LEGO® Crash Simulations in LS-DYNA®
Data Management for Large-Scale Models

DYNAmore Express
June 12

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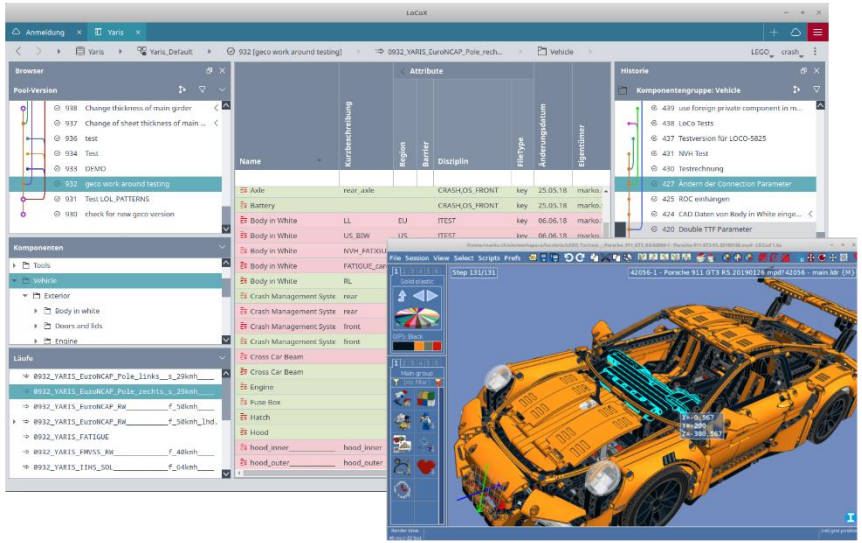
[4]SCALE GmbH

SCALE.model *(LoCo)*

SCALE.project Status.E | **SCALE.model LoCo** | SCALE.result CAViT | SCALE.project Status.E

SCALE.sdm

Requirements → Modelling → Solving → Results → Monitoring



- **Simulation Data- / Variant Management**
  - Workbench for Simulation Engineers
  - Unique RichClient/Offline-concept with sync-mechanism *(internal/external)*
- **Workflows / Features**
  - Integration of arbitrary CAE processes
  - Solver independent: PAM-Crash, LS-DYNA®, Nastran, Abaqus, …
  - Job submit and monitoring
  - Optimization, robustness, DOE, …
  - Quality checks of models
  - Advanced security features
    - Two factor authentication
    - Encryption
    - Sophisticated roles and rights management
  - Distributed, collaborative work environment

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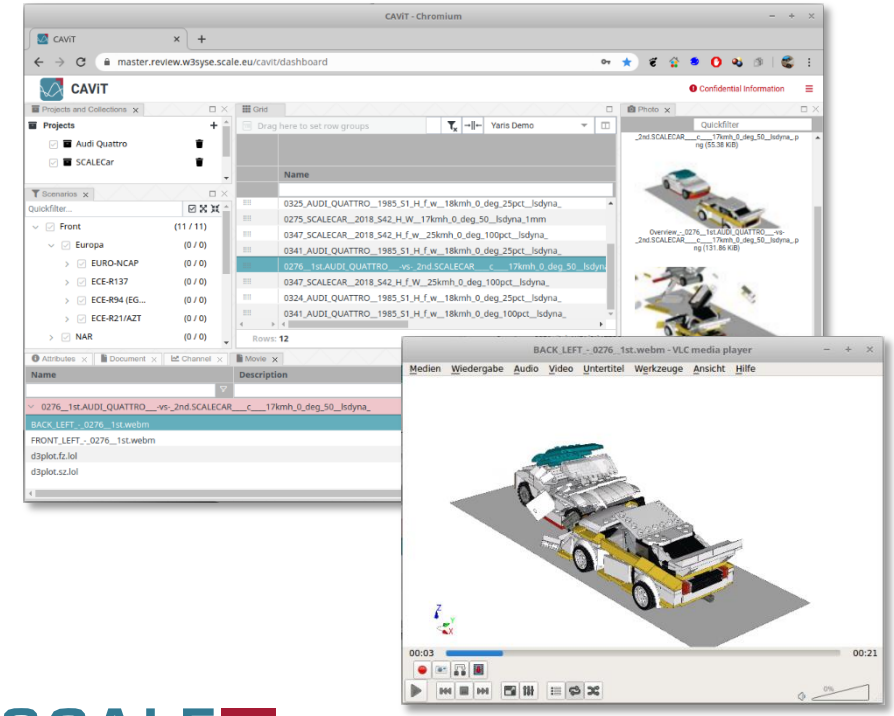
SCALE.result *(CAViT)*

