The Virtual Sandbox: Particle Flow Physics taught with Interactive Tools

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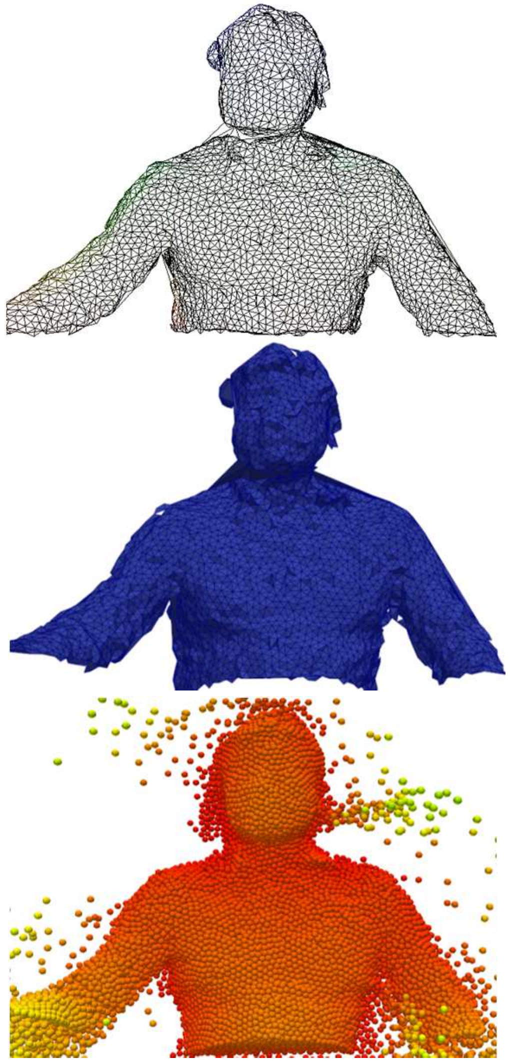
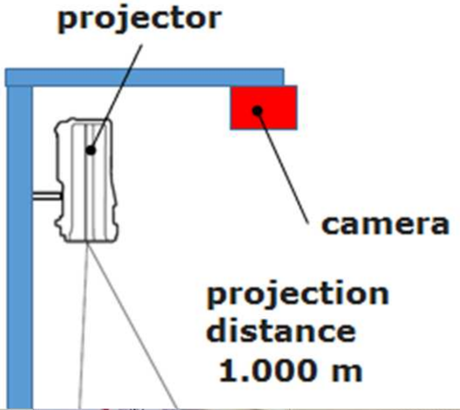


Presented at the AIChE Annual Meeting 2016, San Francisco

Overview

What is the Virtual Sandbox?

- **Dissemination project**: strengthen implementation of **research results in education**
- Research **in the area of wet granular flow** (mainly modeling and simulation tool development)
- **1 year project**, 3 month still to go

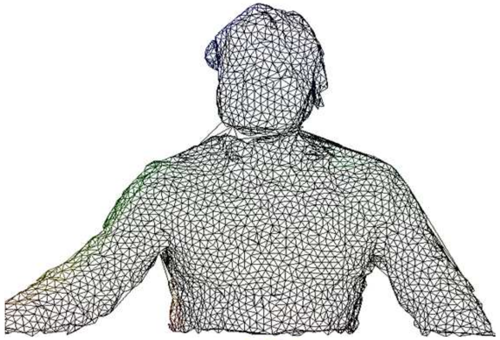


What is new?

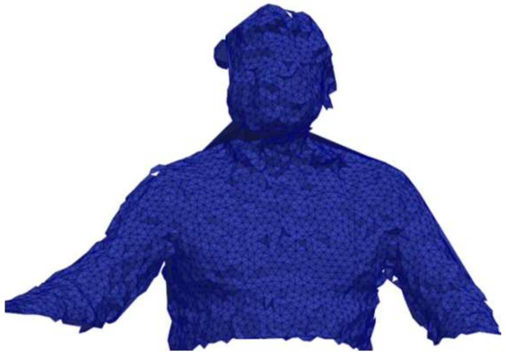
- **Connection** of existing augmented reality tool with **particle simulator**
- **Integration into high school teaching units; particle simulation tools** in undergraduate and graduate projects
- Purely based on **open resources** (open software, open educational resources)

O. Kreylos, Augmented Reality Sandbox, web resource

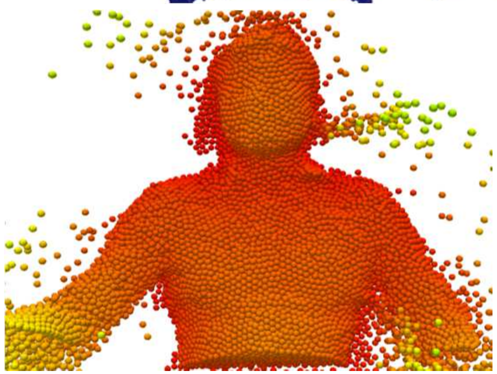
What is the Virtual Sandbox?



