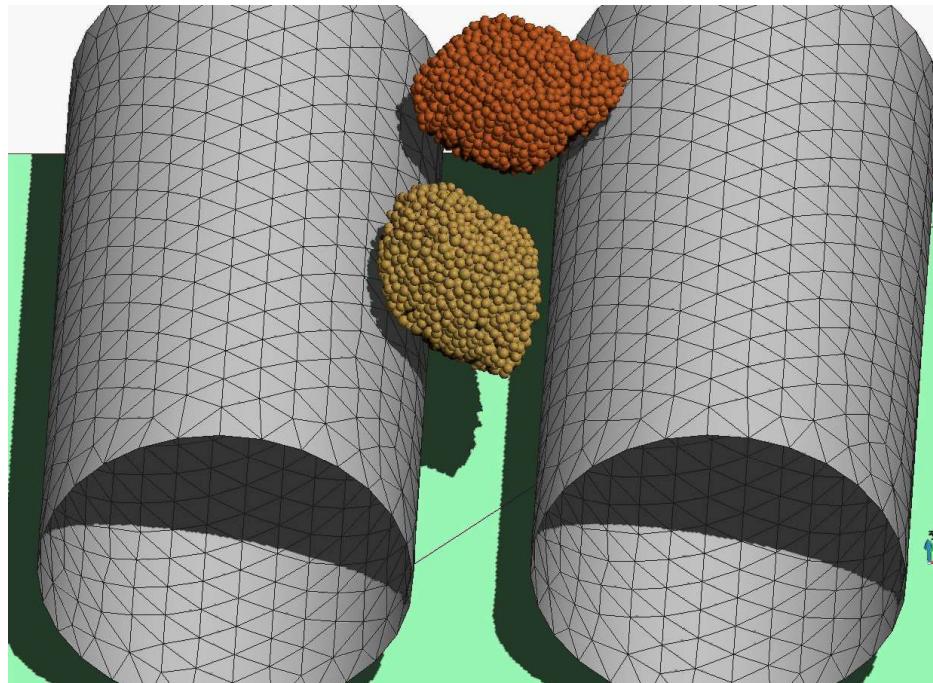


DEM

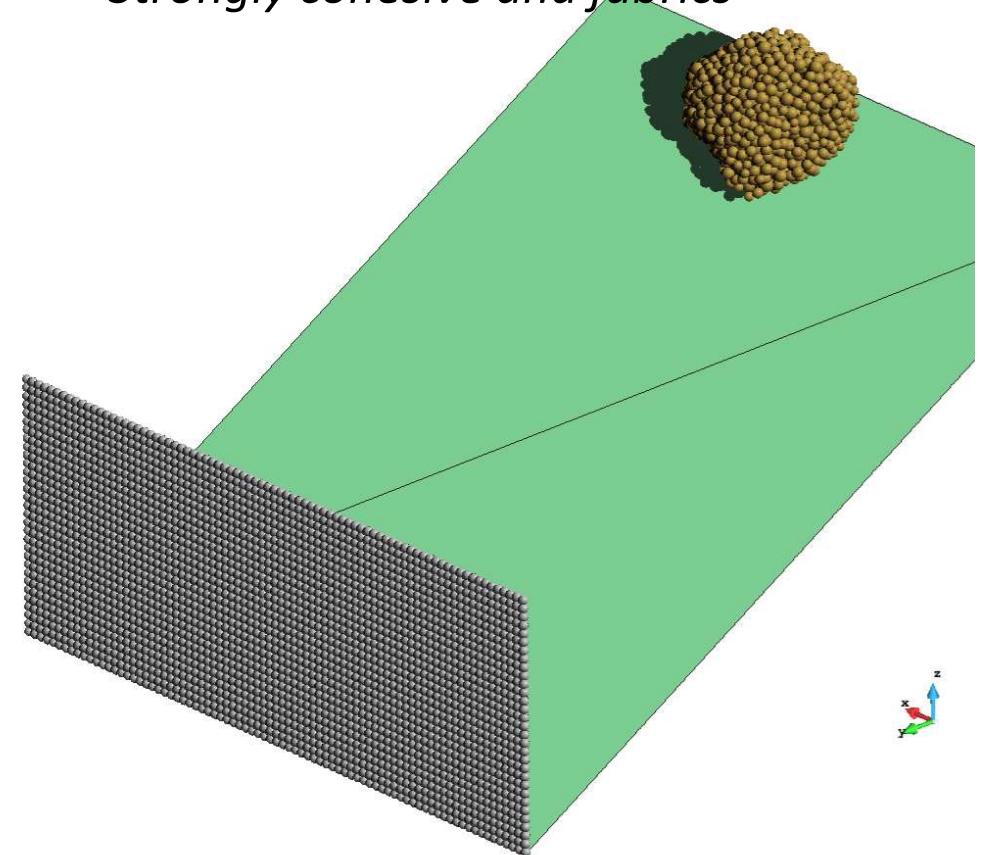
- Bonded particles
- Custom constitutive law
- Bond damage, plasticity, fracture, ...
- Sintering



Slightly cohesive



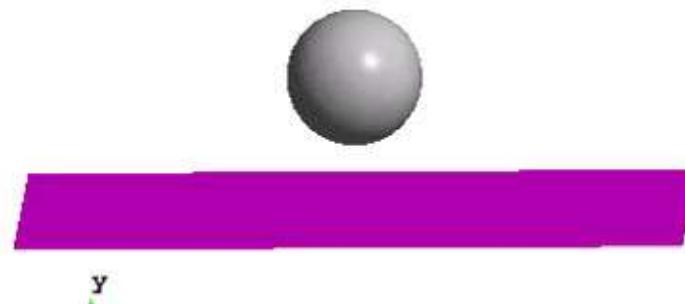
Strongly cohesive and fabrics



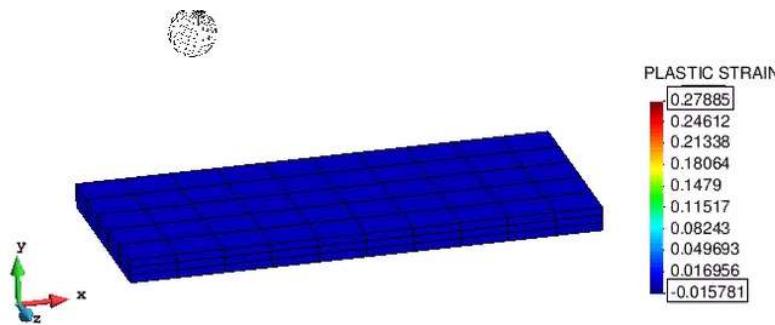


DEM-FEM

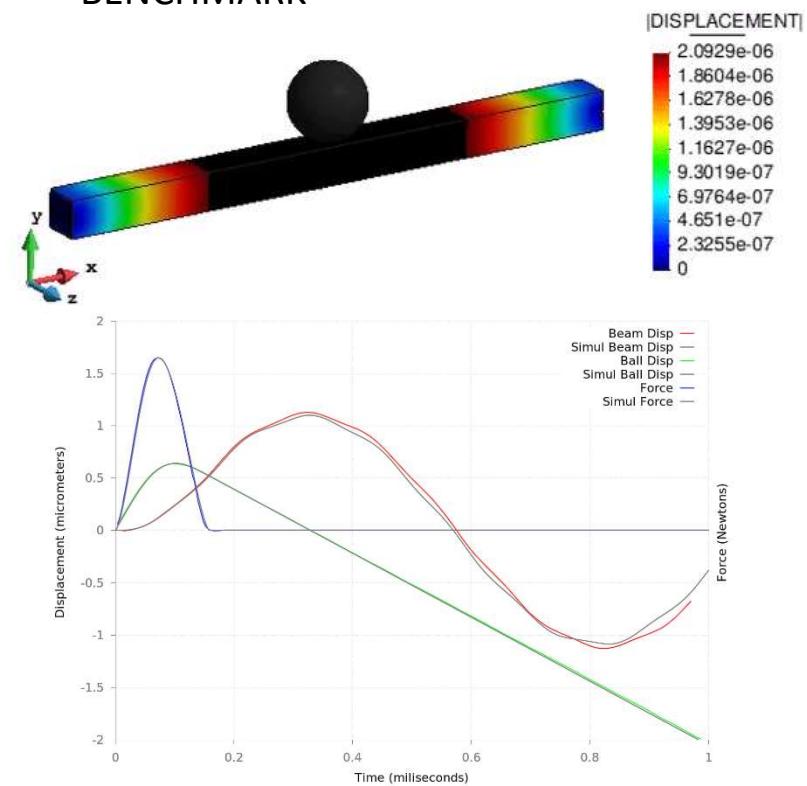
1. MEMBRANE ELEMENTS

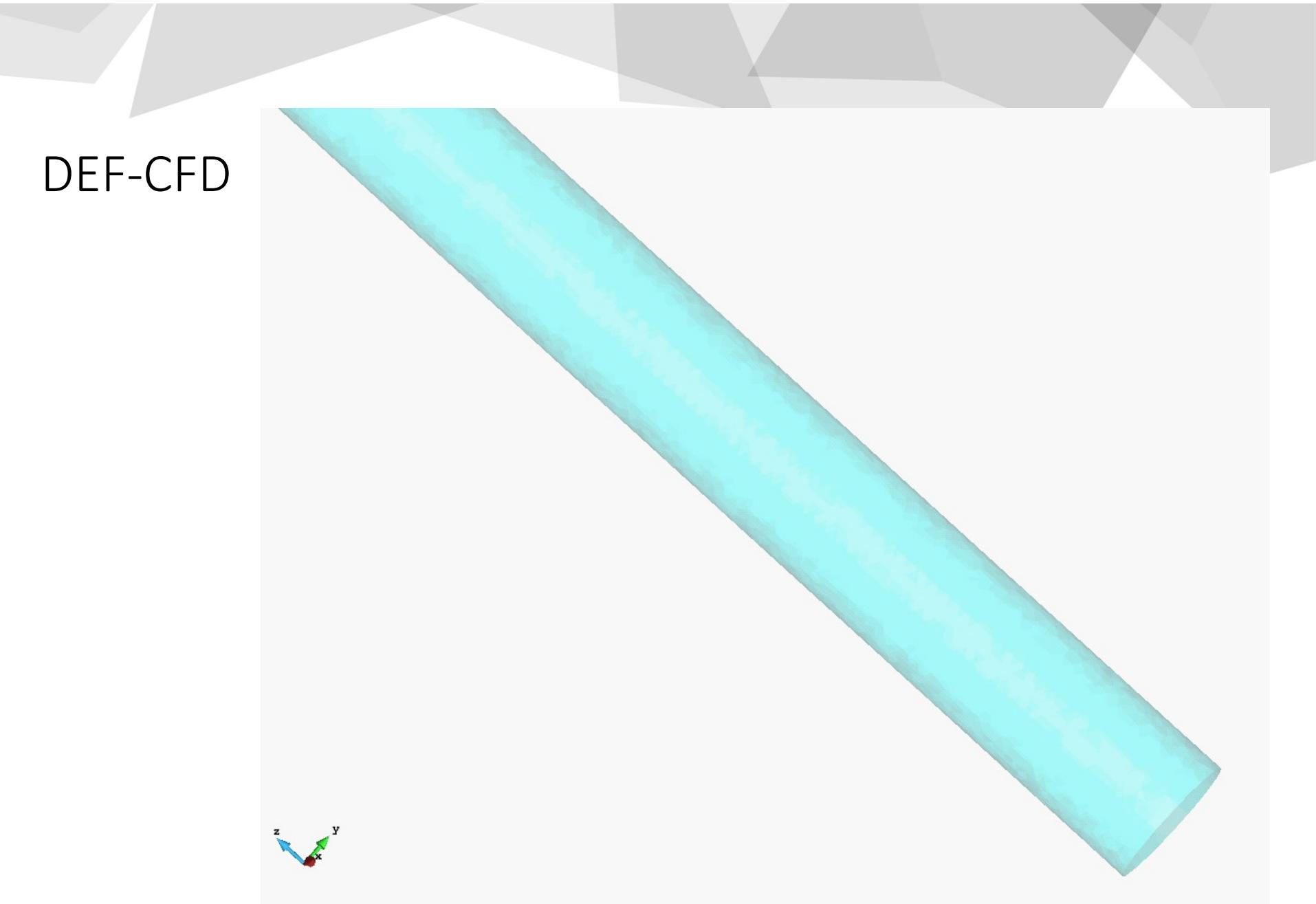


3. PLASTICITY MODEL



2. PARTICLE-STRUCTURE COLLISION BENCHMARK







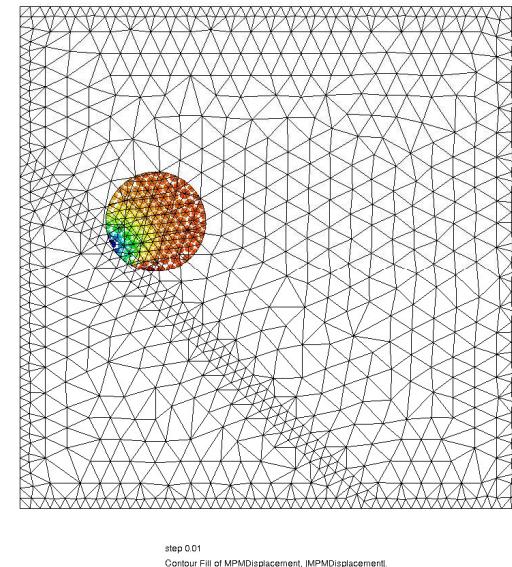
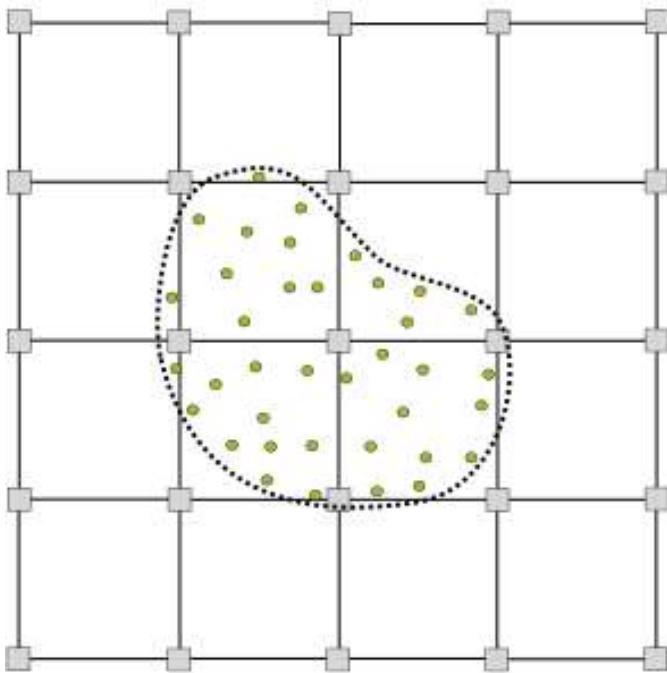
Continuum based particle methods: MPM IN KRATOS

The MATERIAL POINT METHOD

Numerical technique proposed for the first time by [Harlow, 1964];

The Material Point Method uses two different discretizations:

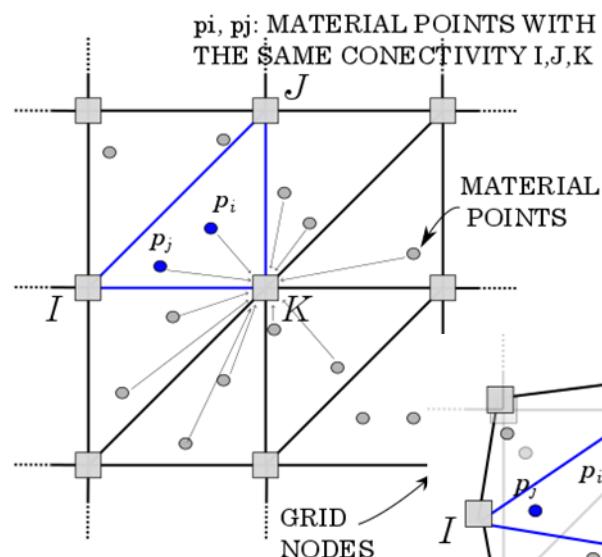
- A BACKGROUND GRID (fixed)
 - Used for the FEM solution system
- A collection of MATERIAL POINTS (MP) (Lagrangian)
 - Moving integration points
 - MPs store historical information



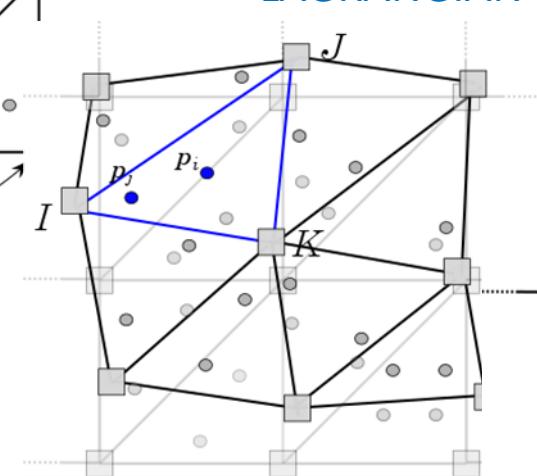
The MATERIAL POINT METHOD

Step 1:

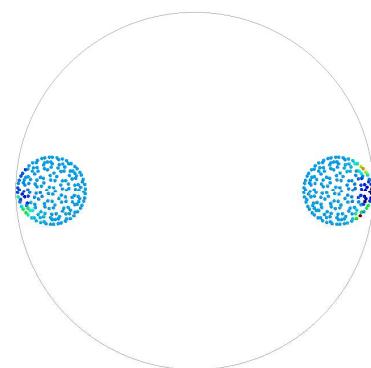
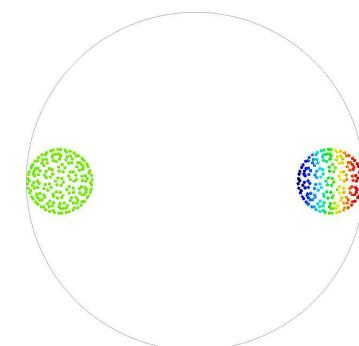
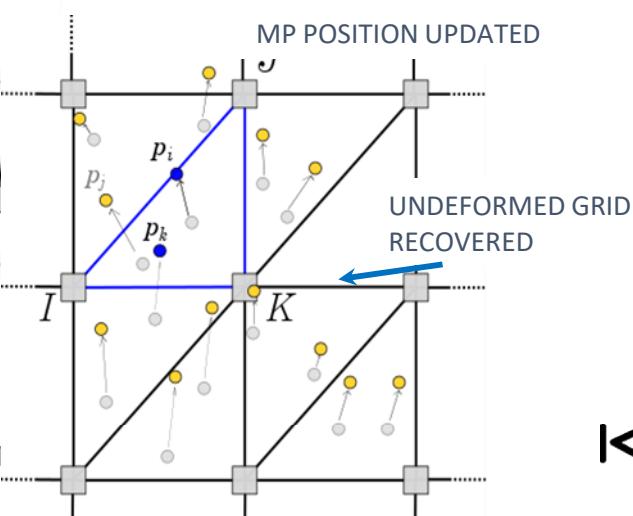
INITIALIZATION