SCALE.project Status.E | SCALE.model LoCo | **SCALE.result CAViT** | SCALE.project Status.E

SCALE.sdm

Requirements | Modelling | Solving | Results | Monitoring



- **Post Data Management**
  - provision of outcome data from simulation and experiment
    (fetching of simulation and test data from various sources)
  - Comparison and visualization of simulation and experiments

- **Features**
  - Assessment of simulation and experimental results
    (scenario based)
  - Easy integration of any application and processes
    (Addons for e.g. Animator, Falcon,..)
  - Automatic report generation
    (Animator, PPTX, just in time within WebInterface)
  - Easy to access WebInterface
    (e.g. hosted at Amazon Web Services, or in house on premise)

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Teaser by c't magazin für computer technik and ADAC

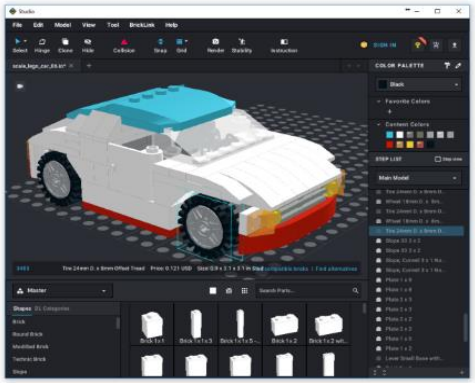
https://youtu.be/LyJ5B---Zdo

1st attempts to set up a virtual LEGO® Model

Prototype

Modeling in CAD

CAD



Physical Build

Rendering

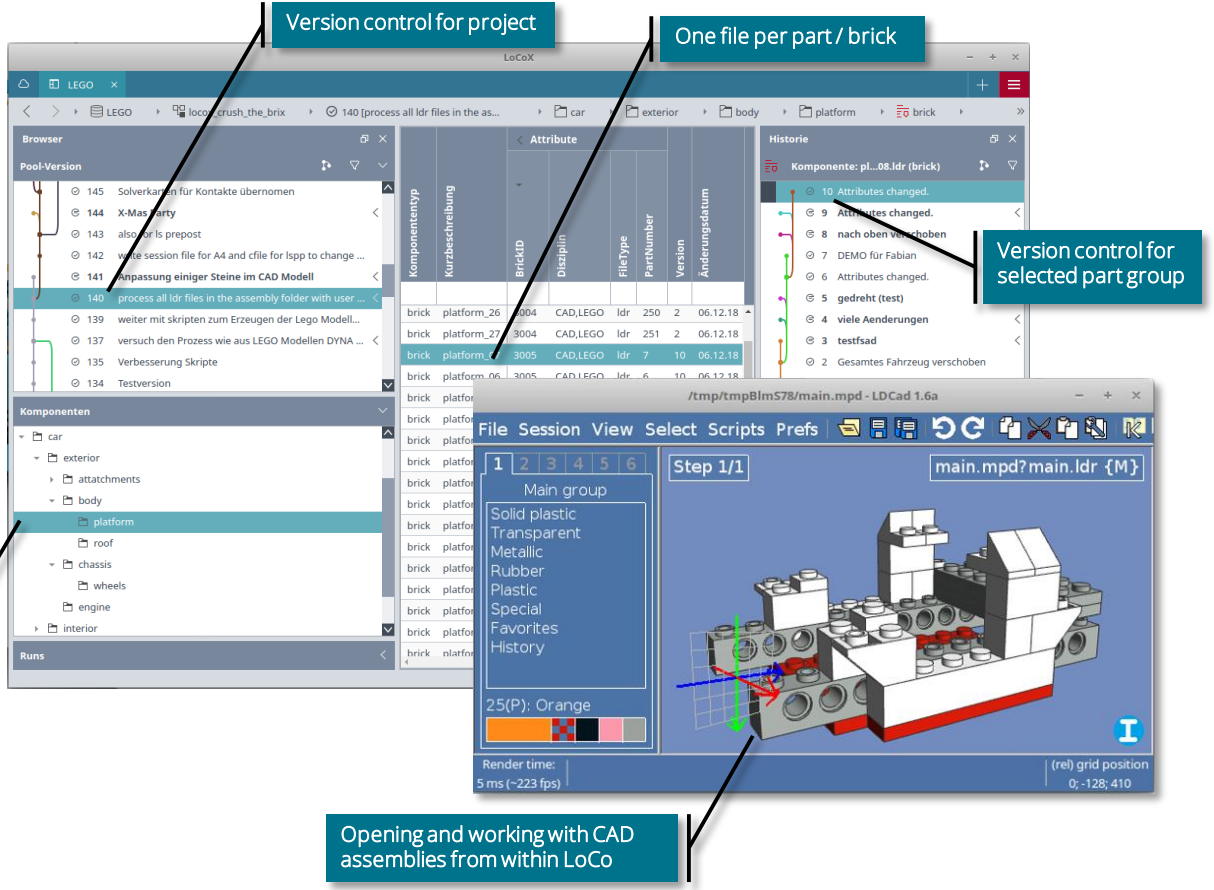
Rendering

Real World Model

- Ldraw.org
  - http://www.ldraw.org/
  - OMR: http://omr.ldraw.org/
- LeoCAD: https://www.leocad.org
- LDCad: http://www.melkert.net/LDCad
- https://www.bricklink.com
- https://www.mecabricks.com/

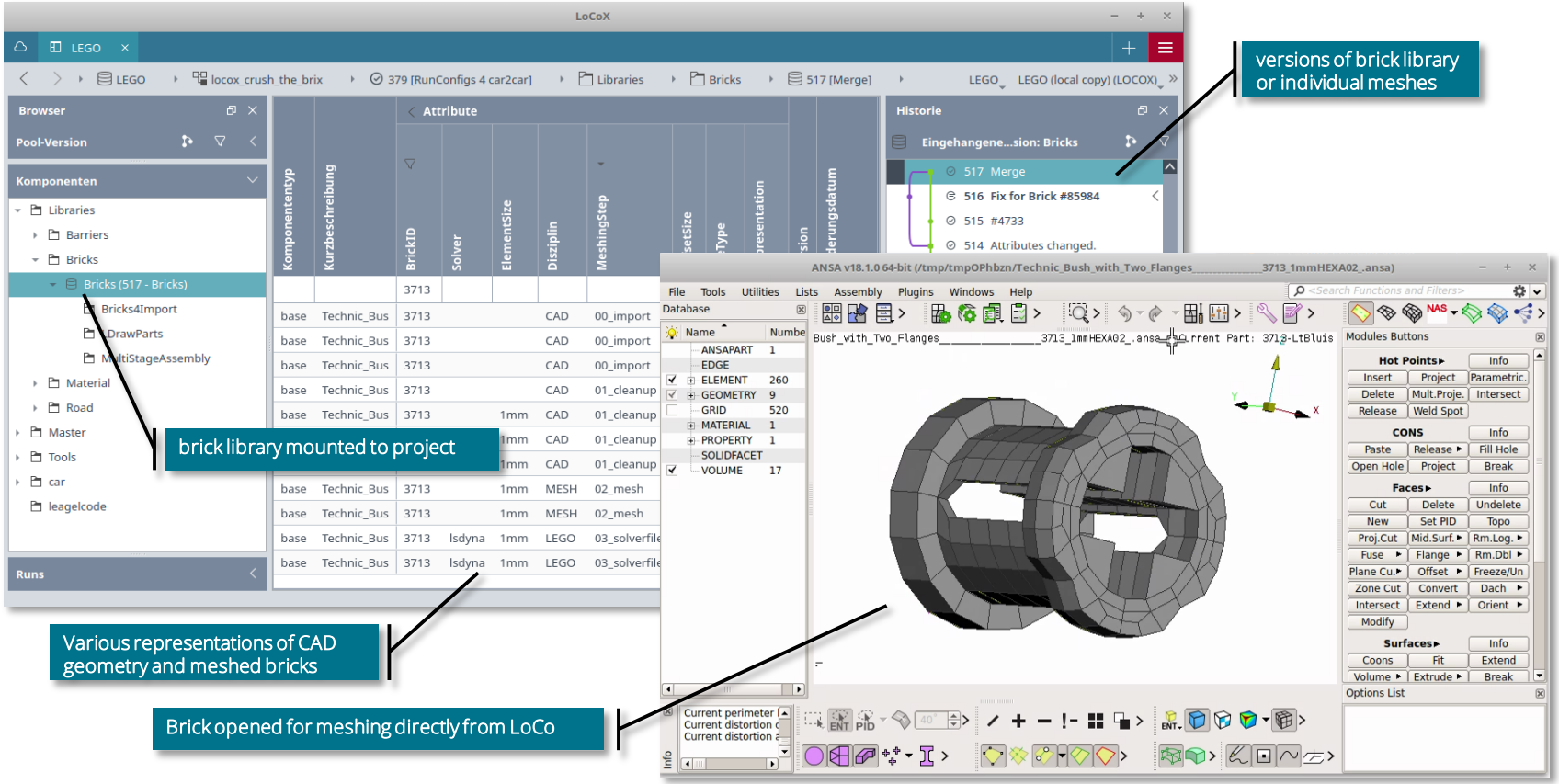
Working with CAD data in LoCo[1]