- **Use 3D camera** to measure surface topology



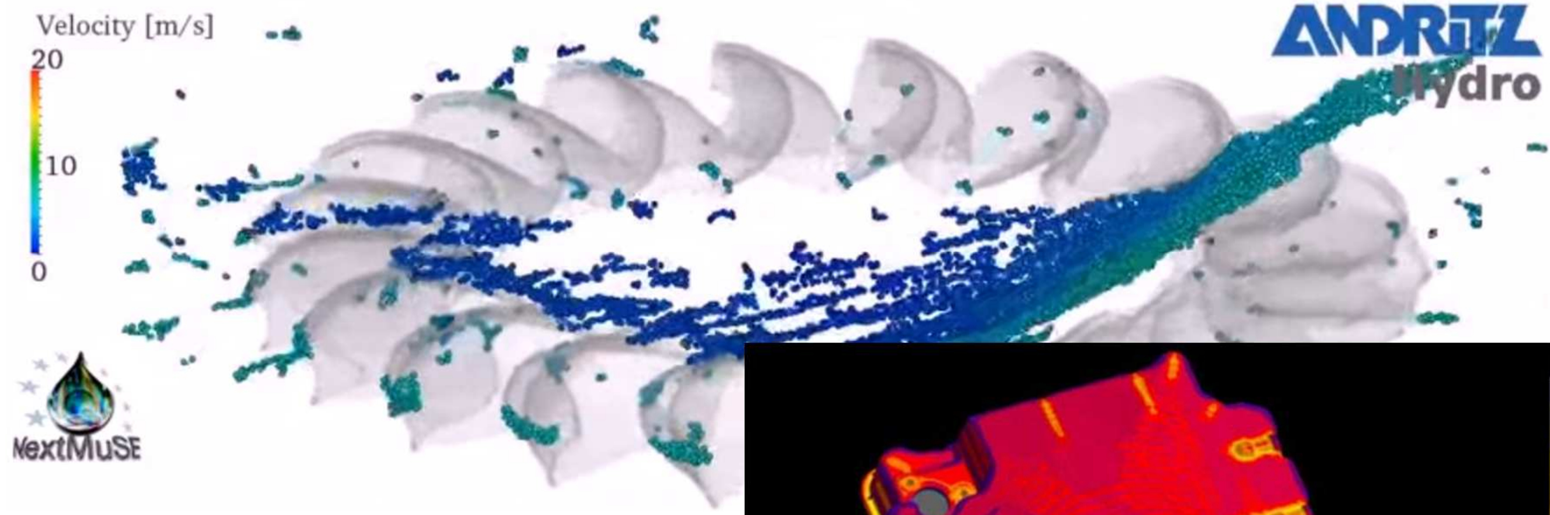
- Generate triangle **mesh**

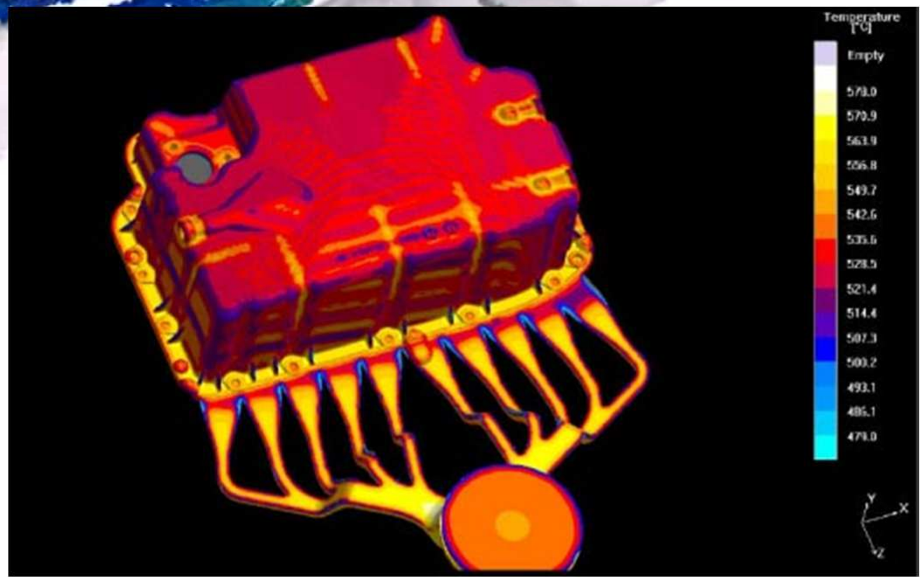


- Run simulation **on the mesh** (e.g., fill particles into topology)