Step 2:
UPDATED
LAGRANGIAN



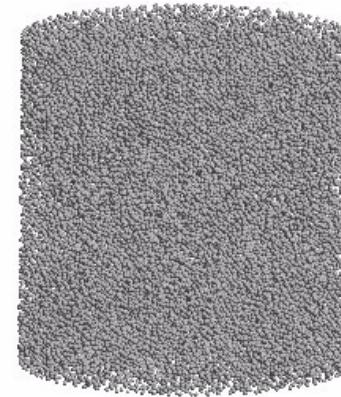
Step 3:
CONVECTION



MPM

Granular flow

Granular collapse

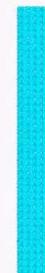
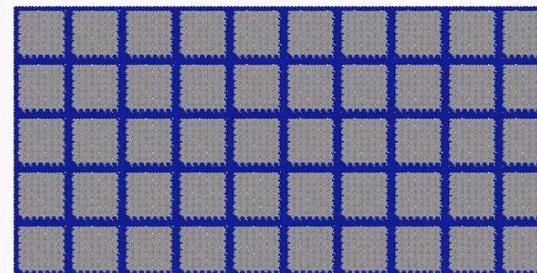


- 2D, 3D and axisymmetric formulations
- Irreducible and Mixed formulations
- Large deformation regimes
- Several constitutive laws

Rigid strip footing



Viscoplastic dambreak
on a flexible body





Continuum-based particle methods: PFEM IN KRATOS

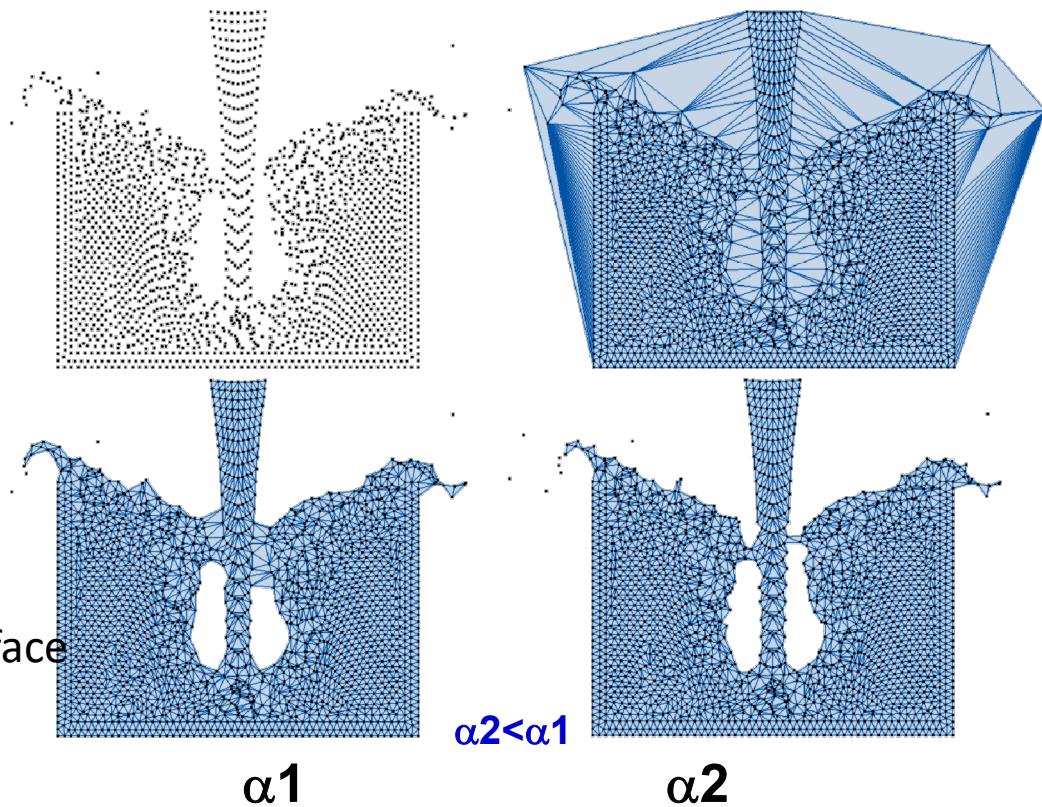
PFEM

Particle Finite Element Method PFEM

(<http://www.cimne.com/pfem>)

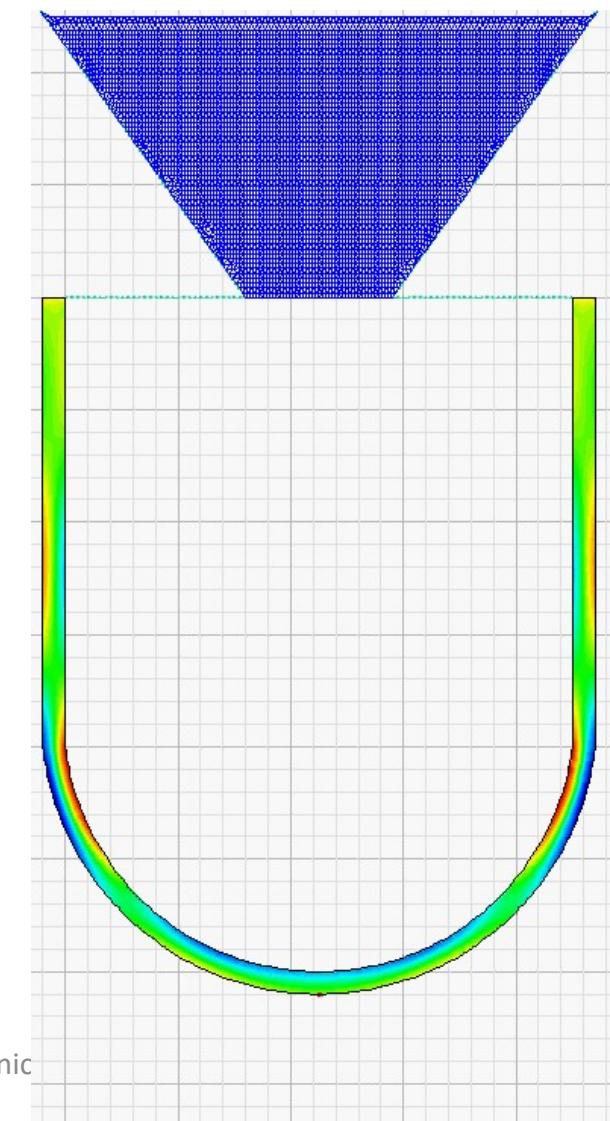
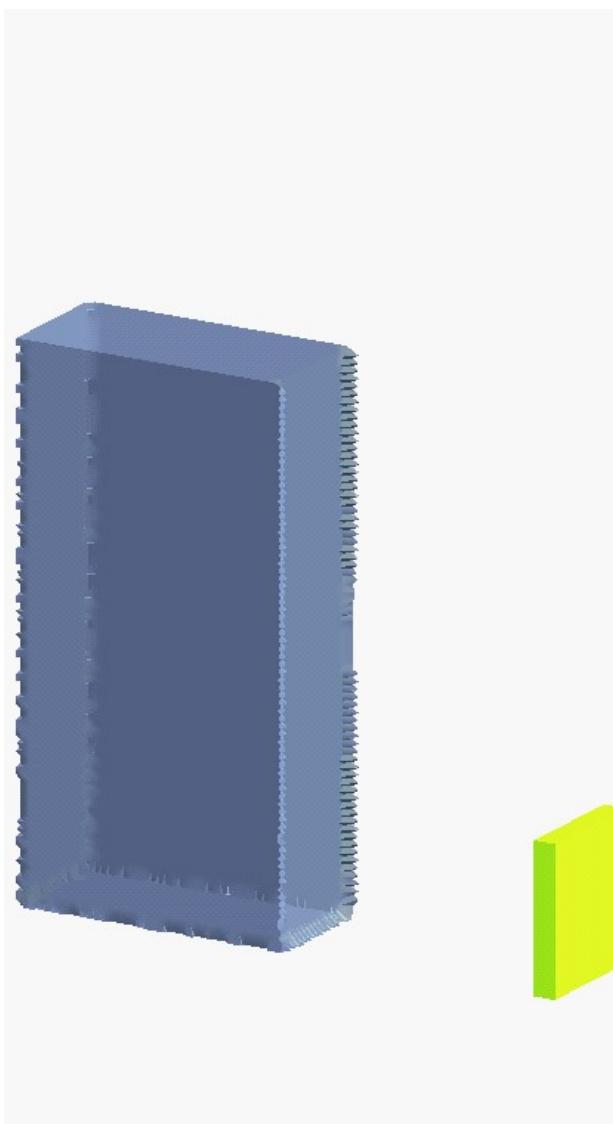
Firstly proposed by Prof S. Idelsohn for simulating breaking waves.

- Finite Element Method (**FEM**);
- **Updated LAGRANGIAN** kinematical description of motion
- **REMESHING** algorithm
- **ALPHA SHAPE** to detect the free surface





PFEM for FSI





IN WHICH FIELDS DO KRATOS WORK?



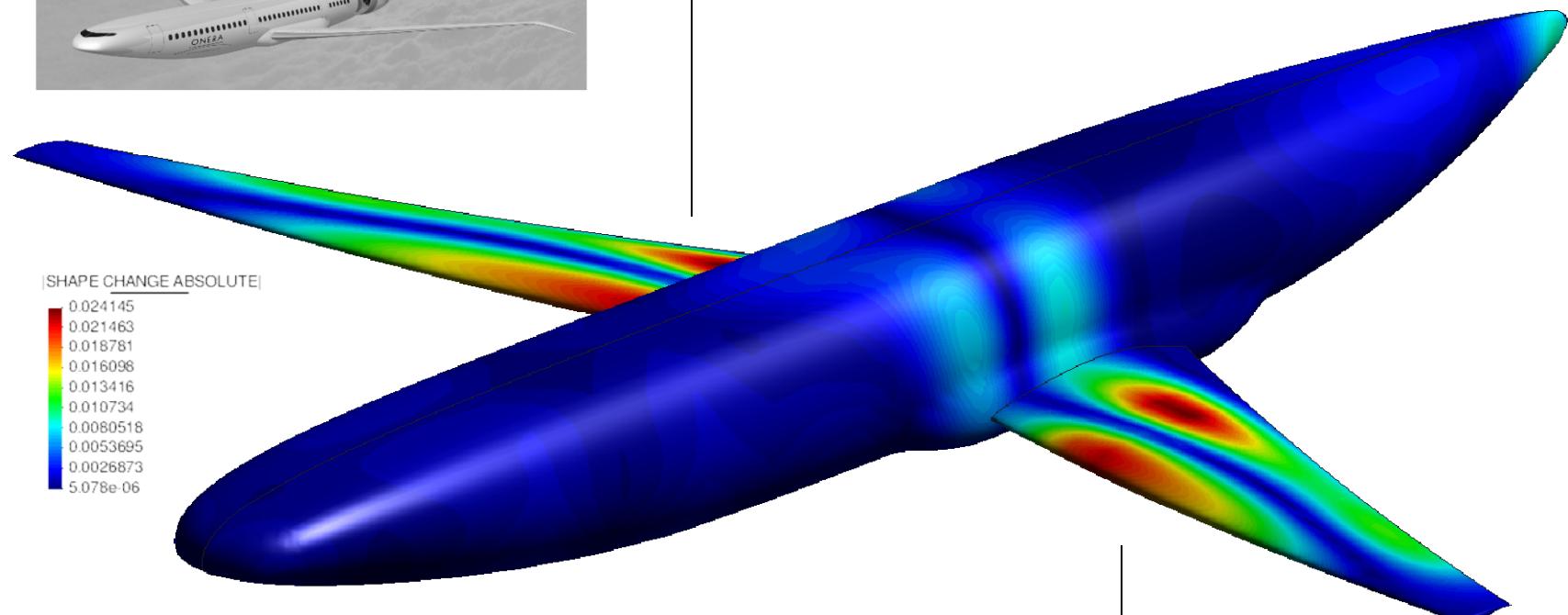
MAIN RESEACH LINES

1. INDUSTRIAL PROCESSES
2. NATURAL DISASTERS
3. DAM ENGINEERING
4. BIOMEDICAL
5.

Aerospace Engineering Node-based shape optimization in Kratos



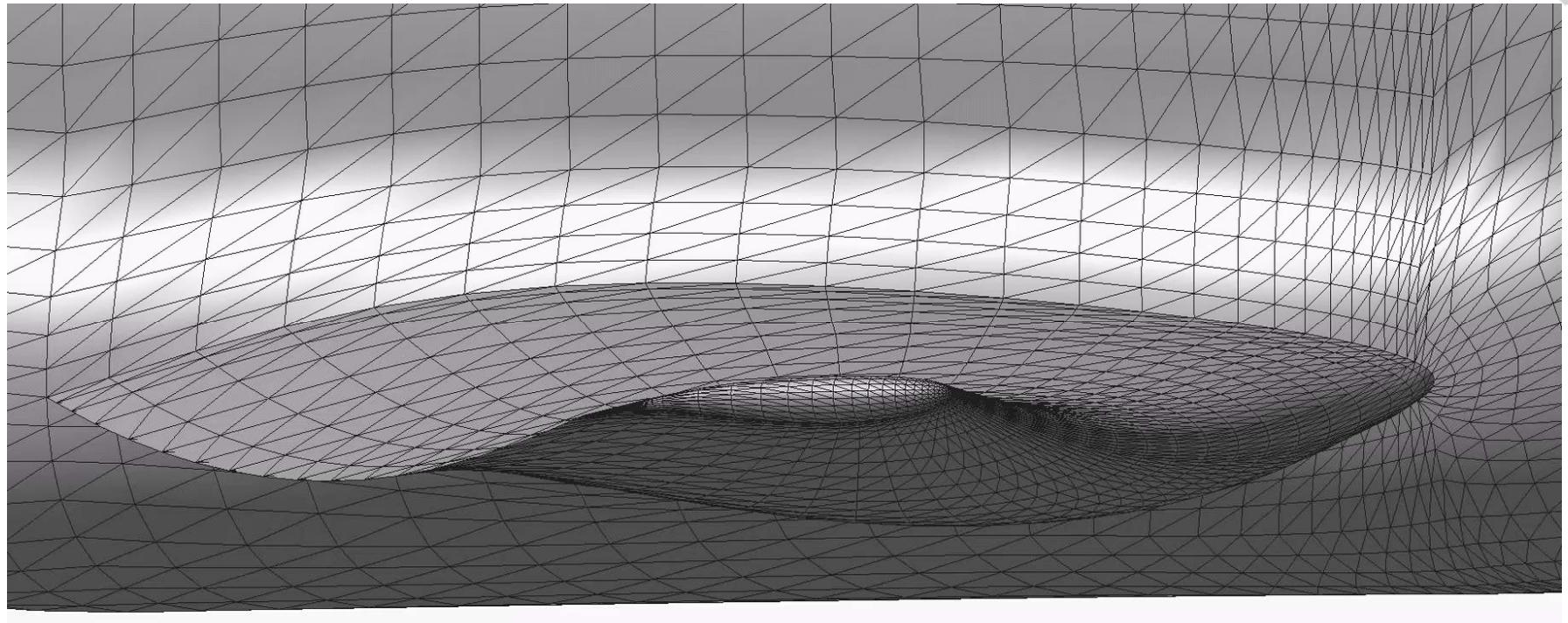
New design proposed using
„Kratos Shape“



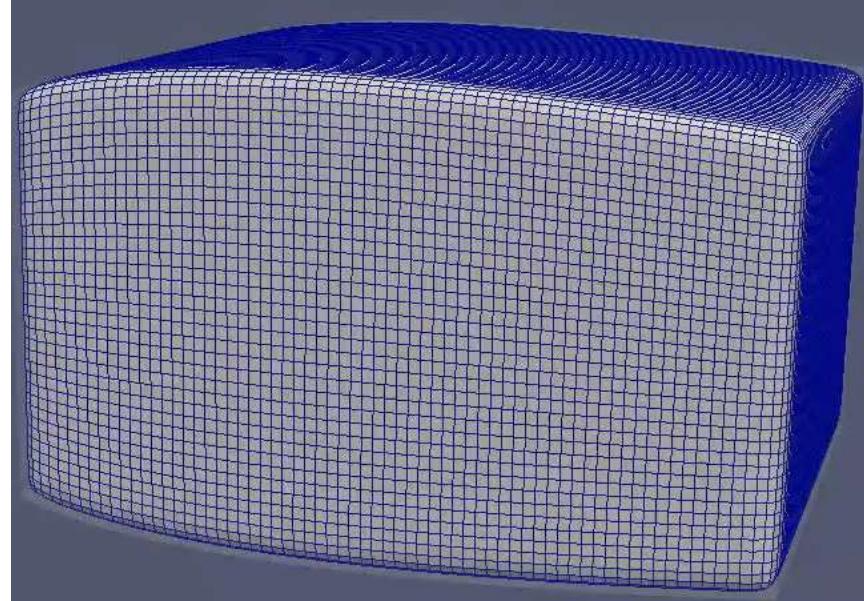
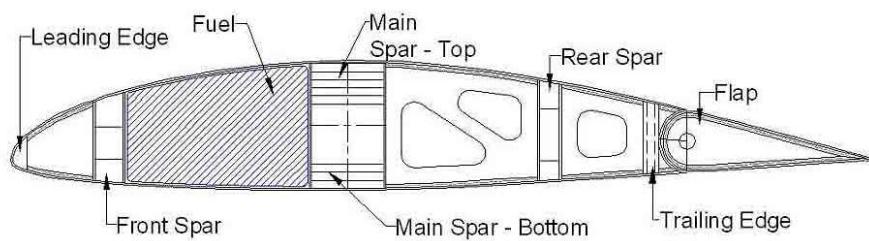
Kratos linked to CFD solvers from aerospace industry

Only open-source optimizer to perform node-based shape optimization.