- LDraw models imported into LoCo
- One file per part *(brick)*
- CAD can be opened directly for assemblies
- Changes are saved automatically and synced to all team members



[1] C. Knehler, M. Thiele, D. Matthus, P. Friedrich, "Prospects of integrating CAD and CAE in Simulation Data Management", NAFEMS European Conference Simulation Process and Data Management (SPDM), 28-29 November 2018, Munich, Germany

Organizing the Meshing of CAD data with LoCo[1]



[1] C. Knehler, M. Thiele, D. Matthus, P. Friedrich, "Prospects of integrating CAD and CAE in Simulation Data Management", NAFEMS European Conference Simulation Process and Data Management (SPDM), 28-29 November 2018, Munich, Germany

From LDraw to LS-DYNA® *.key format

- Each line of LDraw file represents one brick
- Upon assembly a script creates for each brick automatically
  ***DEFINE_TRANSFORMATION** and
  ***INCLUDE_TRANSFORM** cards
- Changes to the LDraw files (components in LoCo) are automatically incorporated in new simulation

- The same bricks are imported over and over again

```
0 FILE 42056 - main.ldr
0 main
0 Name: 42056 - main.ldr
0 Author: Philippe Hurbain [Philo]
0 !LDRAW_ORG Model
0 !LICENSE Redistributable under CCAL version 2.0

0 !THEME Technic

0 ROTATION CENTER 0 0 0 1 "Custom"
0 ROTATION CONFIG 0 0
1 71 -0.567 0 -180.567 0 0 1 0 1 0 -1 0 0 64179.dat
1 1 -60.567 0 -160.567 -1 0 0 0 0 -1 0 -1 0 6558.dat
1 1 -60.567 0 -200.567 -1 0 0 0 0 -1 0 -1 0 6558.dat
1 0 -40.567 -40 -180.567 0 1 0 0 0 1 1 0 0 60484.dat
1 0 -40.567 0 -230.567 0 1 0 0 0 1 1 0 0 2780.dat
1 0 39.433 0 -230.567 0 1 0 0 0 1 1 0 0 2780.dat
```

```
$#########################################################################
$ Include - Transform for:
$ dashboard2_-_nnn_____________558_6558_000000_----_3b16a7a2.ldr
$#########################################################################
$
*DEFINE_TRANSFORMATION
  20115001
$
$  Rotation:
$
    ROTATE       1.0       0.0       0.0       0.0       0.0       0.0      90.0
$
$ um X
    ROTATE       1.0       0.0       0.0       0.0       0.0       0.0       -90
$ um Y
    ROTATE       0.0       1.0       0.0       0.0       0.0       0.0        -0
$ um Z
    ROTATE       0.0       0.0       1.0       0.0       0.0       0.0       180
$
$  Translation:
$          x         y         z
    TRANSL   -0.2268       -80  -109.827
                                       $
$ final rotations
$
    ROTATE       1.0       0.0       0.0       0.0       0.0       0.0     -90.0
    ROTATE       0.0       0.0       1.0       0.0       0.0       0.0     -90.0
$_____________________________________________________________________________
$
*INCLUDE_TRANSFORM
Tile__1_x__1_with_Groove_____________________6558_1mm03_.key
$#  idnoff    ideoff    idpoff    idmoff    idsoff    idfoff    iddoff
  20115000  20115000  20115000         0  20115000  20115000  20115000
$#  idroff
  20115000
$#  fctmas    fcttim    fctlen    fcttem    incout

$#  tranid
  20115001
$
```