Background

Simulation and virtualization tools are indispensable in engineering

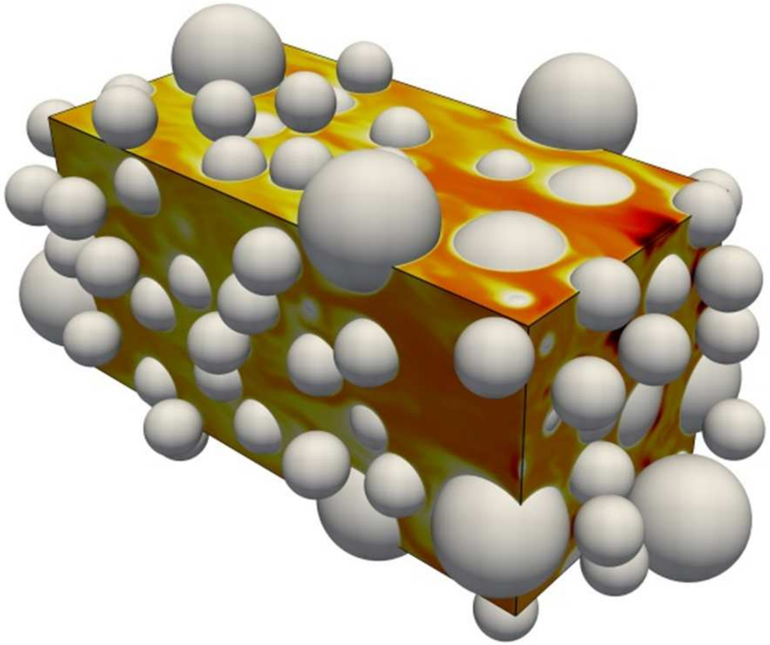


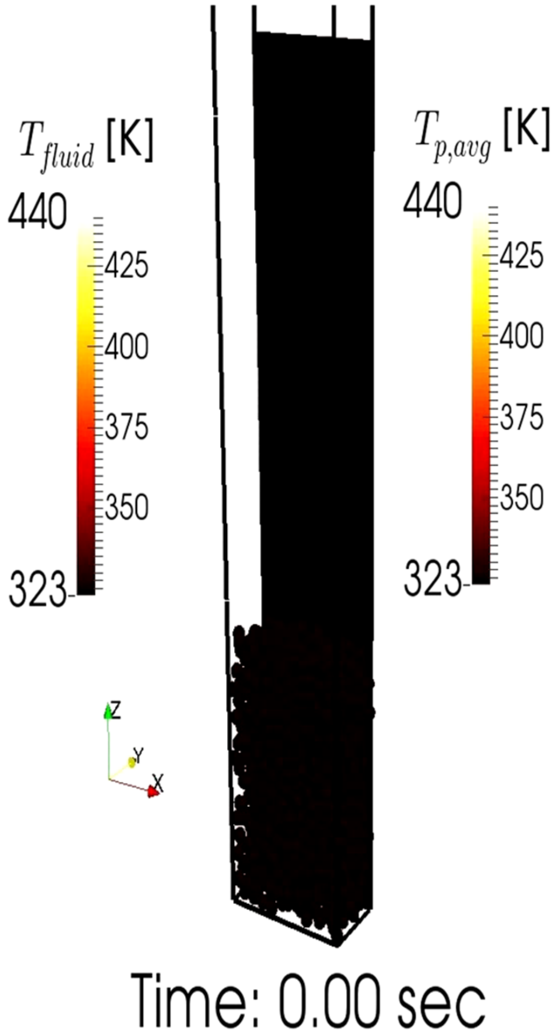


http://www.magna.com/capabilities/body-chassis-systems

Background

Simulation and virtualization tools are indispensable in engineering





Municchi et al., AIChE 2016, Talk 378c

Background

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What are relevant problems?

$$\frac{\partial}{\partial t}\left(\boldsymbol{u}_f \varphi_f \rho_f\right) + \nabla . \left(\boldsymbol{u}_f \boldsymbol{u}_f \varphi_f \rho_f\right) = -\varphi_f \nabla \cdot \tau_f - \varphi_f \nabla P_f + \boldsymbol{\Phi}_d + \varphi_f \rho_f \boldsymbol{g}$$

$$\boldsymbol{\Phi}_d = -\beta_{sf}\left(\boldsymbol{u}_f - \boldsymbol{u}_p\right)$$

$$\beta_{sf} = 18 \rho_f \nu_f \varphi_f \left(1 - \varphi_f\right) \frac{F\left(\varphi_f, Re\right)}{d_p}$$

$$F\left(\varphi_f, Re\right) = 10 \frac{1 - \varphi_f}{\varphi_f^2} + \varphi_f^2 \left(1 + 1.5 \sqrt{1 - \varphi_f}\right) + \frac{0.413\, Re}{24 \varphi_f^2} \frac{\left(\frac{1}{\varphi_f} + 3 \varphi_f \left(1 - \varphi_f\right) + 8.4 Re^{-0.343}\right)}{\left(1 + 10^{3(1-\varphi_f)} Re^{\frac{-1}{2}\left(1 + 4(1 - \varphi_f)\right)}\right)}$$

$$\rho_{p,i} V_{p,i} \frac{\partial \boldsymbol{u}_{p,i}}{\partial t} = \boldsymbol{f}_{cont,i} + \beta_{sf} V_{p,i} \left(\boldsymbol{u}_f - \boldsymbol{u}_{p,i}\right) - V_{p,i} \nabla P_{f,i} + \boldsymbol{g}$$

$$I_{p,i} \frac{d}{dt} \omega_{p,i} = \boldsymbol{t}_i$$

```
fvScalarMatrix mEqn
(

   fvm::ddt(voidfraction, m_)
 - fvm::Sp(fvc::ddt(voidfraction), m_)
 + fvm::div(phi, m_, divScheme)
 - fvm::Sp(fvc::div(phi), m_)

 ==

   fvm::laplacian(nuEff/Sc*voidfraction,
 + mSource_
 + fvm::Sp(mSourceKImpl_, m_)
 #ifndef versionExt32
 + fvOptions_(m_)
 #endif
);
```

… how to illustrate this? How to attract students?