Unique geometry handling



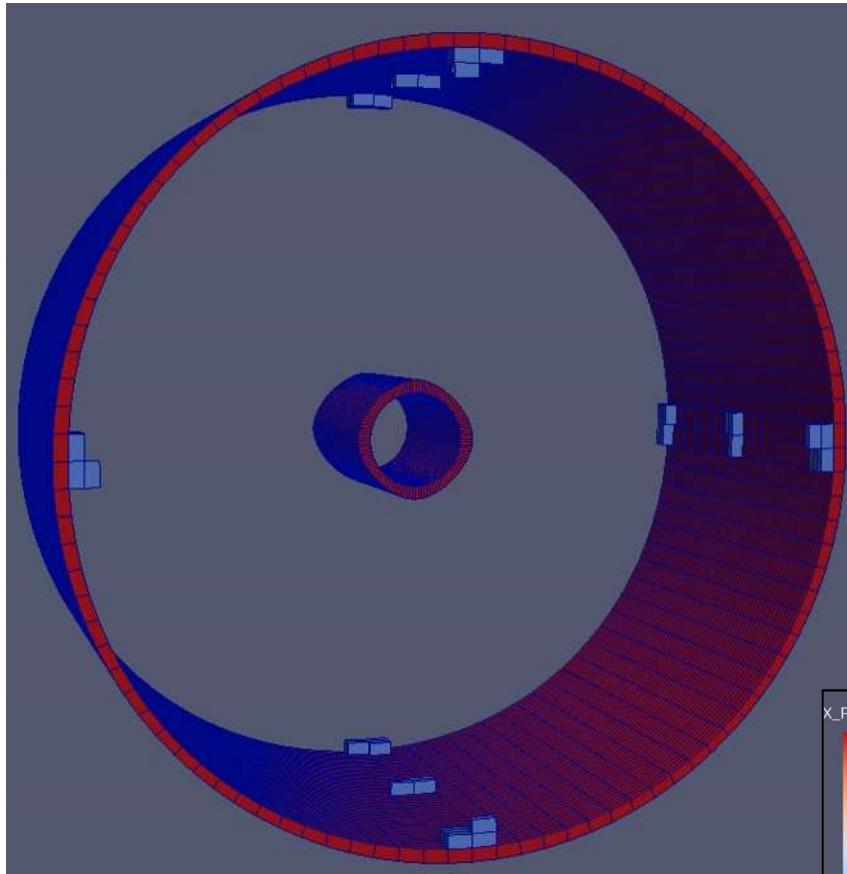
Fully integrated topology optimization in Kratos



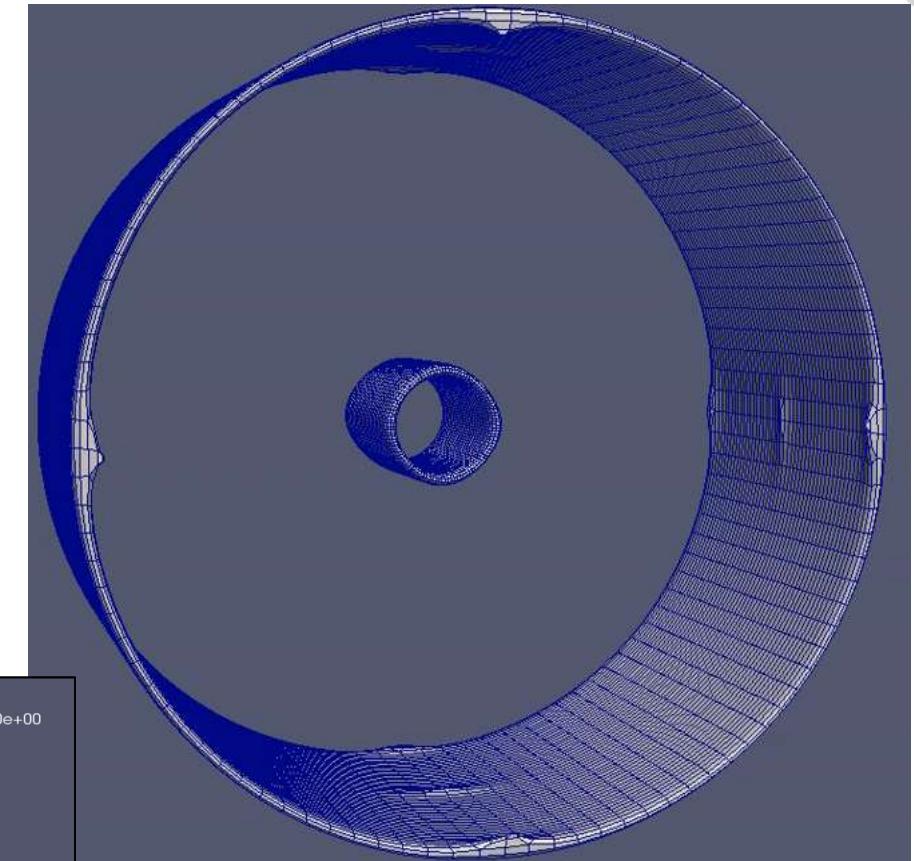
Wing box topology

Only open-source implementation of topology optimization that may analyze arbitrary 3D geometries!

Flexible application and modular set-up



Lots of modelling features

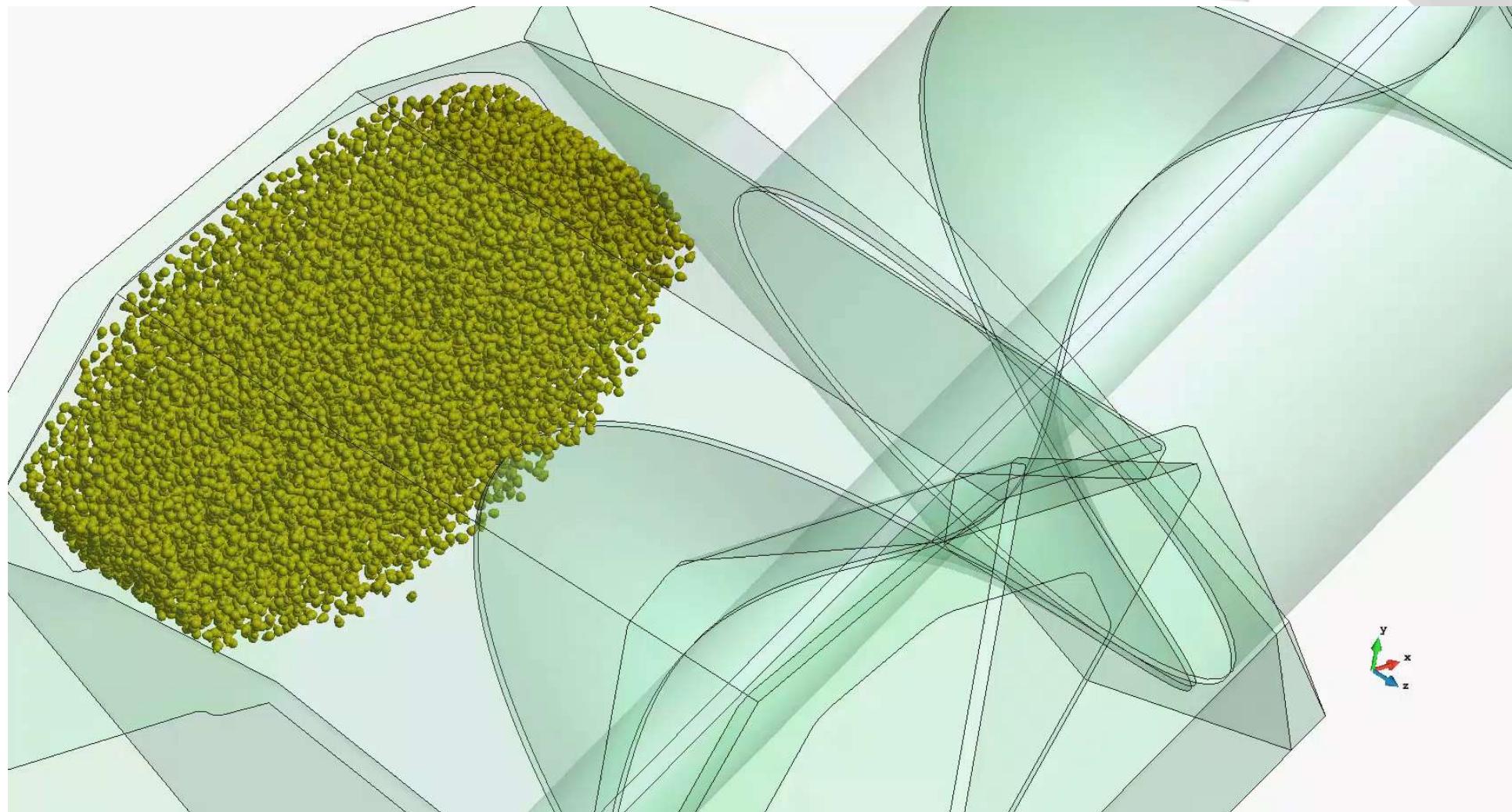


Link to further optimization

Surface extraction using embedded techniques



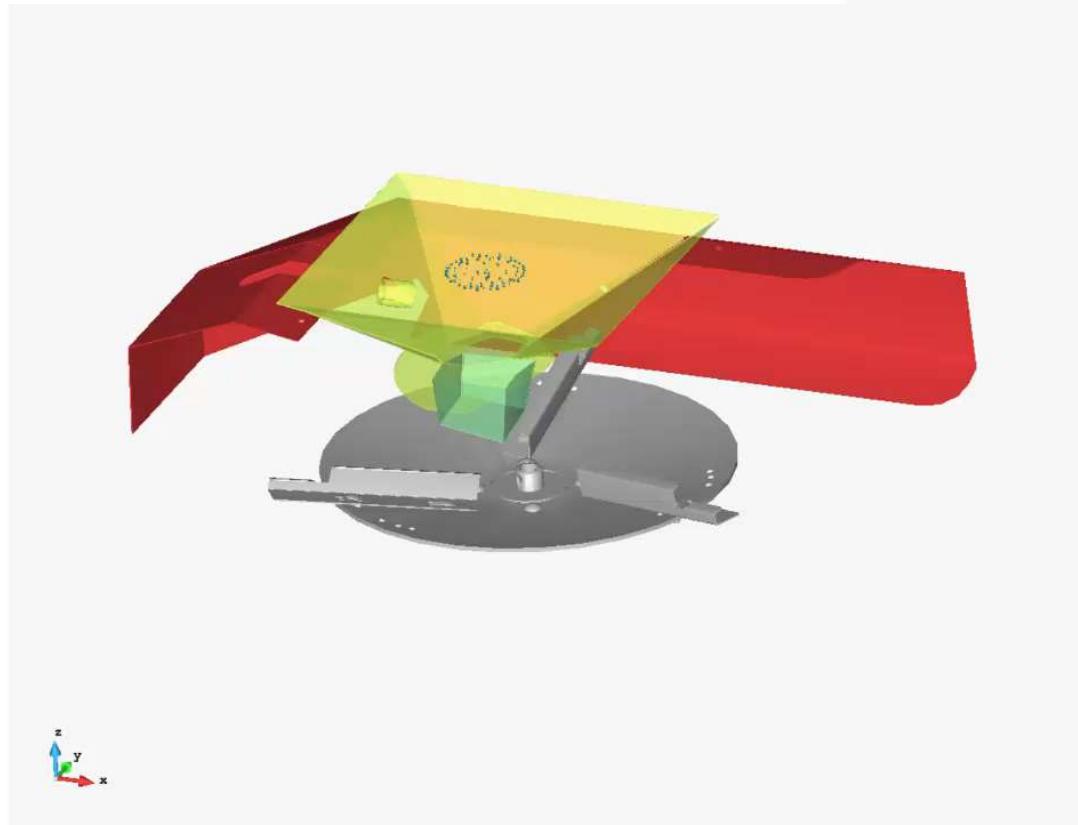
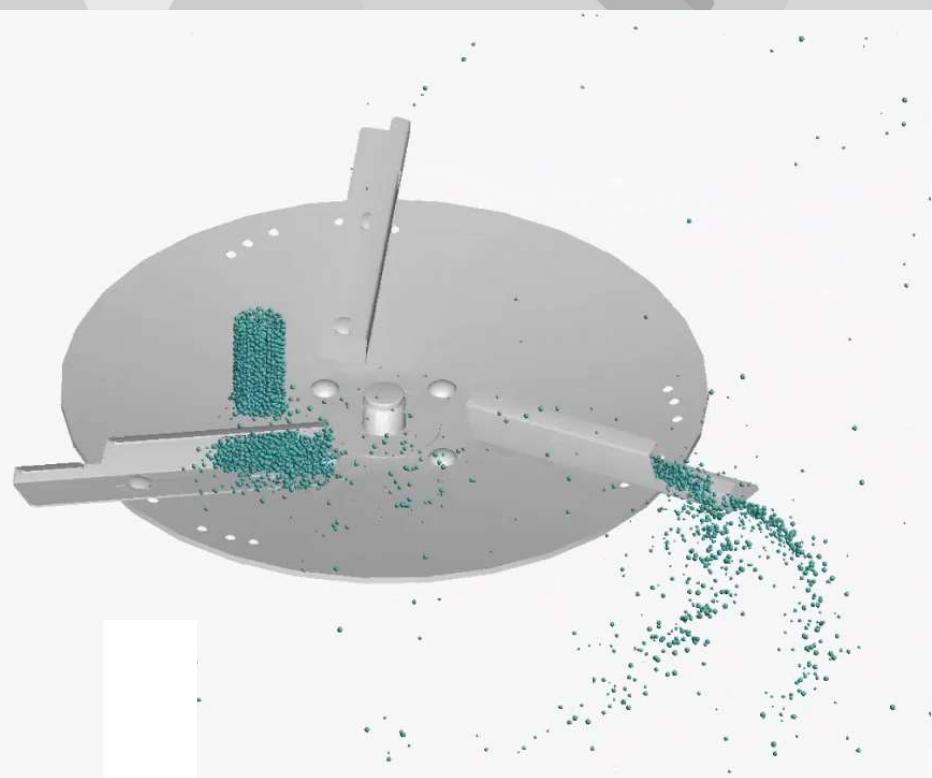
Agricultural operations (processing of seeds)