Brick ID

transformation and rotation of brick

meshed brick

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Job assembly and control through LoCo… 1st simulations

Runs

- SCALECAR
  - Front impact - Rigid Wall
    - overlap 100 pct
    - overlap 25 pct
      - 10 kph
      - 17 kph
        - ⇒ 0381_SCALECAR__8stud_H_f_w__17kmh_0_deg_25pct_1st-pos_
        - ⇒ 0381_SCALECAR__8stud_H_f_w__17kmh_30deg_25pct_1st-pos_
        - ⇒ 0381_SCALECAR__8stud_H_f_w__17kmh_45deg_25pct_1st-pos_
        - ⇒ 0381_SCALECAR__8stud_H_f_w__17kmh_60deg_25pct_1st-pos_
        - ⇒ 0381_SCALECAR__8stud_H_f_w__17kmh_90deg_25pct_1st-pos_
      - 25 kph
    - overlap 50 pct
  - car 2 car impact - no barrier
- AUDI_QUATTRO
  - Front impact - Rigid Wall
    - overlap 100 pct
      - 18 kph
        - ⇒ 0381_AUDI_QUATTRO__S1_H_f_w__18kmh_
        - ⇒ 0381_AUDI_QUATTRO__S1_H_f_w__18kmh_

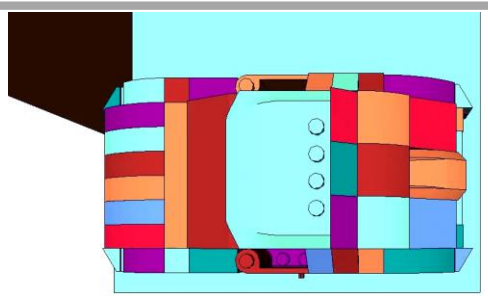
Flexible grouping of runs by their properties

Setup of multiple different scenarios

Setup of multiple cars

Job submit directly in GUI

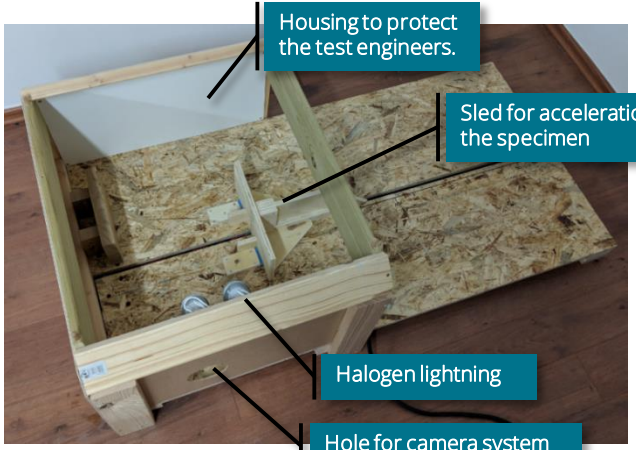
- Lokal aufbauen
- Remote aufbauen
- Anrechnen
- Run-Konfiguration entfernen
- Run-Konfiguration duplizieren
- Bild hinzufügen…
- Tags