Step 1: Simple Experiments

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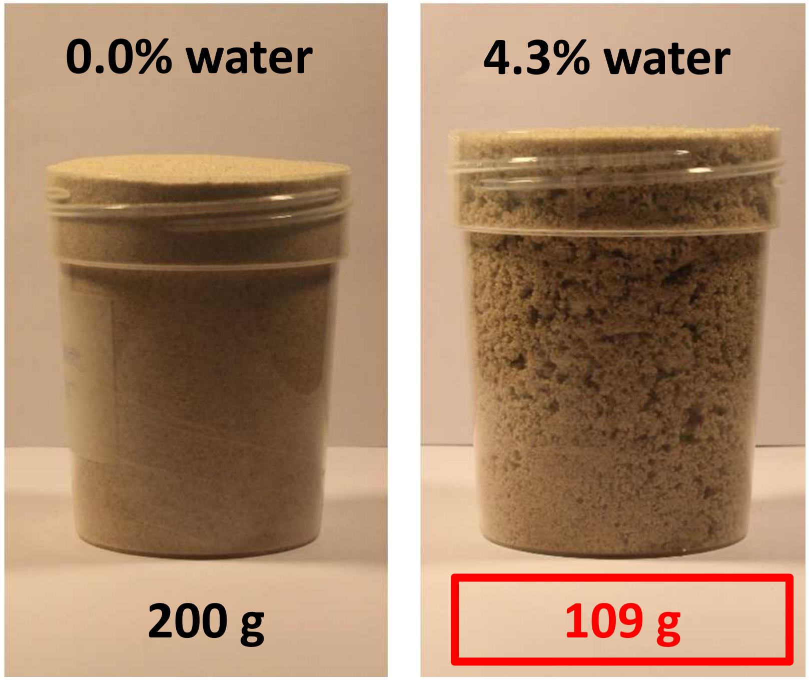
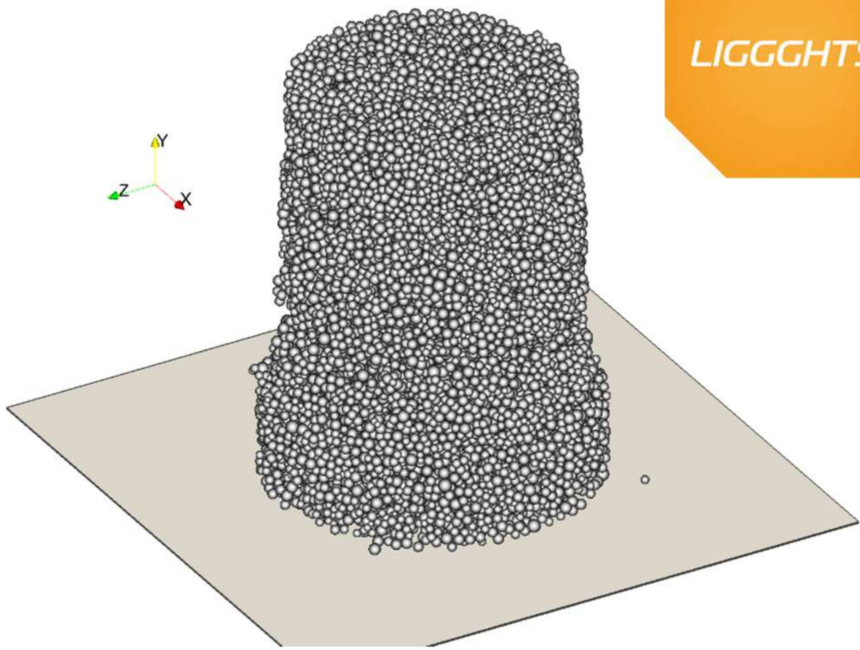
1.1 Density of Cohesive Powders





LIGGGHTS®

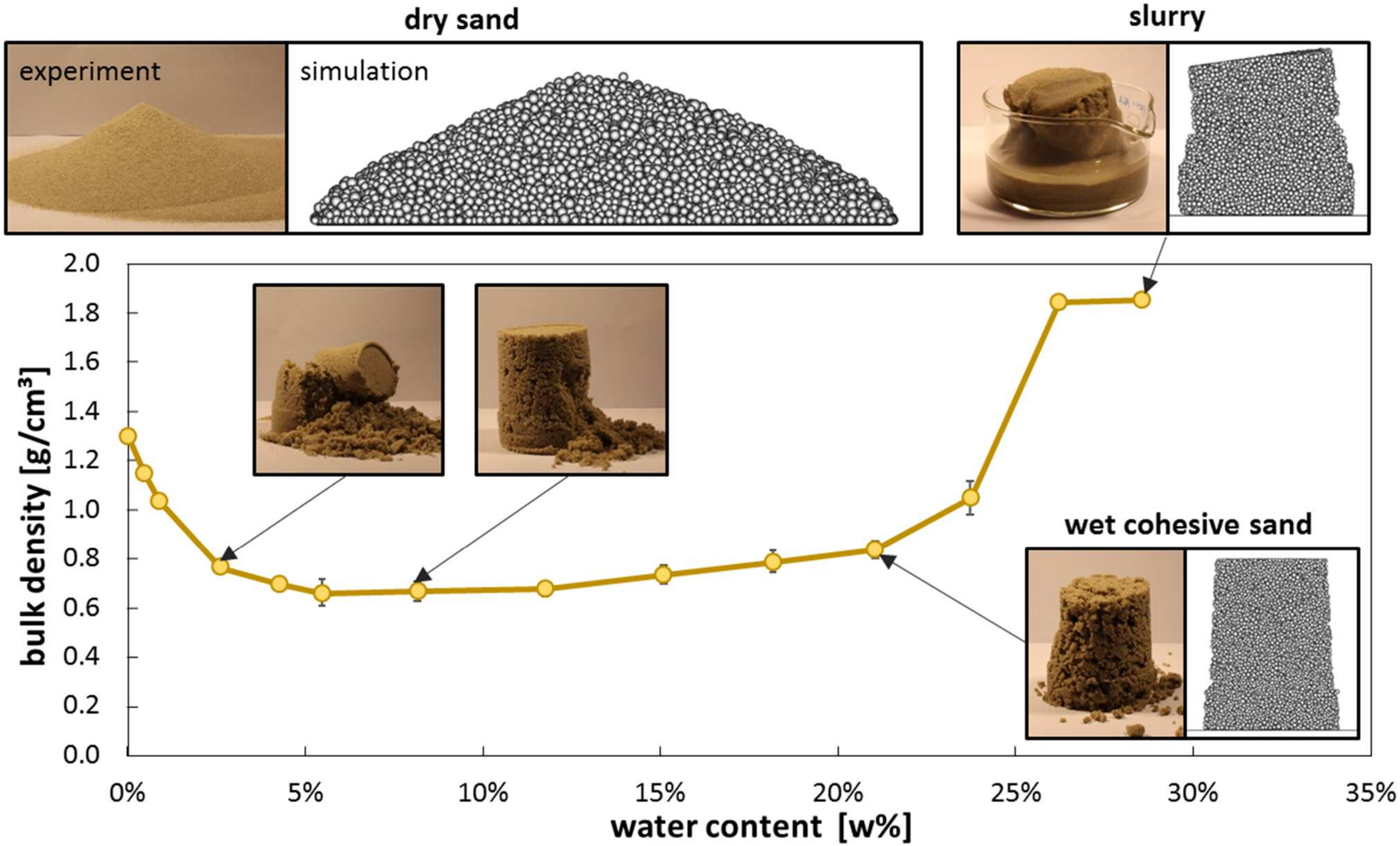
- Illustrates **complexity** of cohesive powders with minimal effort
- Connection to **powder testers** (tapped density measurements, powder rheology)