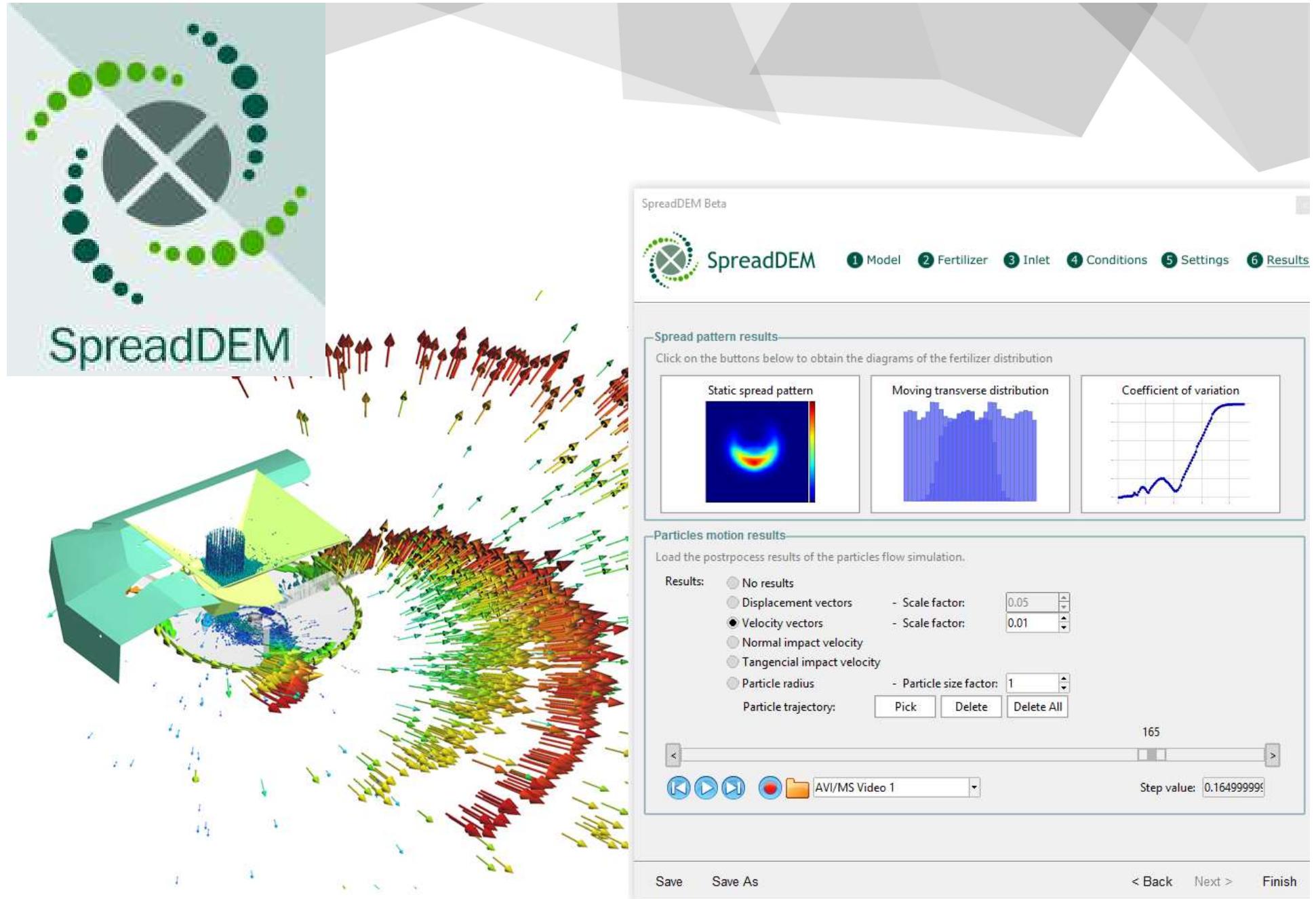
SpreadDEM

Centrifugal Spreading Simulation Software

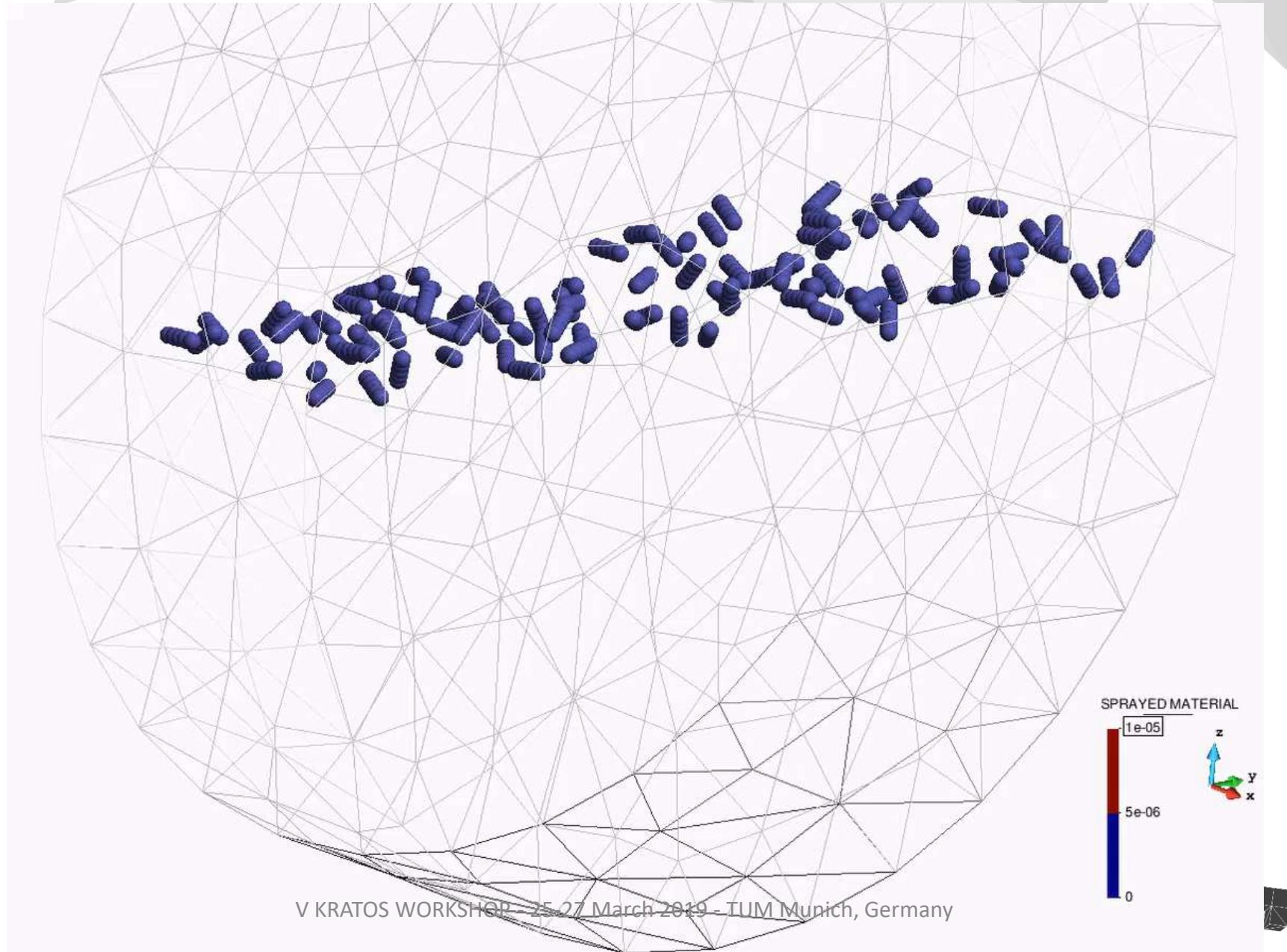


Munich, Germany

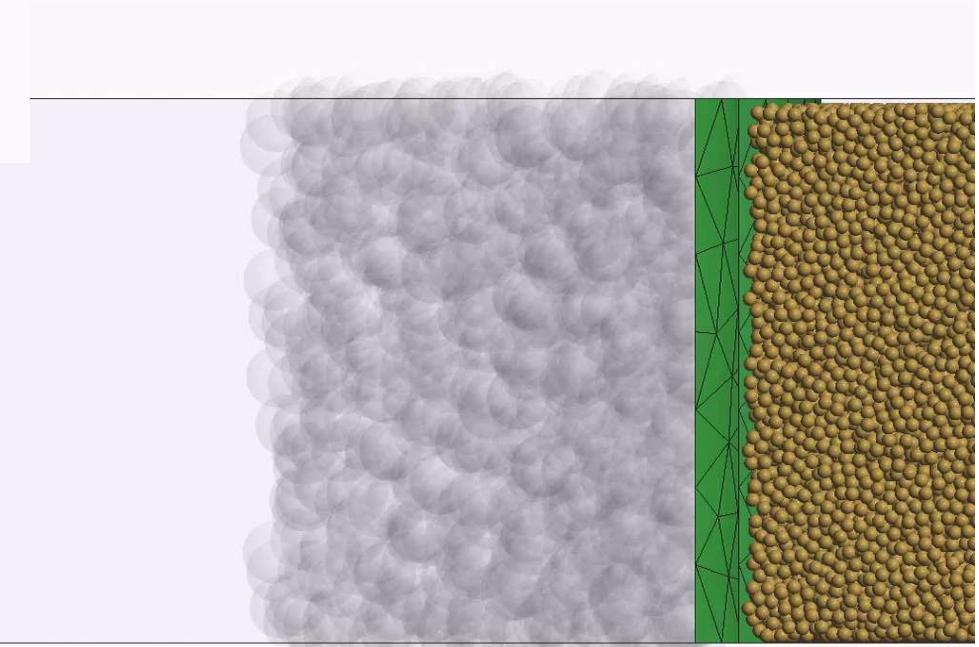
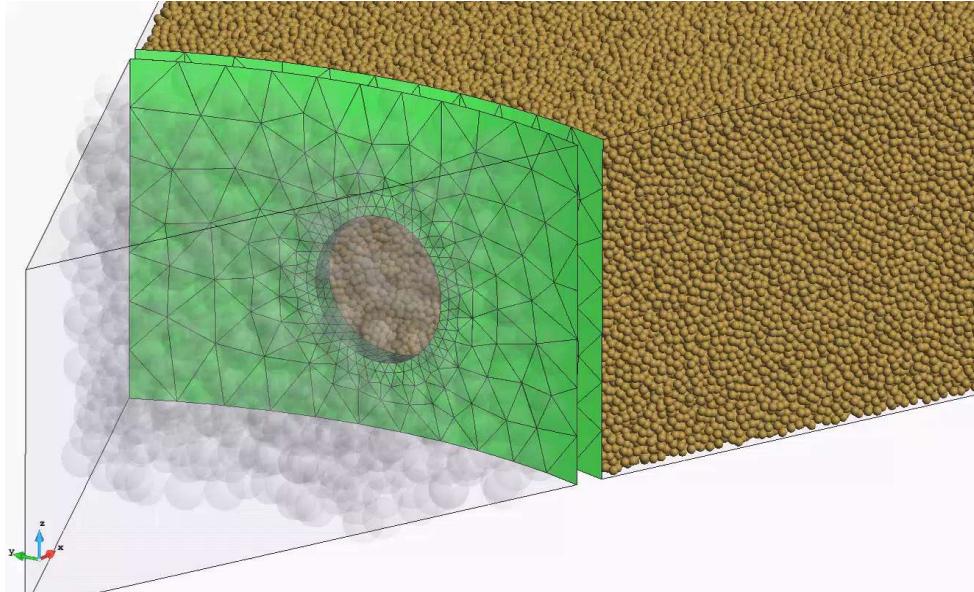
KRATOS
MULTI-PHYSICS



DEM - Pharmaceutical procedures (pills coating)

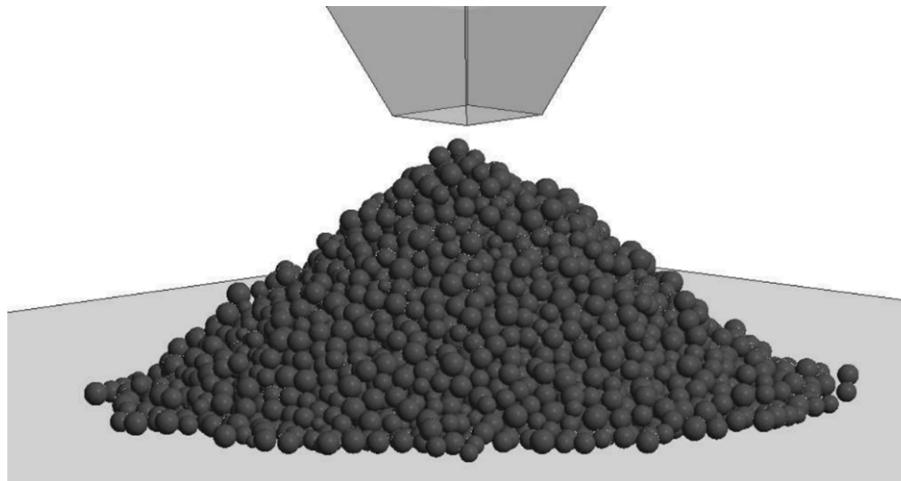


DEM - Sand production (getting undesired sand volume when oil drilling)



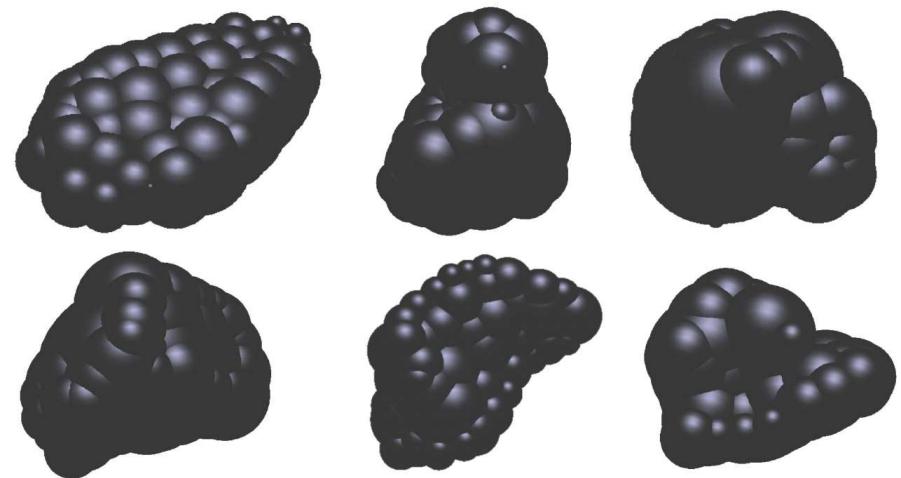
DEM-BALLAST

Spherical Particles with
Rolling Friction



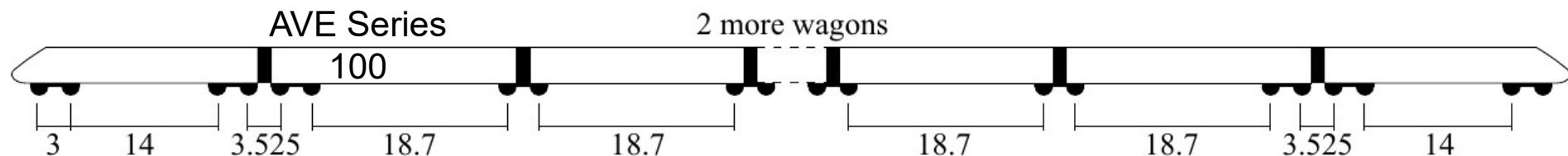
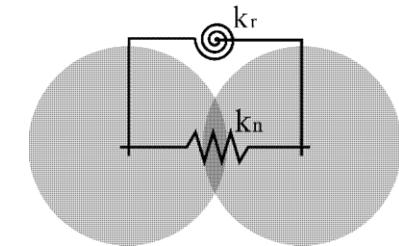
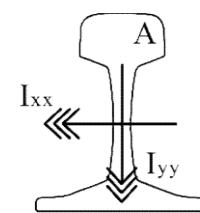
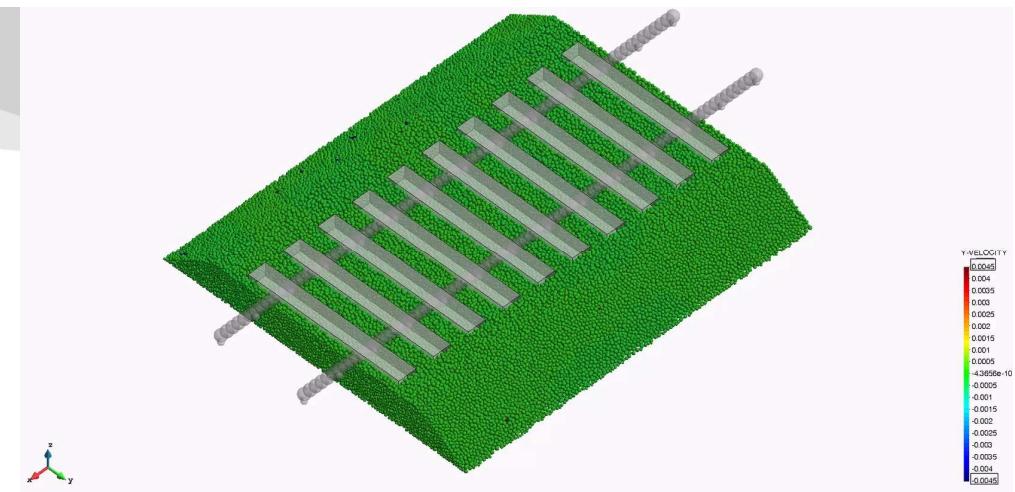
Large amount of particles
Macroscopic results

Clusters of spheres

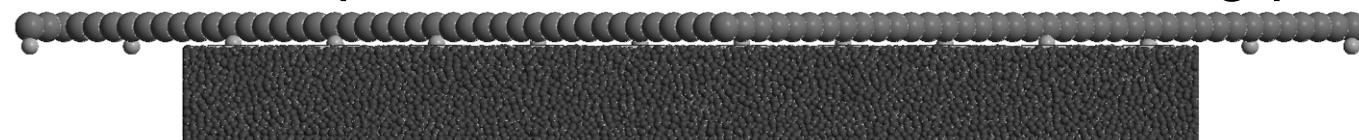


Detailed distribution of contacts

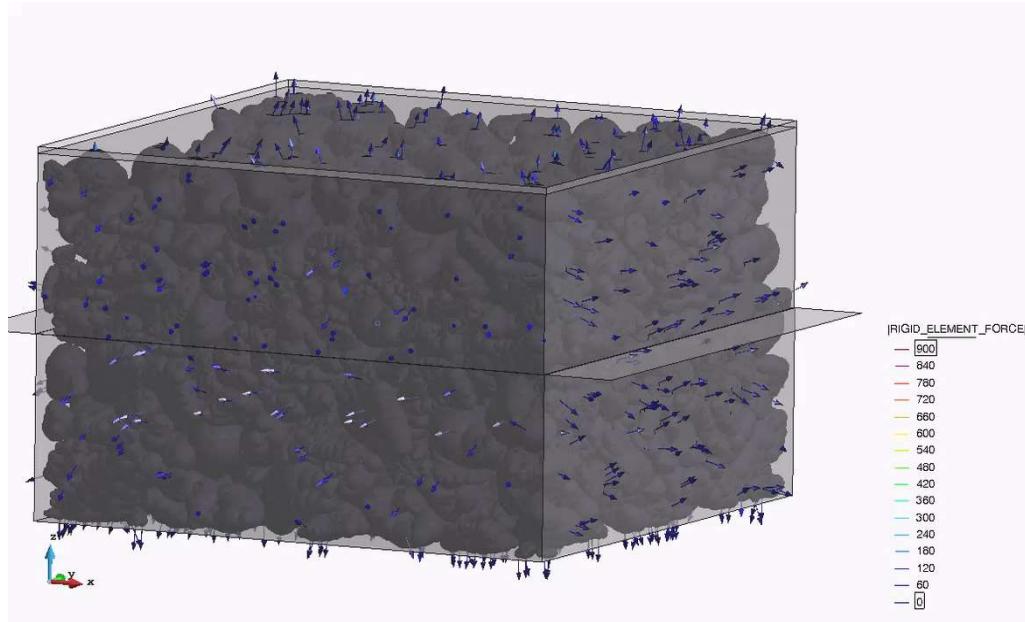
High speed train - ballast



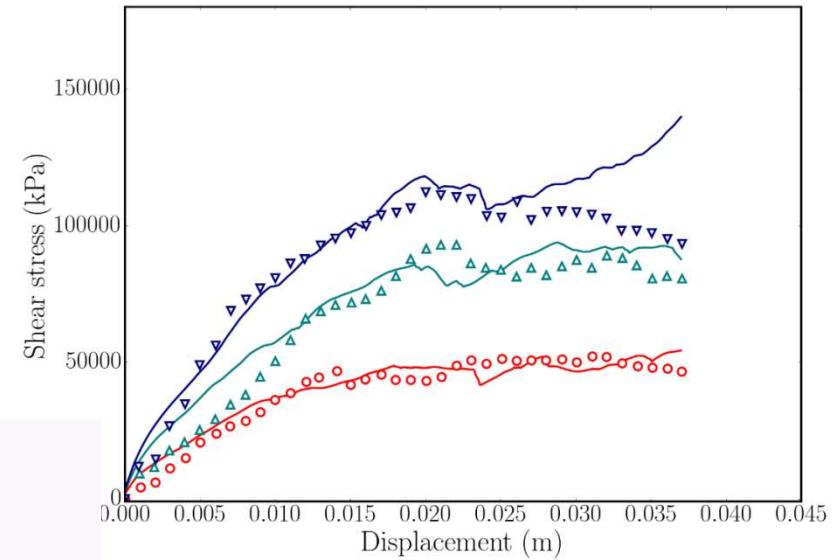
Numerical representation of rails and bearing plates



DEM-BALLAST



DEM 27 kPa	○ ○ ○	Lab. 27 kPa
DEM 51 kPa	△ △ △	Lab. 51 kPa
DEM 75 kPa	▽ ▽ ▽	Lab. 75 kPa



V KRATOS WORKSHOP - 25-27 March 2019 | TUM Multi-Physics Full scale tests

KRATOS
MULTI-PHYSICS

NATURAL DISASTERS

Study the effects of flow related extreme events on structures and landscape

- CFD
- FREE SURFACE FLOWS
- WIND ENGINEERING
- FLUID-STRUCTURE INTERACTIONS
- FLUID-SOIL INTERACTION

CHALLENGES:

- Large deformations
- Complex material laws
- Contact
- Damage/fracture
- MULTI-PHYSICS
- MULTI-SCALE

NATURAL DISASTERS



Consequences of a mud flow at Mariana, Brazil,
11/ 2015 (businessinsider.com)



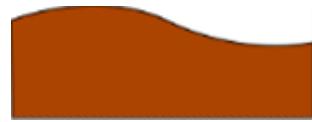
Breakdown of the cofferdam protecting the Jerte
Dam construction site (Euroestudios)



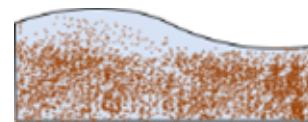
Tsunami at Kamaishi port, Japan 11 March 2011 (the
Atlantic)

MODELS FOR PARTICULATE FLOW

MUD FLOWS



MULTI COMPONENT MODELS



FULLY RESOLVED MODELS

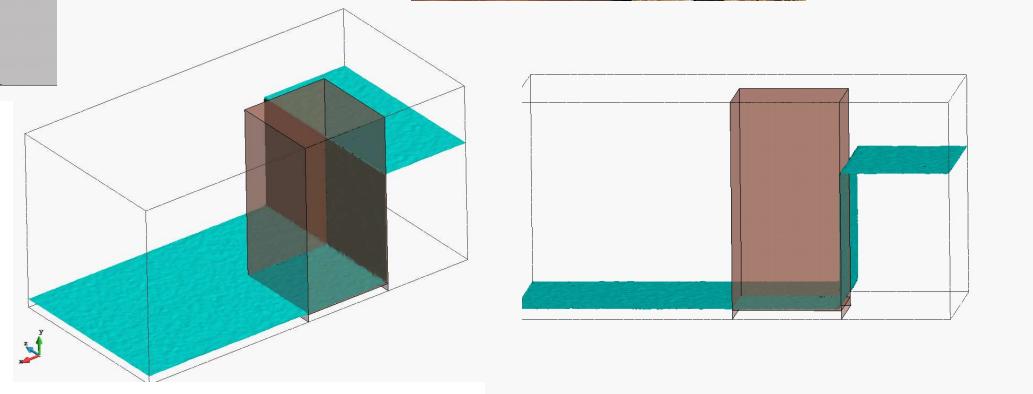
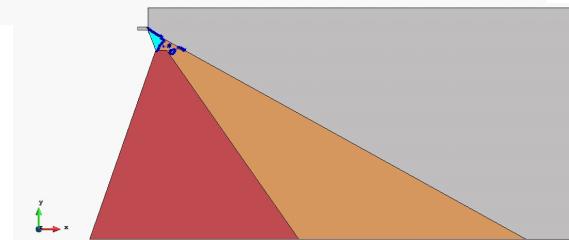
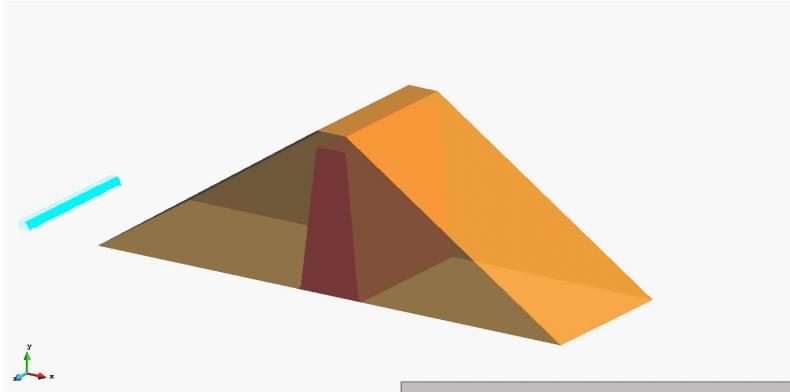