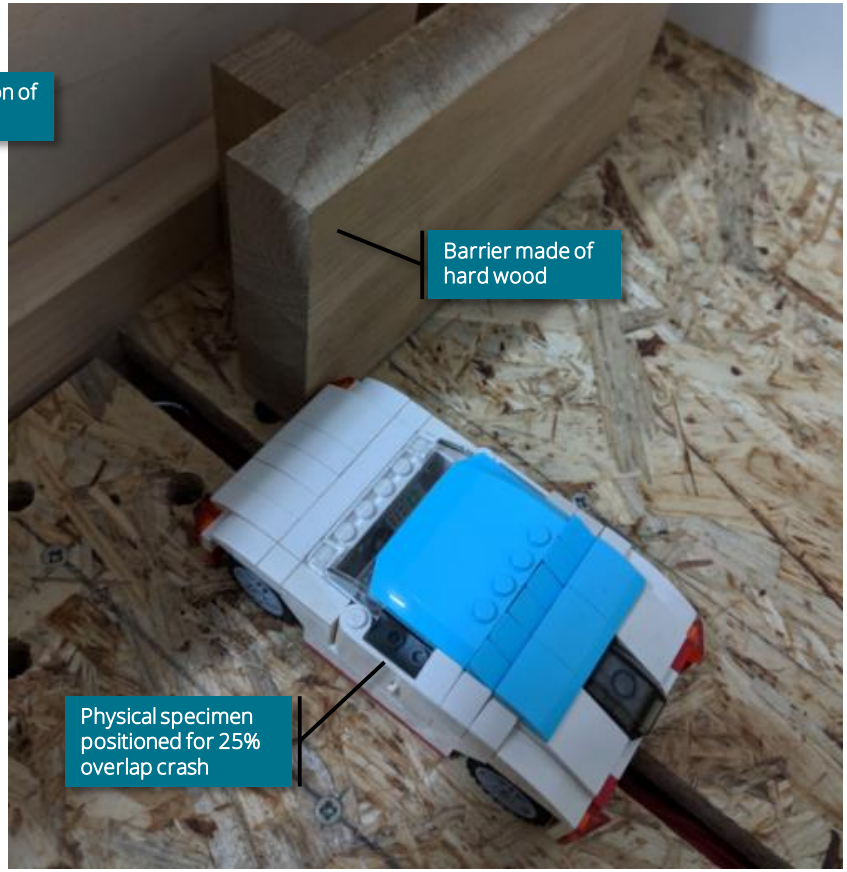


- Changes on CAD are instantly reflected on model
- Results can be opened directly in CAViT *(SCALE.result)*

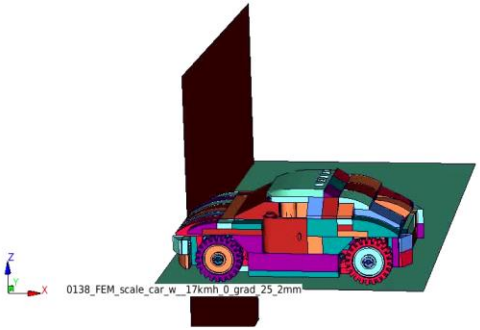
Wooden slingshot crash test sled

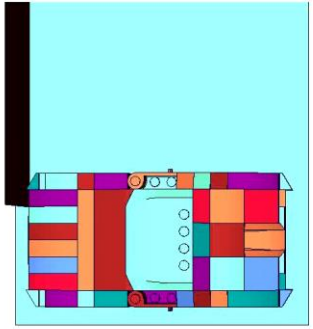
- One weekend
- Made of wood
- 15-20km/h
- 6 halogen spots for lightening
- 3 barrier positions
- 2 smart phones for slow motion video capturing
  (Samsung S7, Pixel 2)
- 240fps
- Lots of fun