- Demonstrate that **simulation tools** are able to capture key phenomena

Kloss et al., Progress CFD 12:140 - 152, 2012

Step 1: Simple Experiments

1.1 Density of Cohesive Powders



Step 1: Simple Experiments

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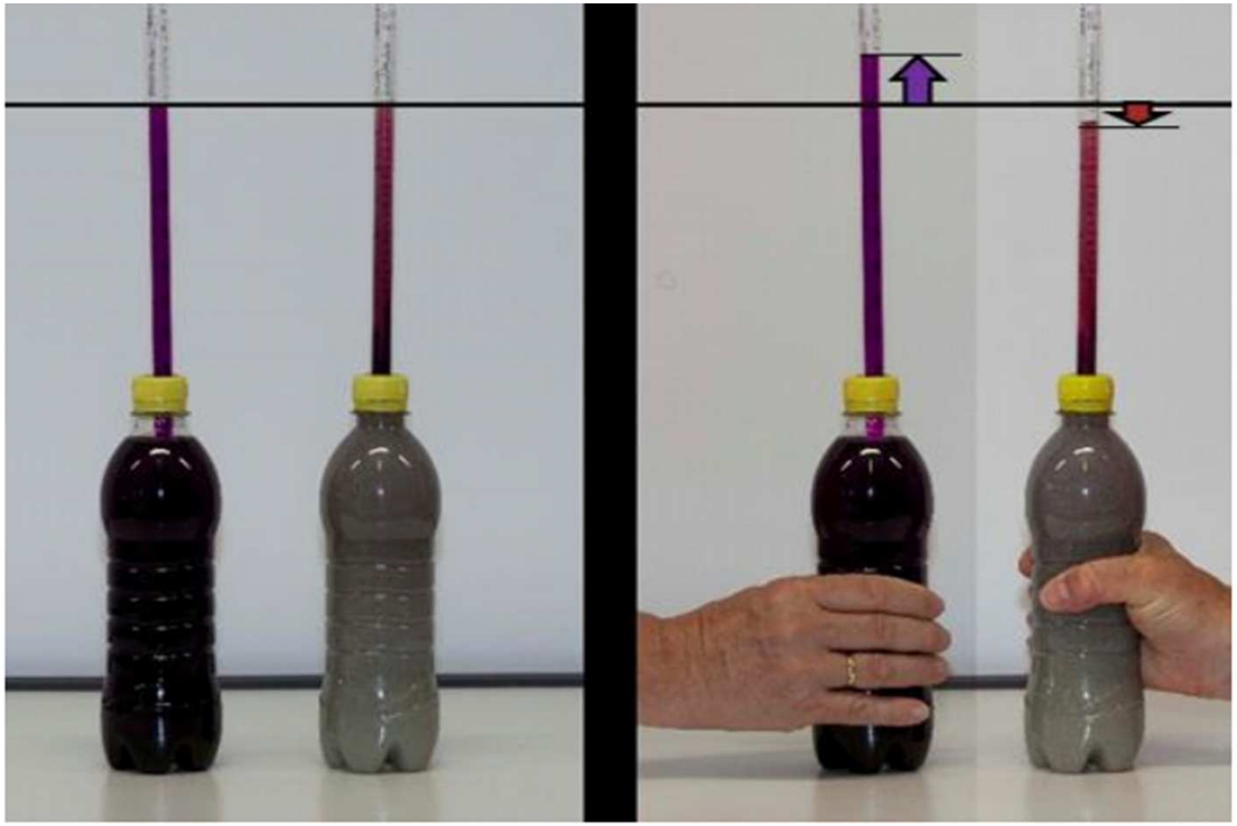
1.2 The Reynolds Dilatancy