NUMERICAL TECHNIQUES

- **NON NEWTONIAN RHEOLOGICAL MODELS**
- **CFD FREE SURFACE COUPLED WITH MPM LARGE DEFORMATION FORMULATION**
- **EMBEDDED BOUNDARY METHOD**

NATURAL DISASTERS

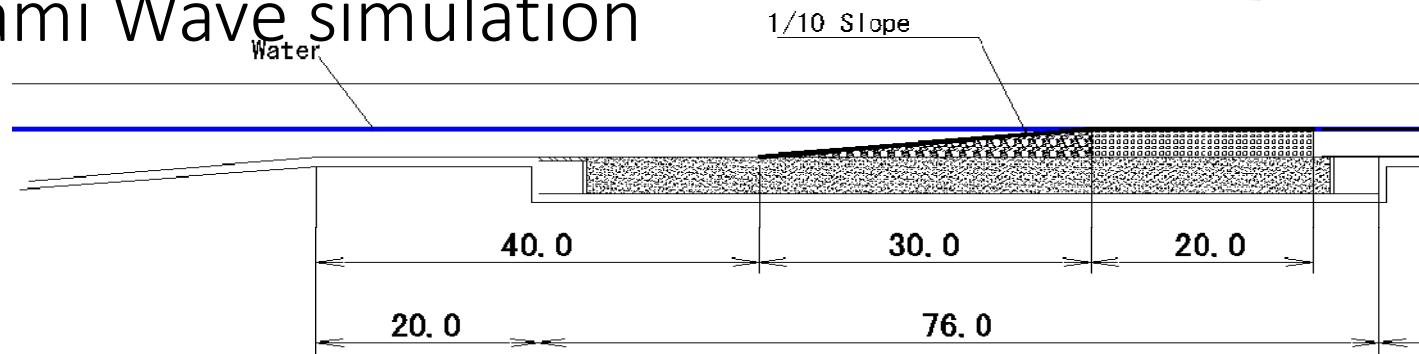
Rockfill dams or harbour dikes under overtopping



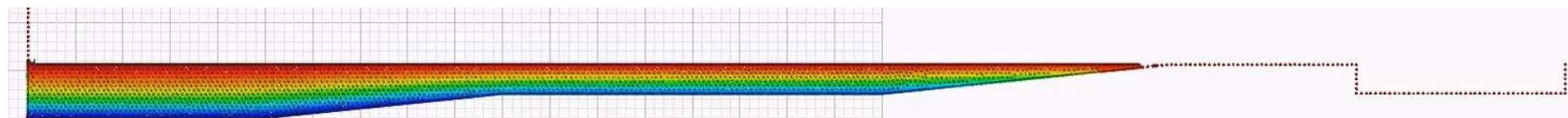
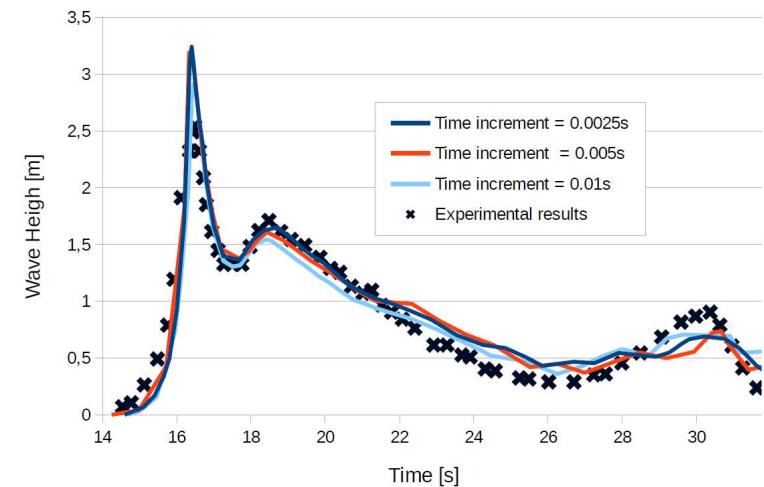
- Navier Stokes Eulerian solver
- Level set technique to track the evolution of the free surface and seepage line
- Non linear resistance law

NATURAL DISASTERS

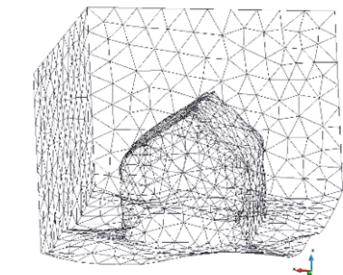
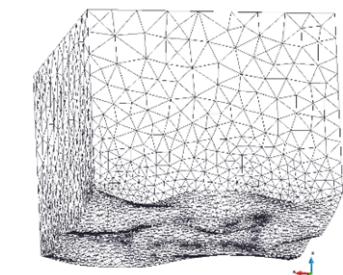
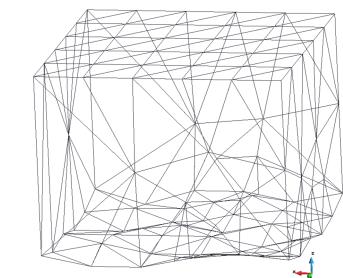
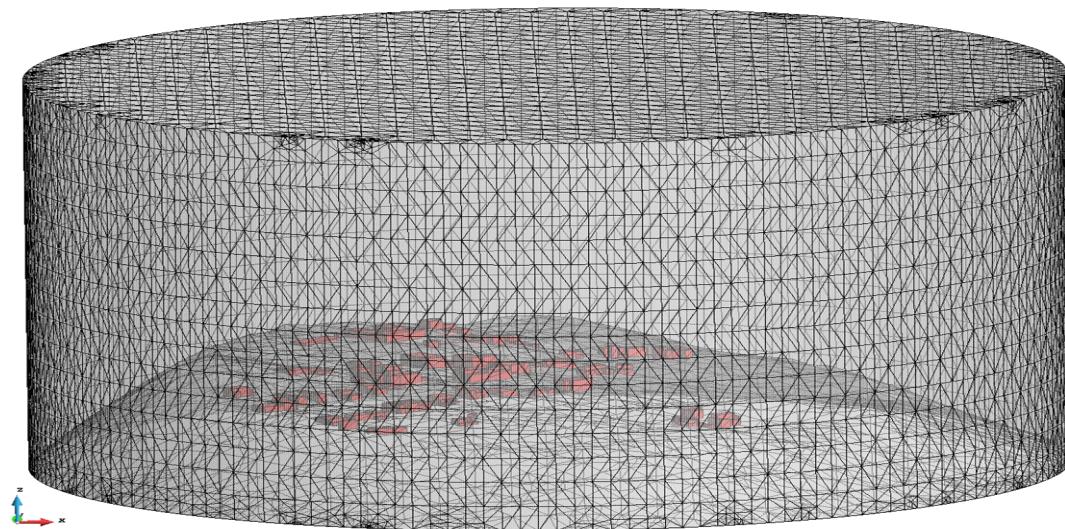
Tsunami Wave simulation



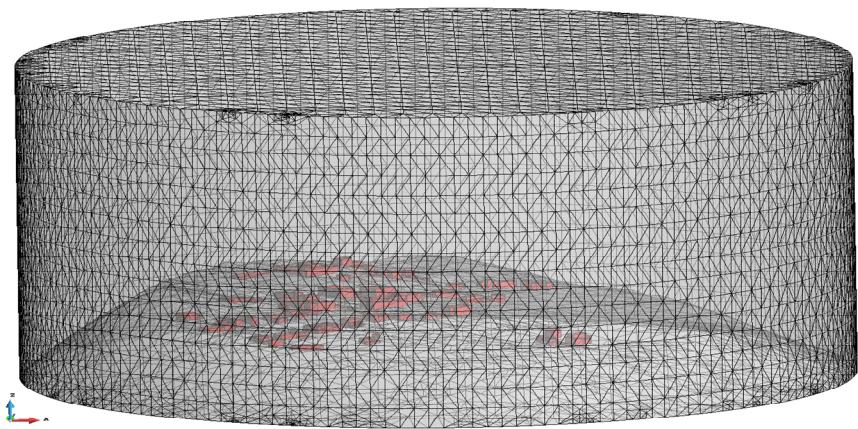
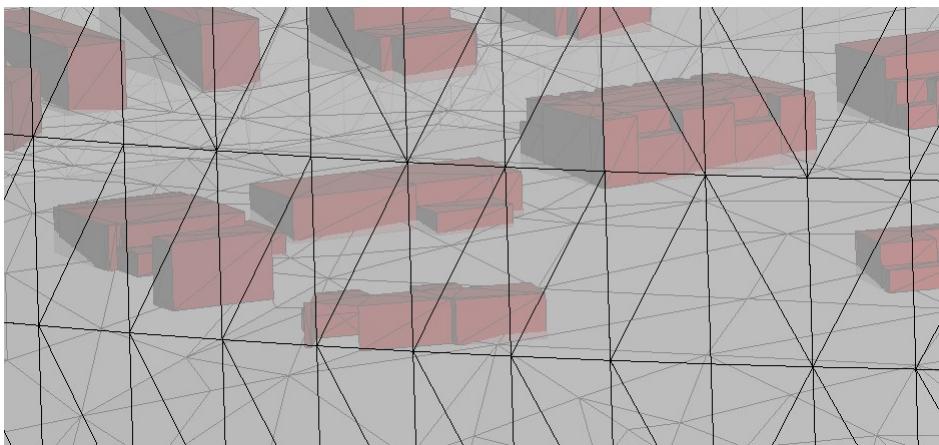
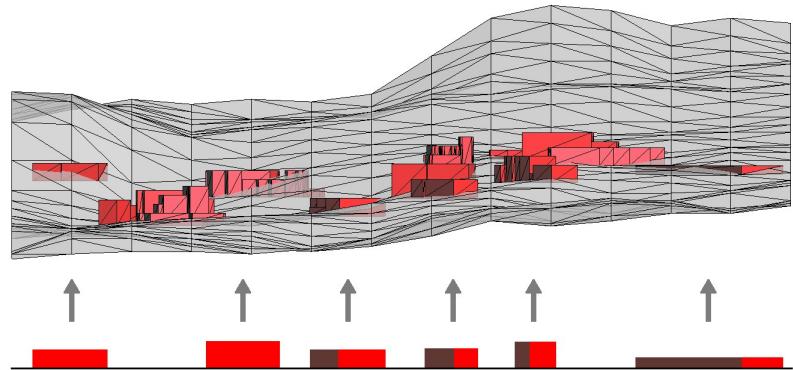
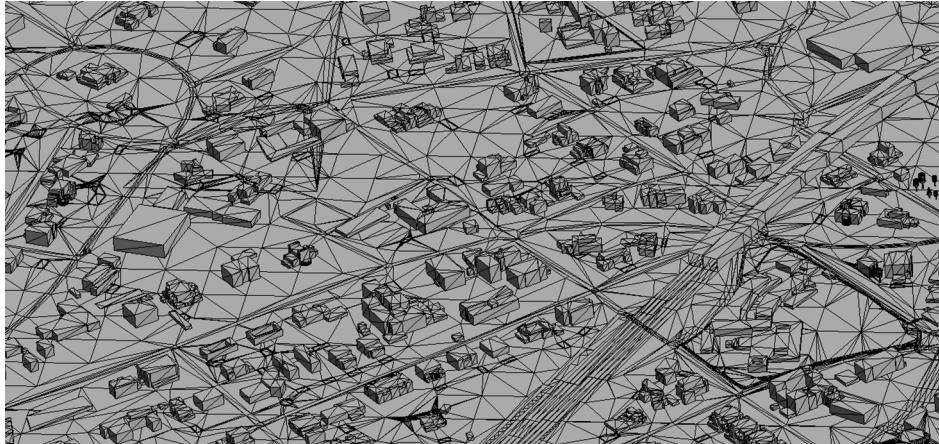
Courtesy of T. Arikawa (Chuo University), K. Shimosako (Port and Airport Research Institute), N. Ishikawa (National Defense Academy)



Geodata Processing for Large-Scale Fluid Simulations



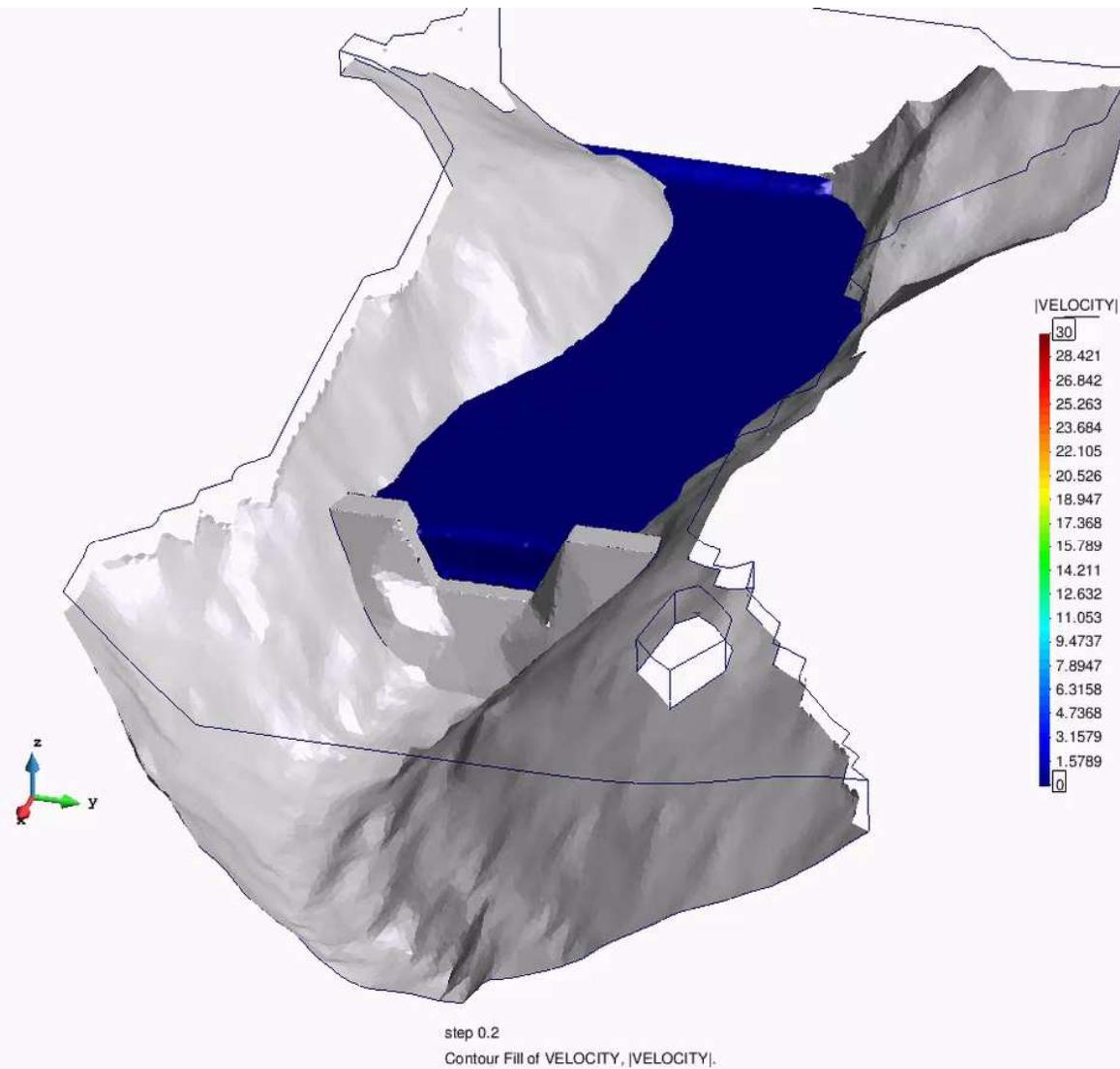
Geodata Processing for Large-Scale Fluid Simulations



Large-Scale Fluid Simulations

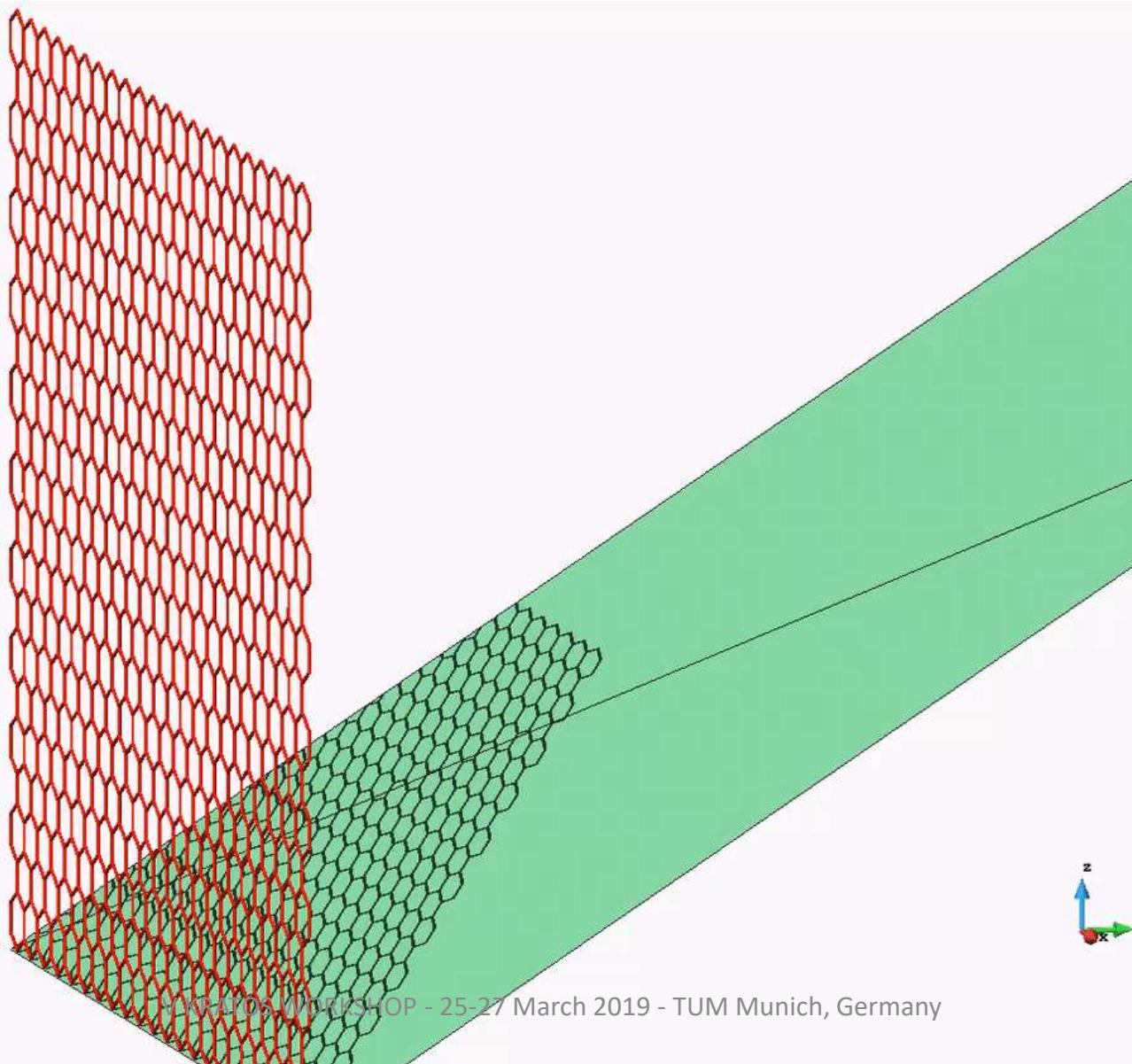
Computation data

- 84 processors
- computation time of 2 hours
- 1 500 000 elements
- 440 time steps



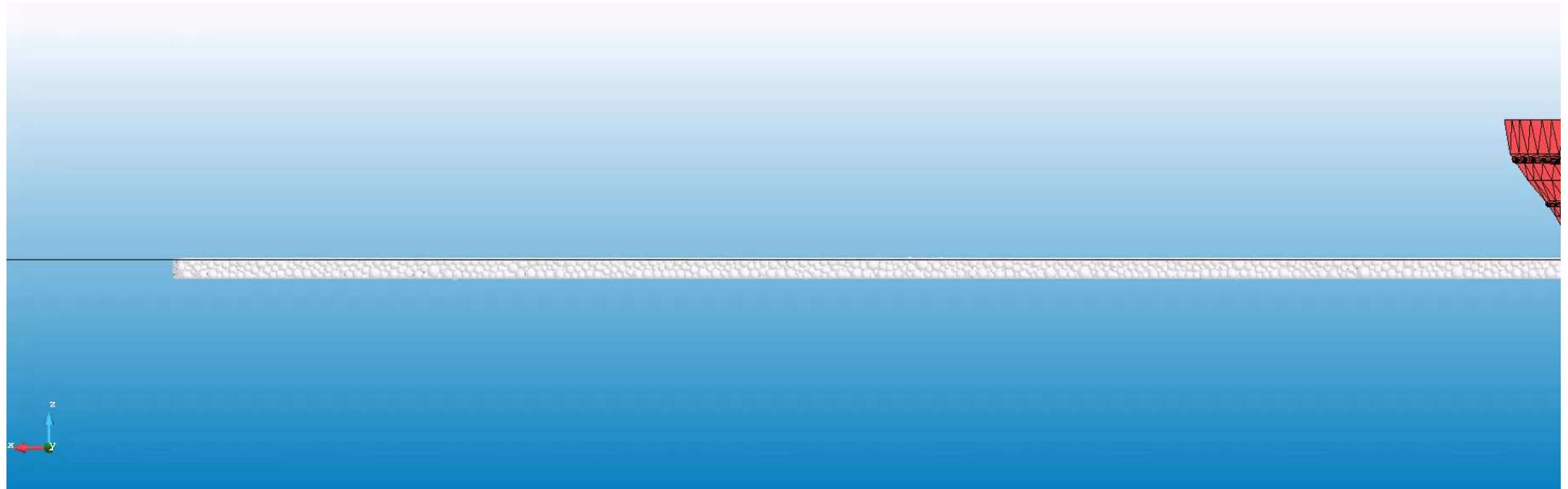
NATURAL DISASTERS

Rockfall protection nets (roads safety)



Icebreakers

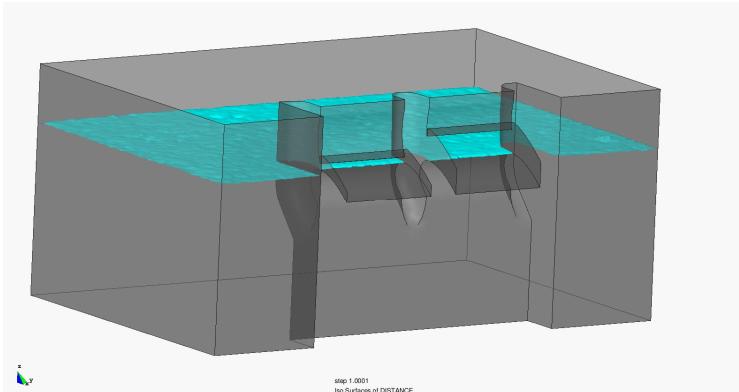
(understand ice-ship interactions)



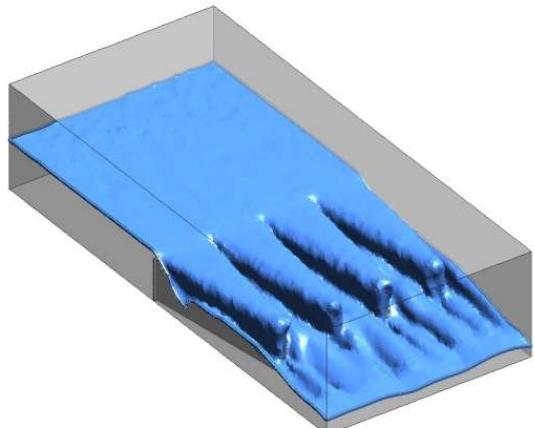
DAM ENGINEERING

Dam Hydraulic: Spillways

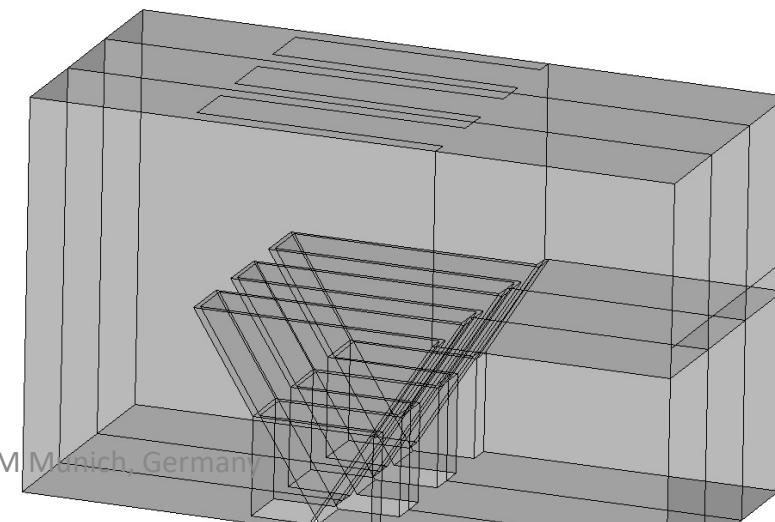
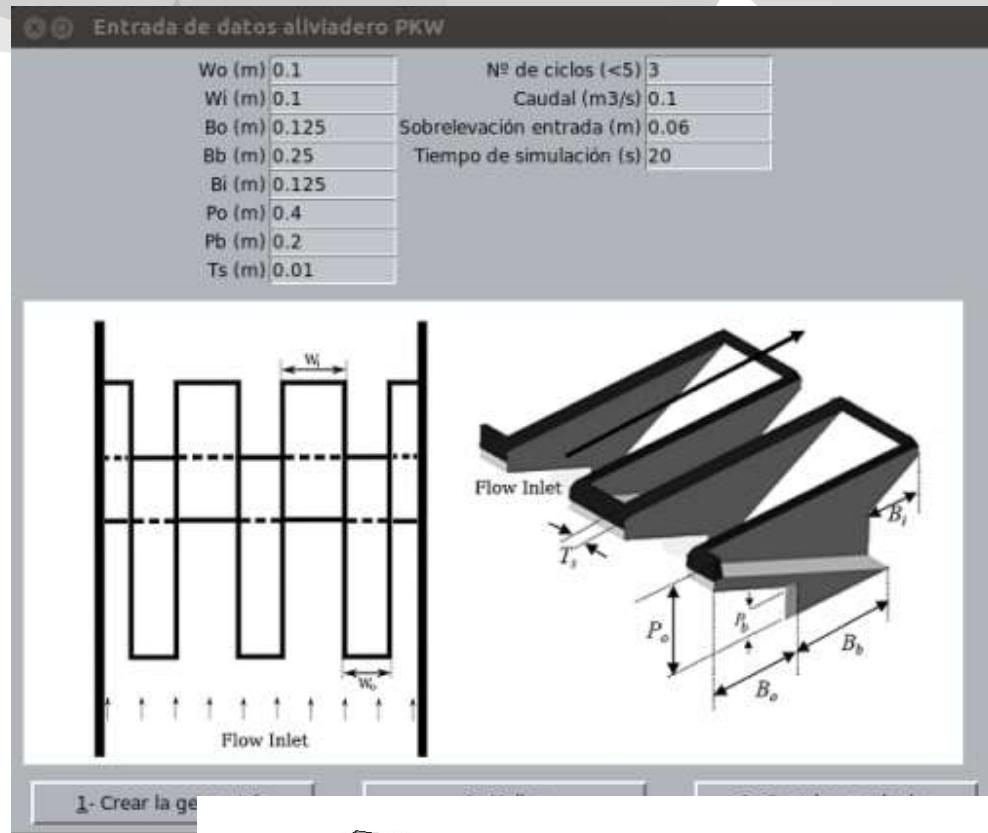
GATED SPILLWAYS



LABYRINTH AND PIANO-KEY SPILLWAYS



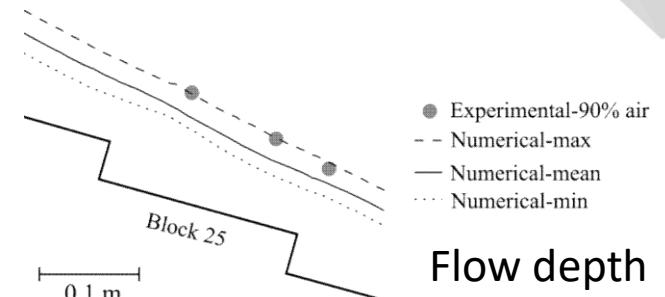
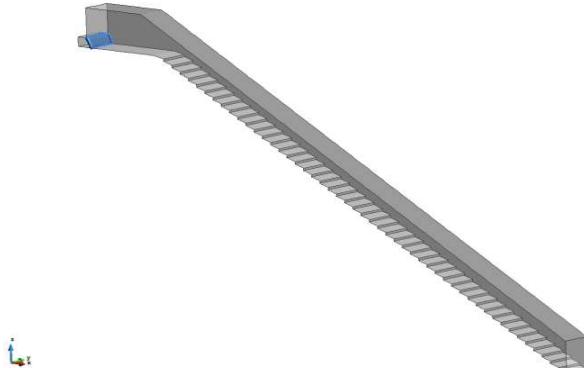
WIZARD



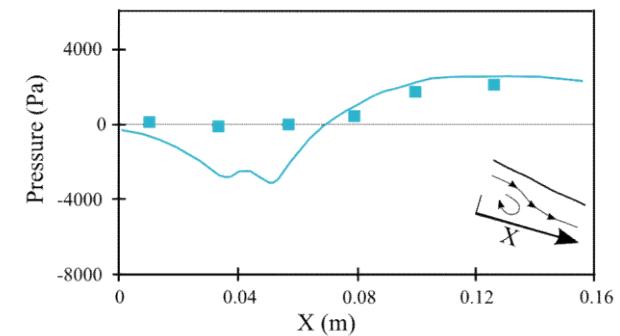
DAM ENGINEERING

Dam Hydraulic: Spillways

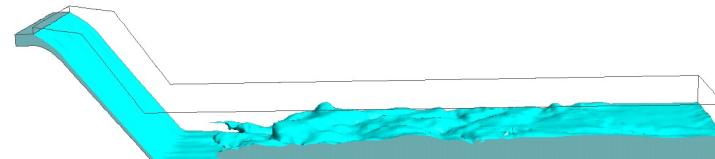
Stepped spillways



Pressure



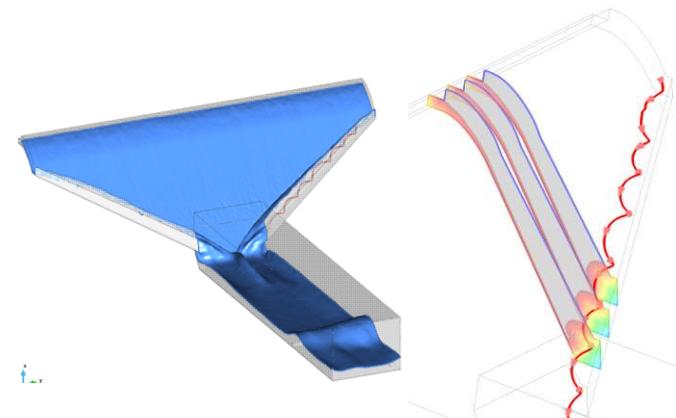
Stilling basin. Hydraulic jump



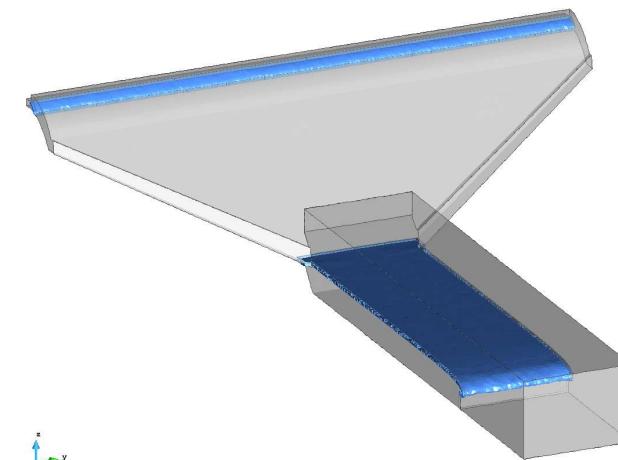
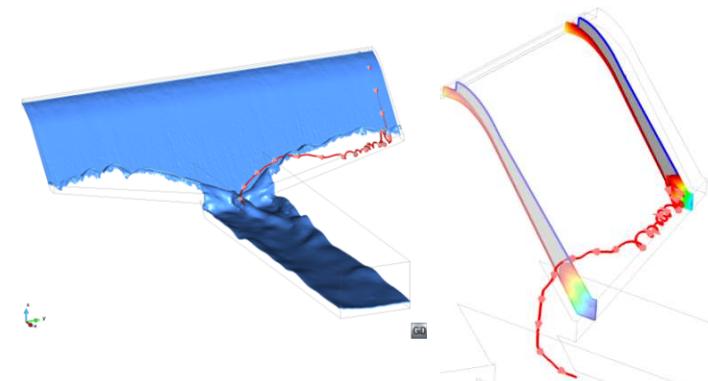
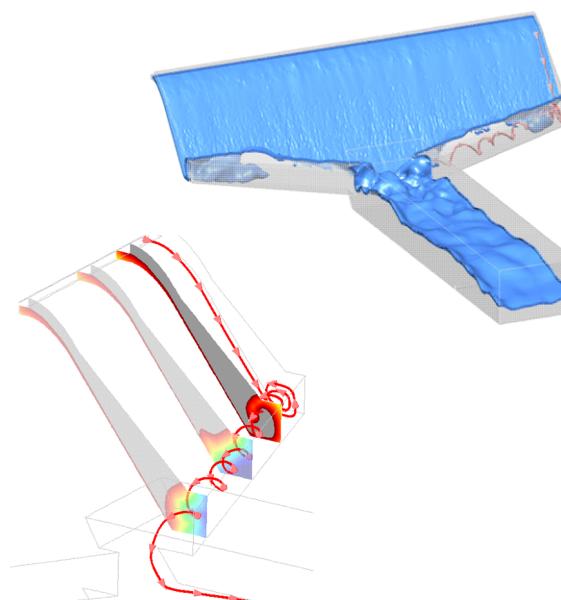
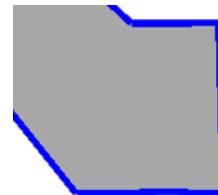
DAM ENGINEERING

Dam Hydraulic: Spillways - Highly convergent chutes

Standard
channel

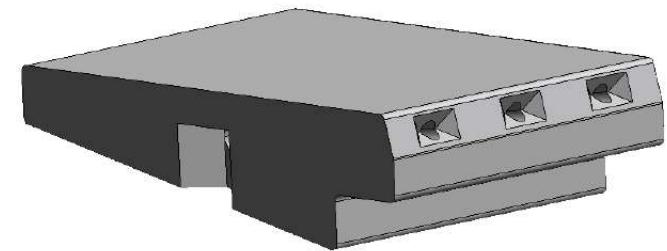


Modified
channel



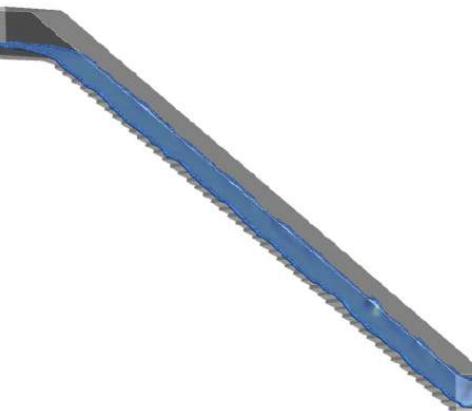
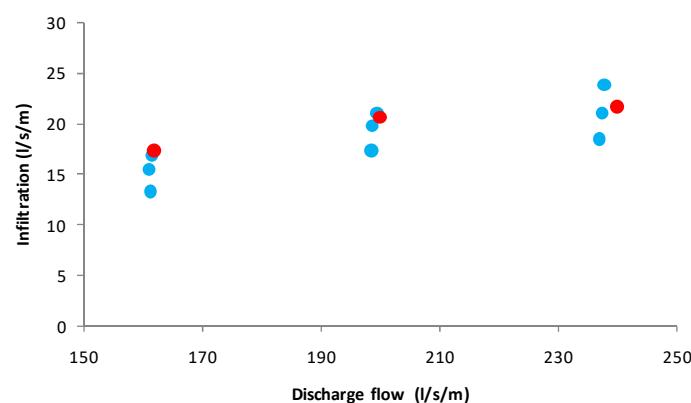
DAM ENGINEERING

wedge shaped blocks spillways

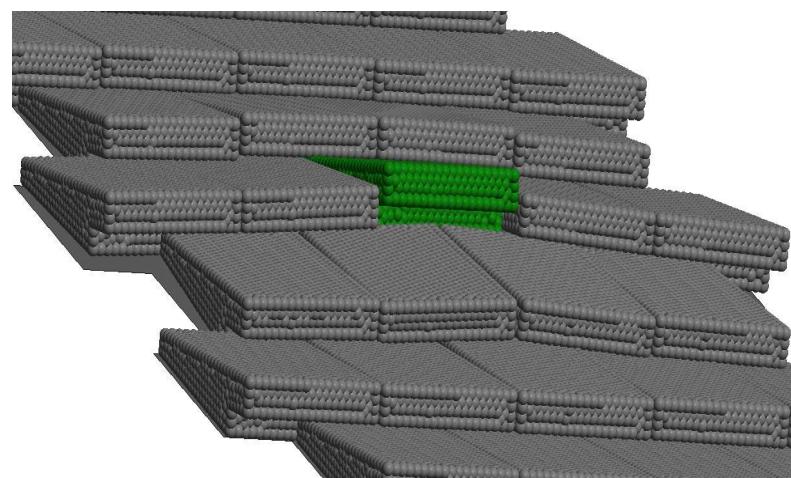


1. Hydraulic performance
and design

Experimental-numerical tests



1. Security analysis to
anthropic risk



WIZARD FOR WSBs DESIGN

The screenshot shows the main interface of the software with several tabs:

- Welcome:** Displays a photograph of a dam with a wedge-shaped spillway.
- Layout:** Shows input fields for dam height (15 m), slope (2), and width (40 m). It includes a graph of the dam profile and a 3D view of the valley shape.
- Optimization:** Shows a graph of cost vs. porosity for different materials (Riprap, Toe, Concrete, Blocks).
- Single model:** Shows a graph of cost vs. porosity for different materials.
- Provider tab:** Shows a graph of cost vs. porosity for different materials.