- Illustrates **expansion of granular materials** subject to shear deformation
- Connection to **applications in particle technology (e.g., granulation)**

Step 1: Simple Experiments

1.2 The Reynolds Dilatancy



- Illustrates **expansion of** granular materials subject to shear deformation
- Connection to **applications in particle technology (e.g., granulation)**
- Use **simulation tools** to illustrate key phenomena

Step 2: Particle Models

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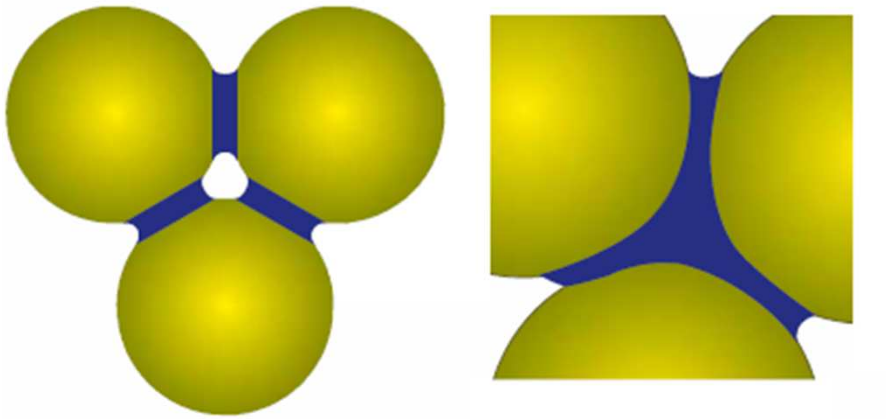
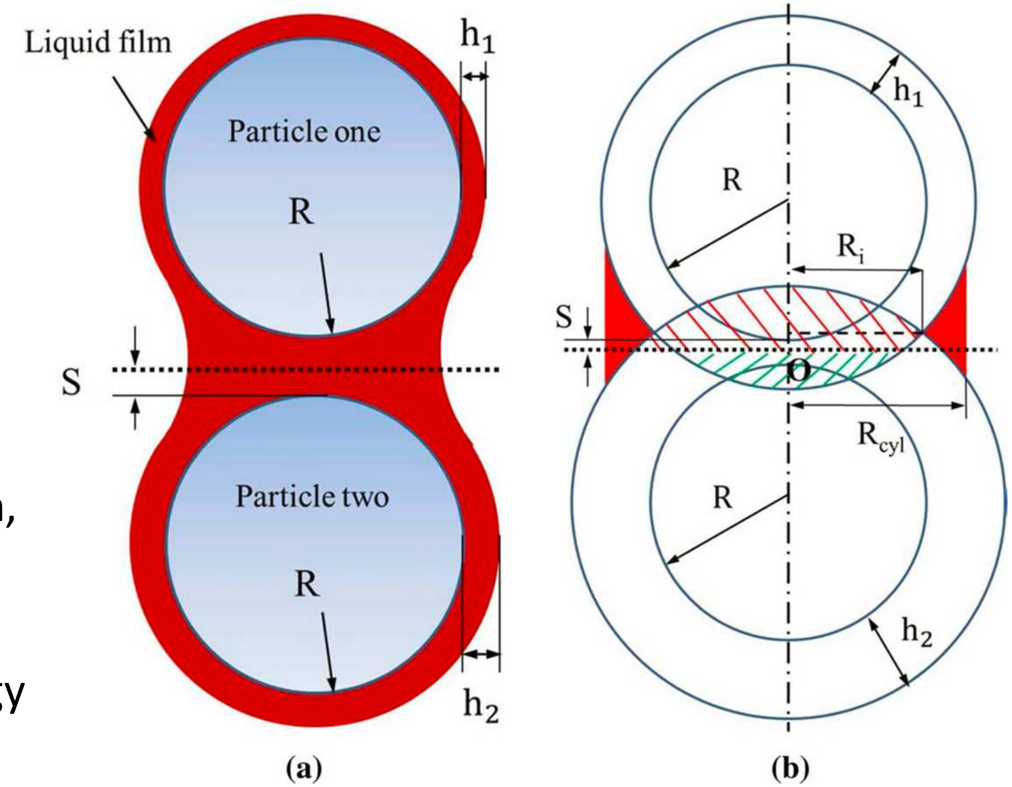
2.1 Liquid Bridge Filling