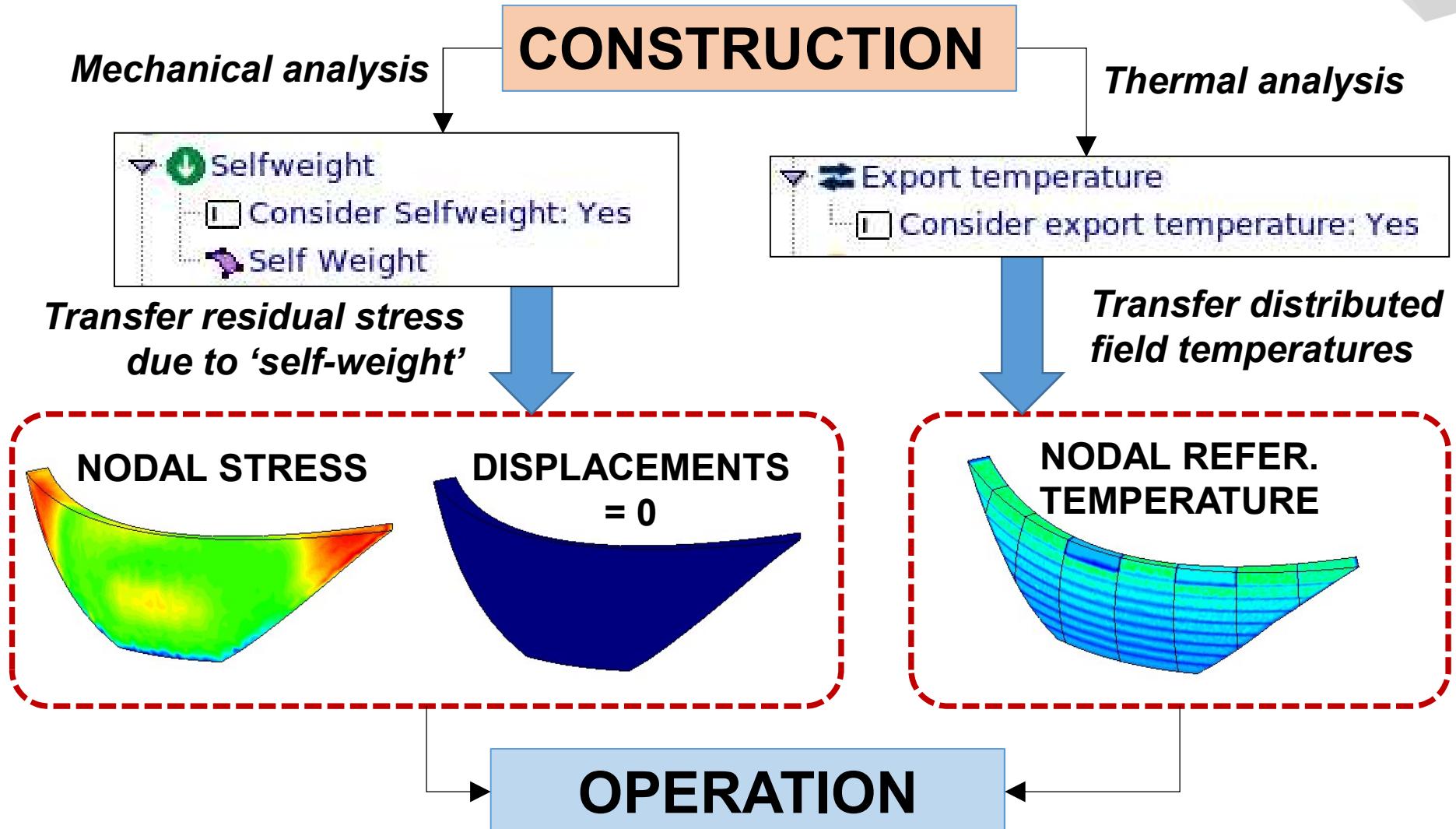
How to obtain the design criteria and parameters
instantaneously in a few clicks

The screenshot shows the武昌设计工作室 (WU昌) software interface:

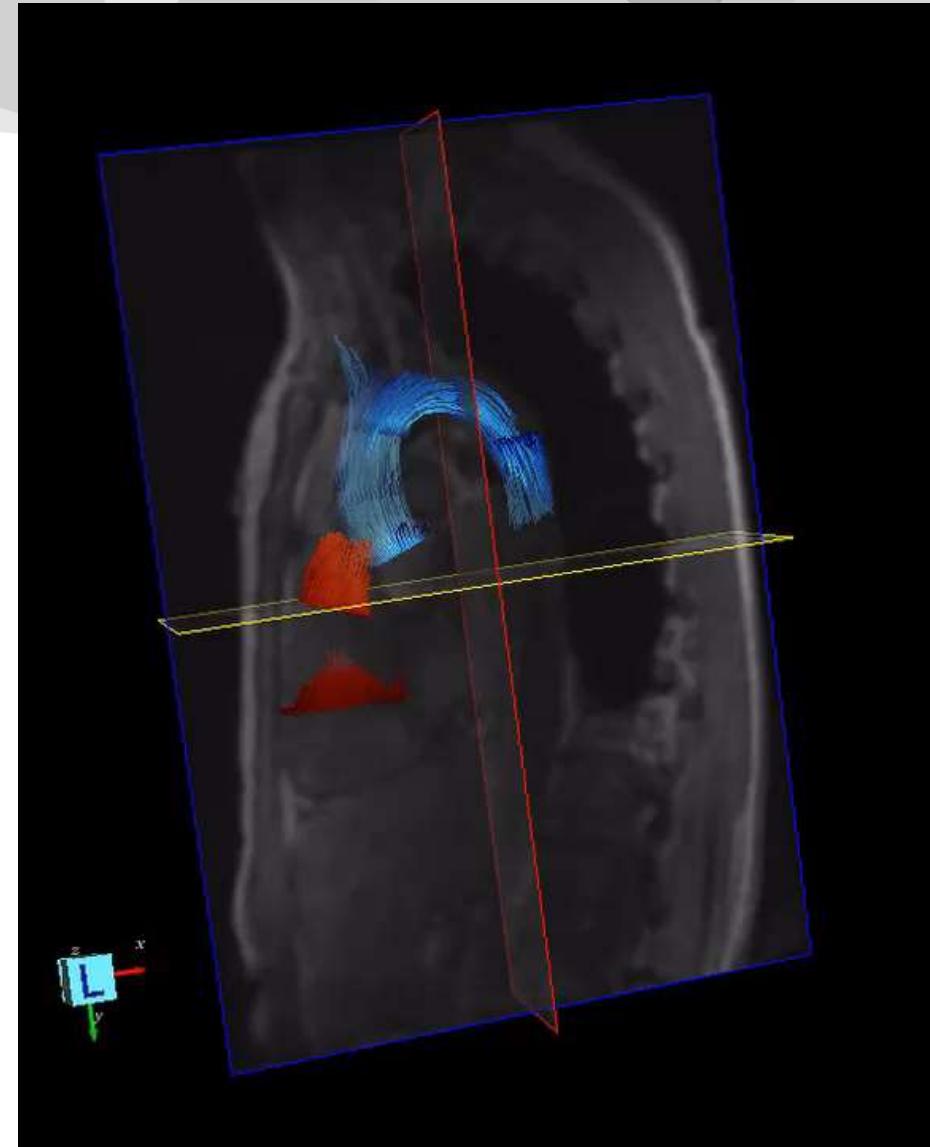
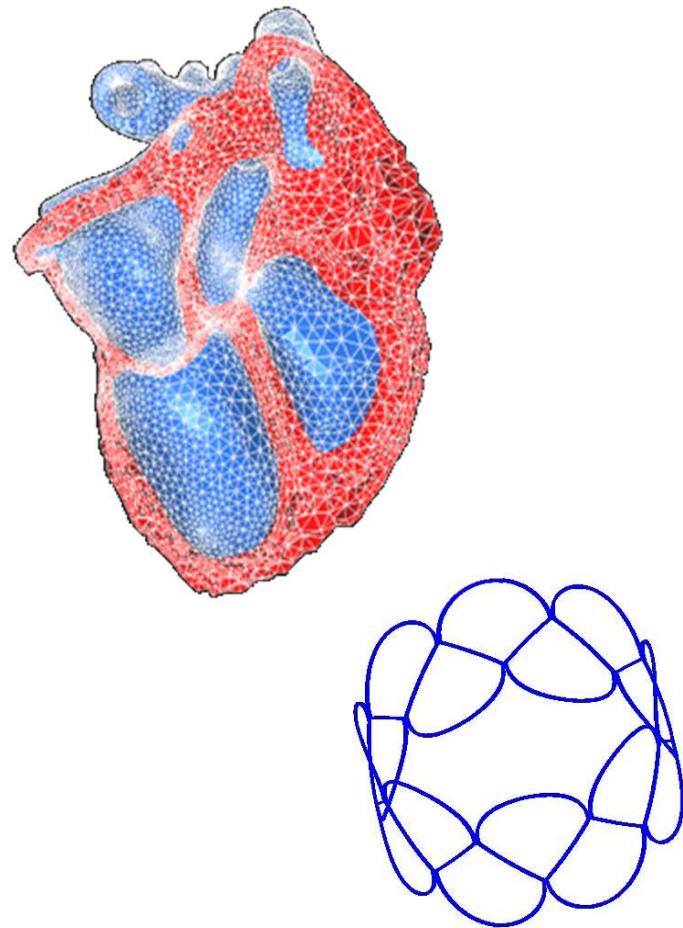
- CALCULATION PARAMETERS:** Set to "3.2-Single model". Input fields include Flow discharge (100 m³/s), Toe water level downstream (1 m), Width of spillway (32 m), Mass of block (110 kg), Security factor of toe (1), Security factor of drainage layer (1), and Max saturation of porous material (80%).
- GRAPHICAL RESULT:** Shows a sideview scheme of the spillway with dimensions and material types (Spillway, Toe, Riprap, Drainage layer, Blocks, Flag board).
- RESULTS:** Main figures, Volume of materials, and Budget sections.

DAM ENGINEERING

Thermo-mechanical analysis of concrete dam



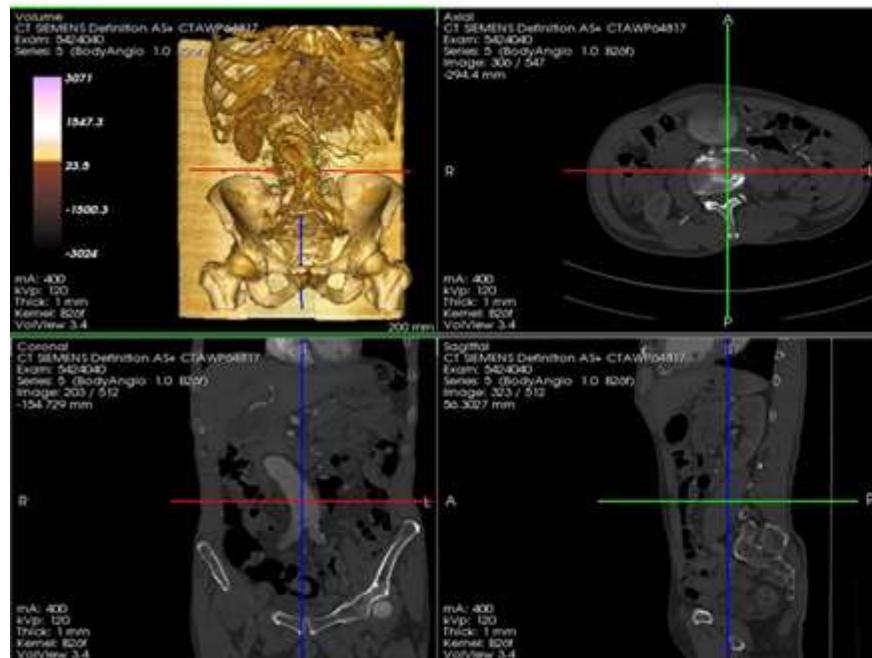
BIOMEDICAL



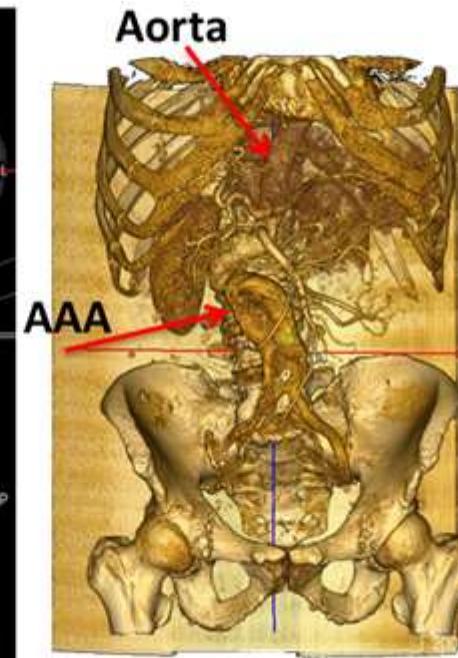
BIOMEDICAL

COMPUTATIONAL TOOL of the cardiovascular system

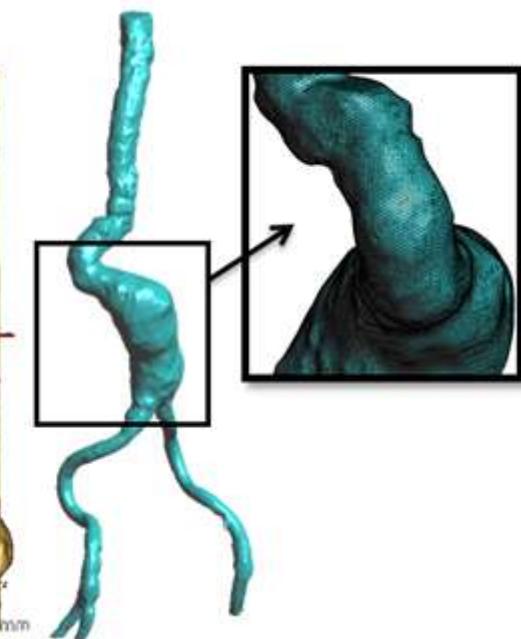
Image
Processing



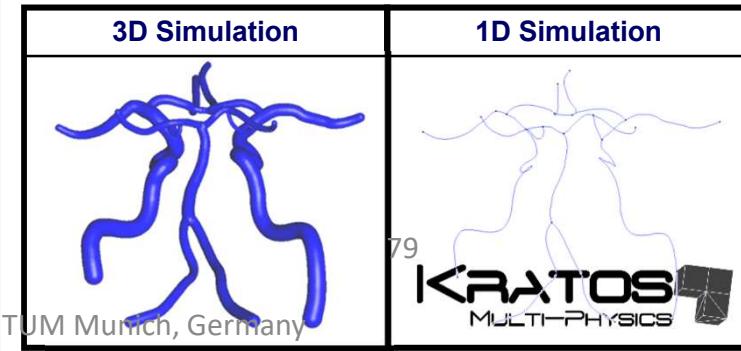
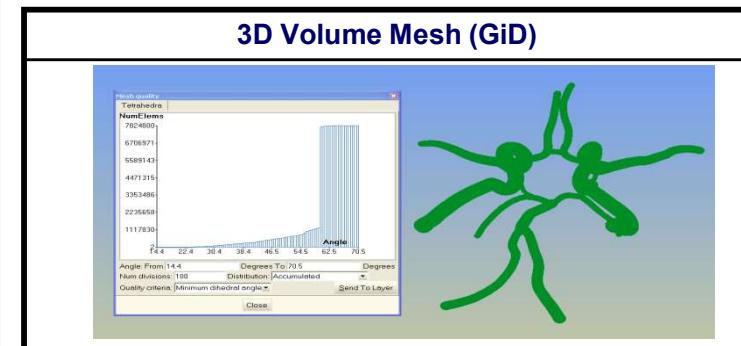
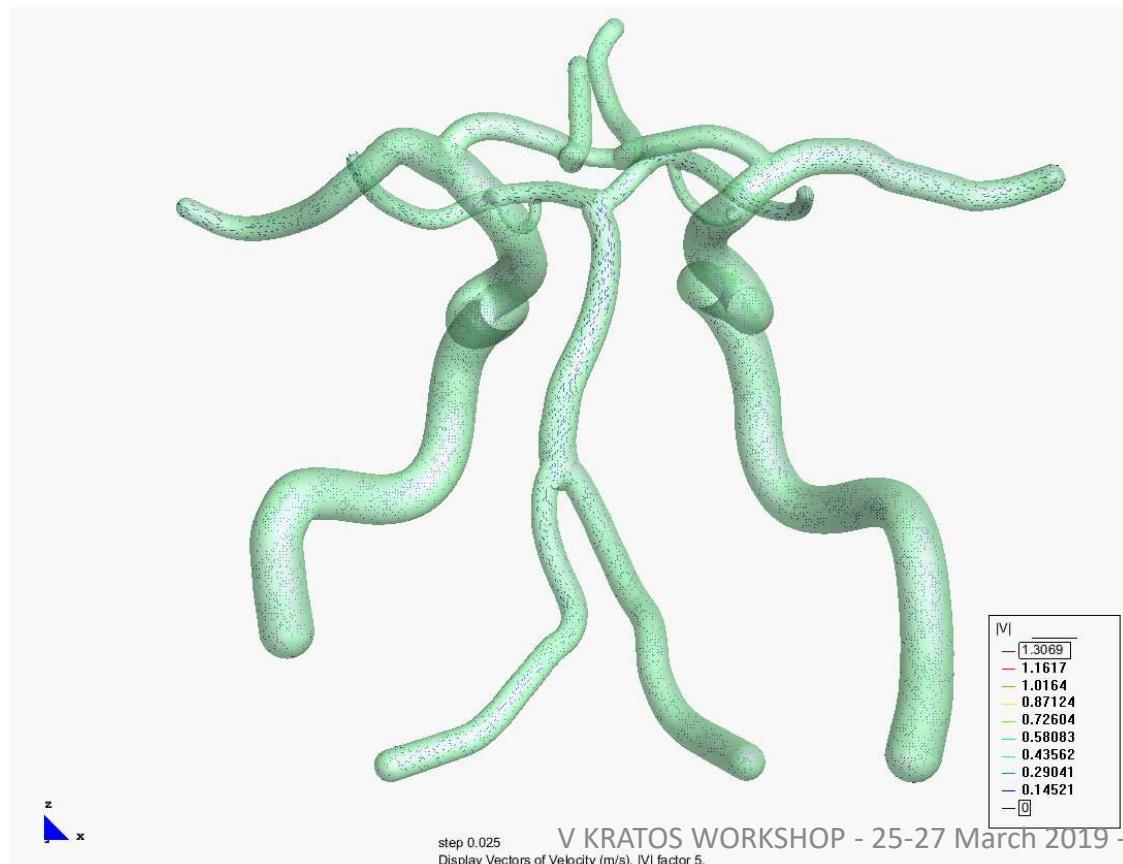
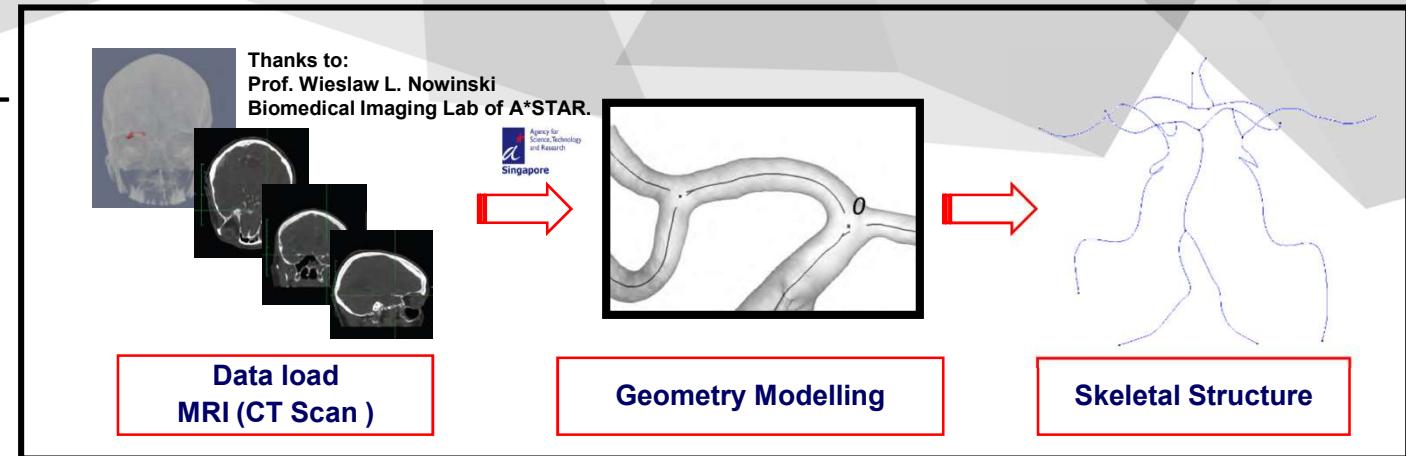
Numerical
Model



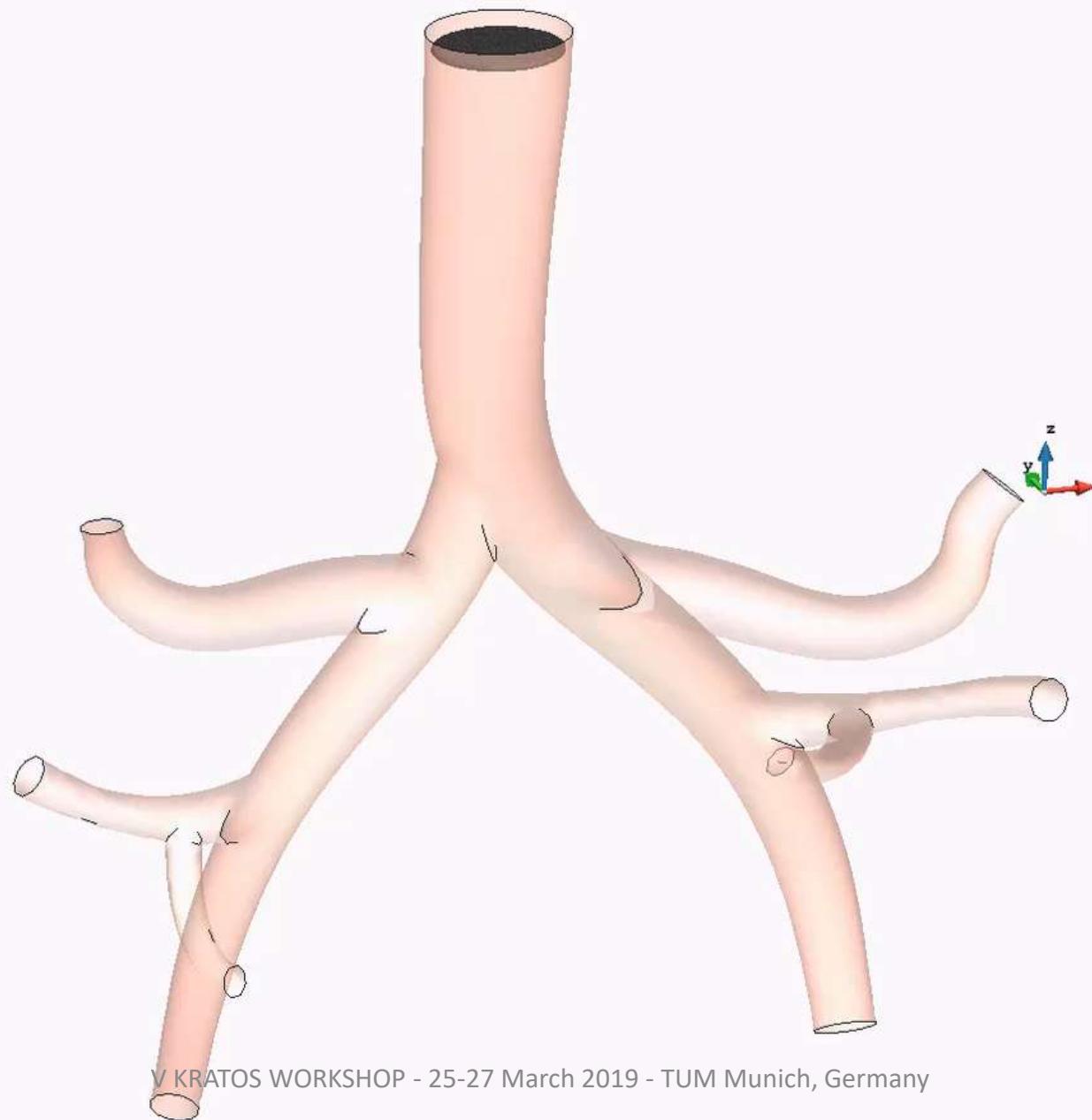
Numerical
Validation



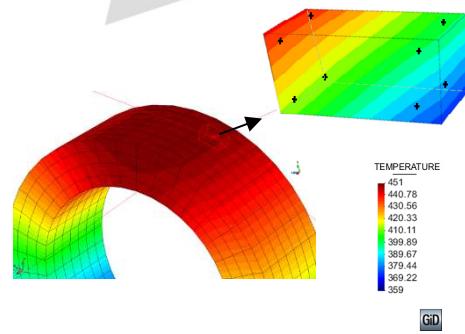
BIOMEDICAL Blood Flow



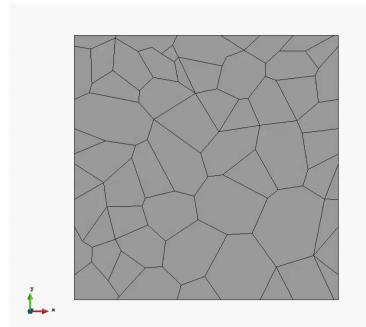
BIOMEDICAL



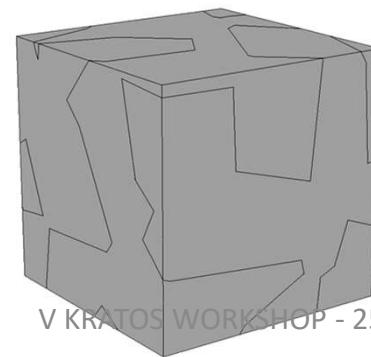
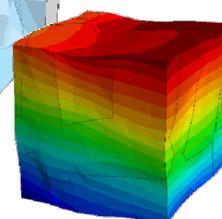
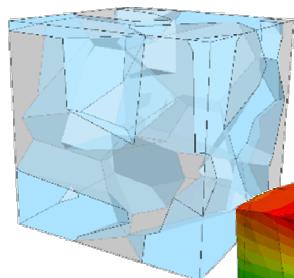
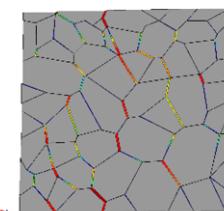
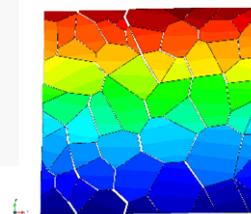
CIVIL ENGINEERING



Ceramic ring with
radial temperature
distribution

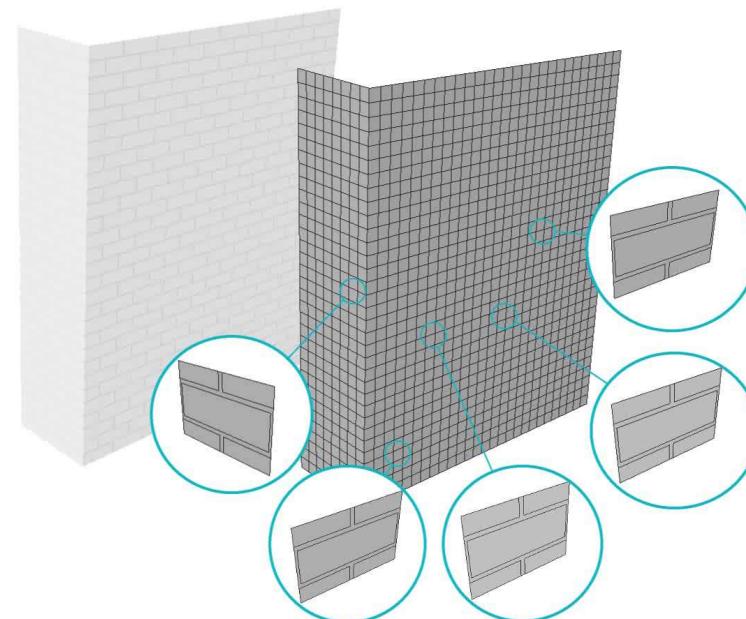


Granular
microstructure
with interfaces

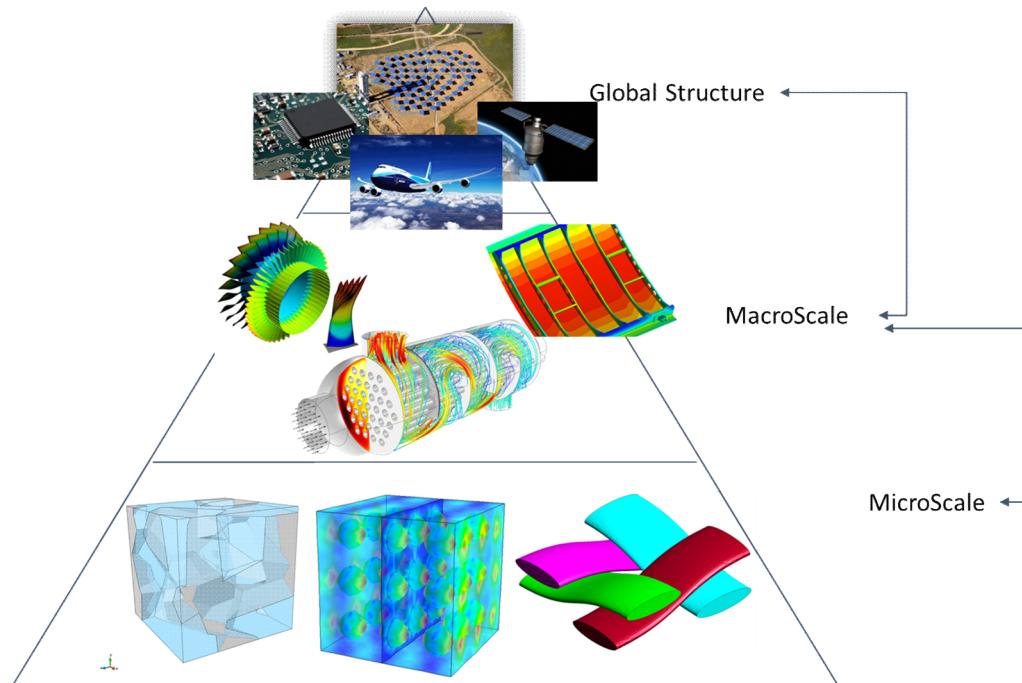


Kratos Multiscale Application

Out-of-plane
failure of a brick
masonry wall



Other features MULTI SCALE APPROACHES

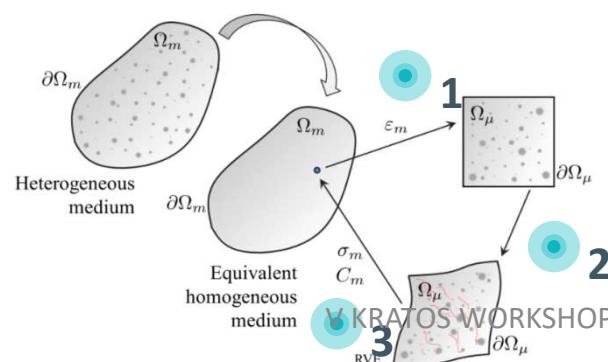


Based on computational homogenization methods for:

- 2D/3D 1° order continua
- Shell-like continua

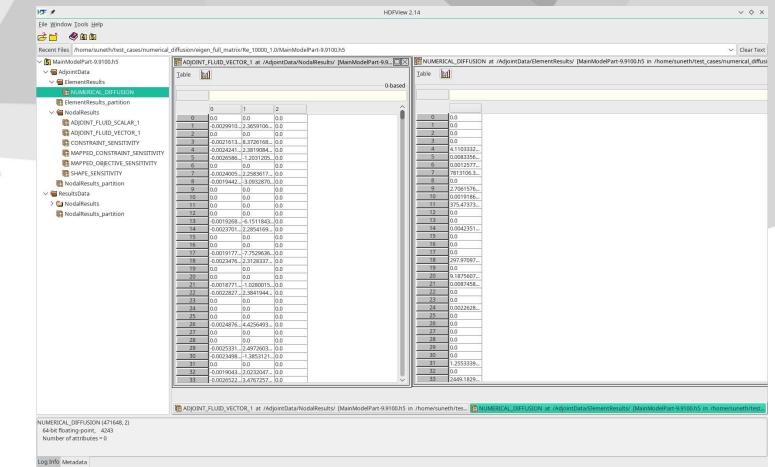
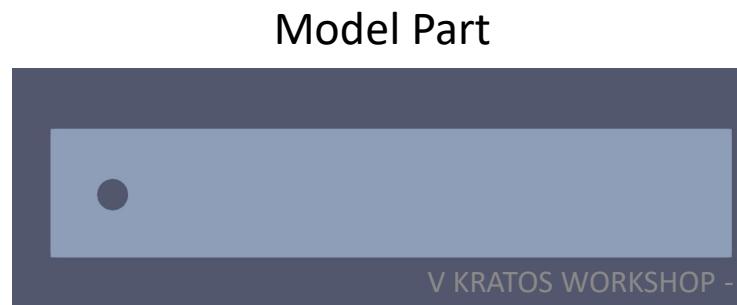
Homogenization of:

- Mechanical and ...
- Thermo-Mechanical problems

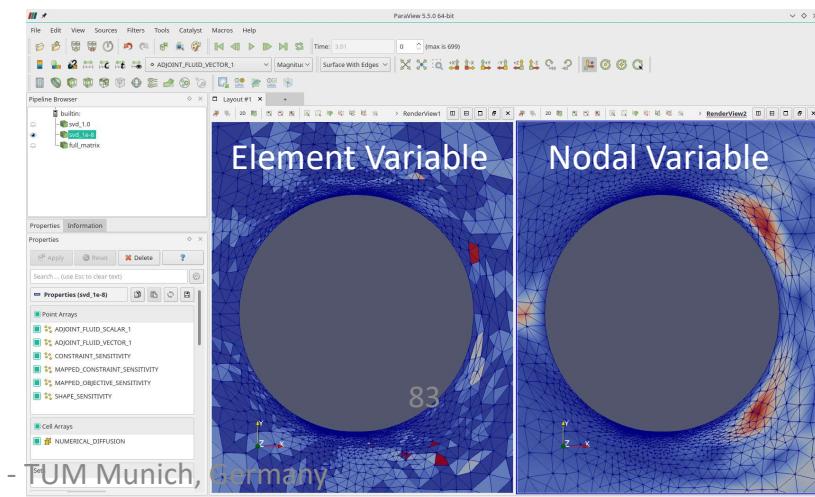


Other features HDF5 Application

- Capabilities
 - Output data to HDF5 file format.
 - Nodal Variables
 - Element Variables
 - Can be used to store temporal history of element variables
 - Paraview can be used to visualize temporal variables from HDF5 files
 - MPI Implementation



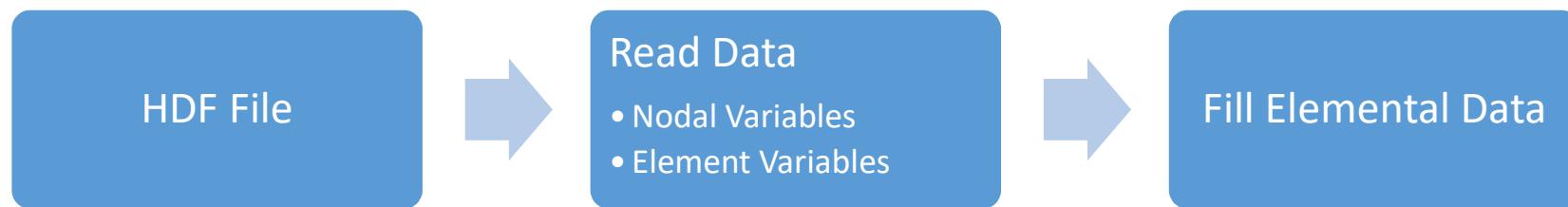
HDFView



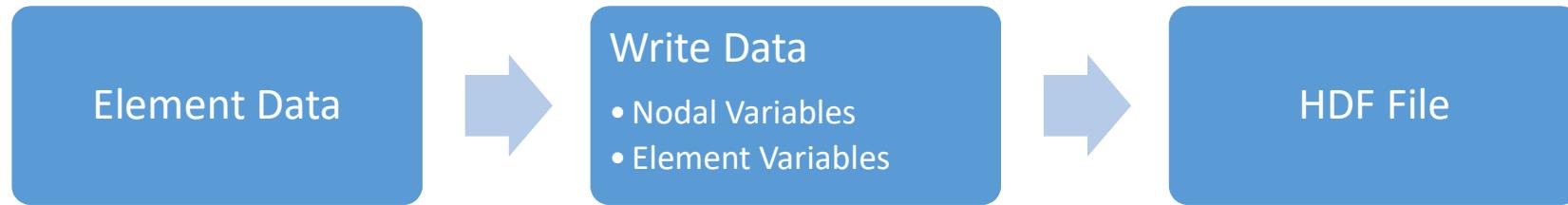
Other features HDF5Application

Michael Andre

Fill element variables from HDF file



Create HDF file from element data



WHY KRATOS?

- Customizable and flexible work flow (ROMs, optimization, ...)
- Combining different data structure (FEM, DEM, MPM or PFEM)
- Inherent capability of coupling:
 - ✓ MULTIPHYSICS
 - ✓ Easy team working (even in different locations)

THANK YOU FOR YOUR ATTENTION!



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