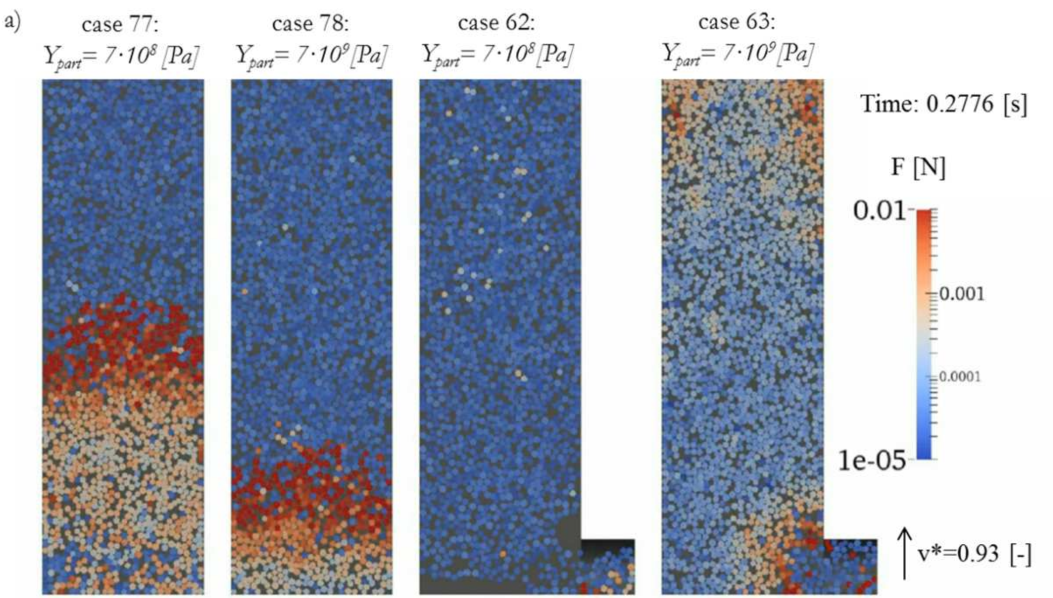
- Illustrates (i) geometrical analysis, (ii) **numerical solution of nonlinear equation**, (iii) solution of **ordinary differential equations, (iv) critical review of models**
- Group work to connect particle technology with **programming exercise** (octave)
- Thesis project for **experimental investigation**

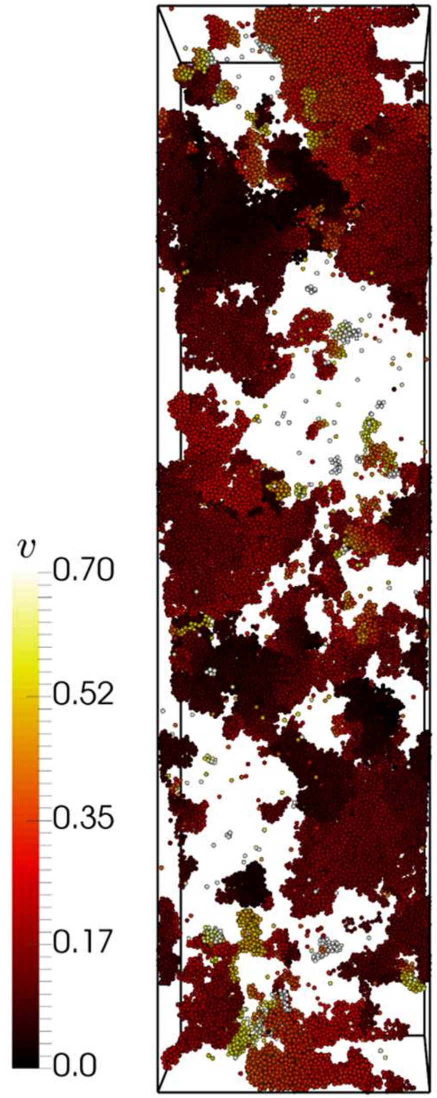
Scheel et al., Nature Materials 7:189-193, 2008
Halsey and Levine, Phys Rev Letter 80:3141-3144, 1998
Wu et al., AIChE J 62:1877-1897, 2016

Step 2: Particle Models

2.2 Discrete Element Simulations

- **LIGGGHTS**: open-source discrete element method-based solver for Newton's equation of motion
- Widely used, **well documented, tutorials and screencasts**, professional support if desired
- Ideal for thesis work **(learning curve: 1-3 weeks)**





Reif, Master Thesis, TU Graz, 2014.
Wu et al., Powder Technol, under review,2016.

Step 3: Bring it to the People!

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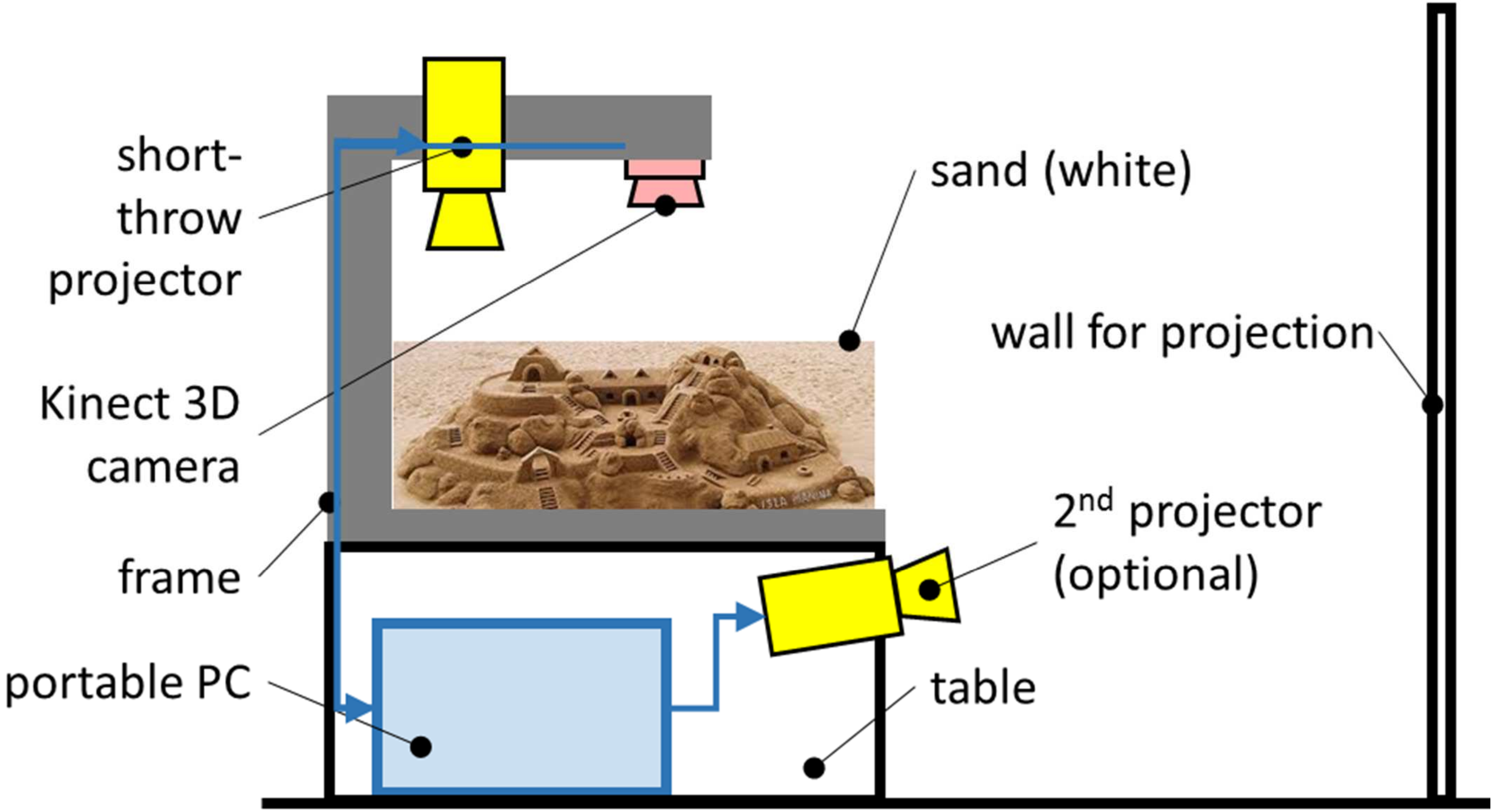

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Conclusions

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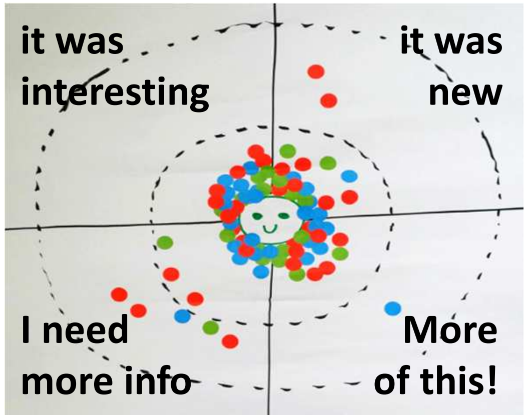
Key Findings

- hardware **inexpensive** (beamer highest cost, construction of support, 2 month ramp up)
- documentation, tutorials, and **screencasts** for software usage
- **inquiry-based learning concept** successfully demonstrated in primary schools



Challenges

- switch to **LINUX-based operating system** often time consuming
- implement inquiry-based learning at **university level**

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Resources

Project Information

- www.tugraz.at/institute/ippt/publikationen/the-virtual-sandbox

Software

- github.com/CFDEMProject
- meshlab.sourceforge.net
- idav.ucdavis.edu/~okreylos/ResDev/SARndbox
- www.gnu.org/software/octave

Training Material

- https://github.com/NanoSim/CoursesAndTrainingPortfolio

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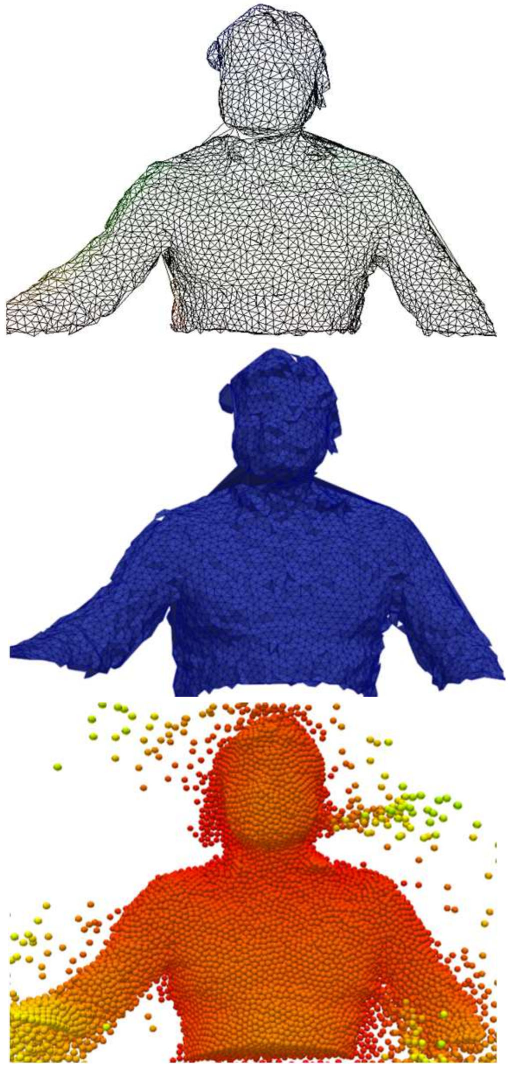

Radl et al.

AIChE Annual Meeting 2016, San Francisco, CA

FWF
Der Wissenschaftsfonds.

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Code available via **https://github.com/CFDEMproject**

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