1st simulation results compared to videos of physical test





- Initial simulation already showed surprisingly good correlation with test videos
- Setup of simulation process gave insight into various challenges for our software products.
  - What is needed to integrate CAD and meshing?
  - Performance
- Basis to start with more complex challenges

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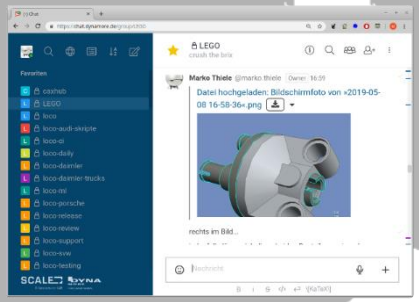
Organizing Teamwork with aid of LoCo and ROCKET.CHAT



DYNAmore Corporation USA
- **Nils** *(LS-DYNA®)*
- Thomas *(Meshing)*

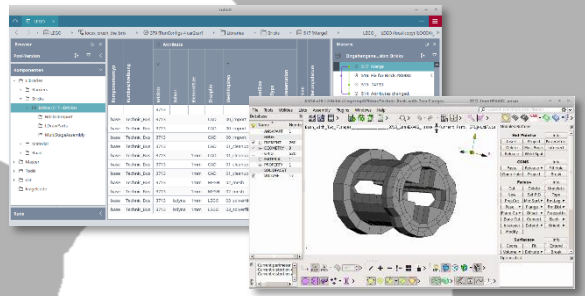
SCALE GmbH Dresden
- **David** *(Software)*
- Peter *(Process, Submitting to HPC)*

SCALE GmbH Ingolstadt
- **Alexandru** *(Model, LoCo)*
- Marko *(LEGO® CAD, Process, LoCo, ...)*

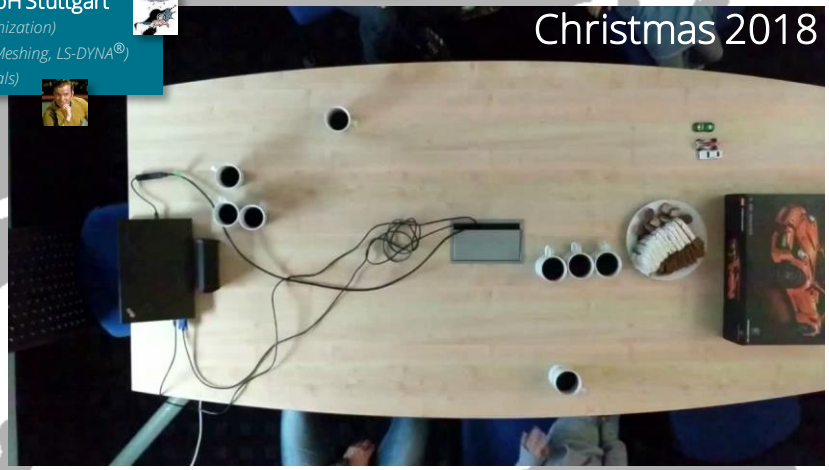
DYNAmore France SAS
- **Pierre** *(Meshing, LS-DYNA®)*

DYNAmore GmbH Stuttgart
- **Andre** *(Organization)*
- **Thorsten** *(Meshing, LS-DYNA®)*
- David *(Materials)*

LoCo



Christmas 2018



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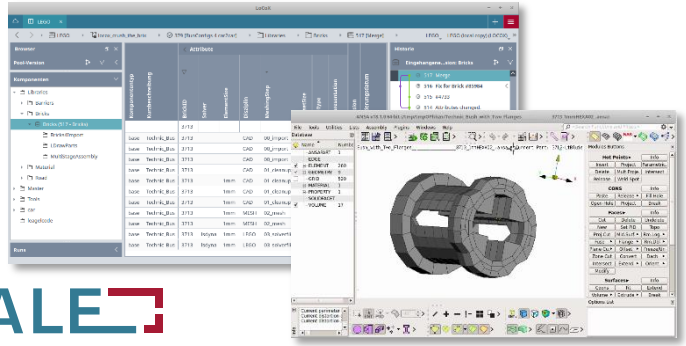
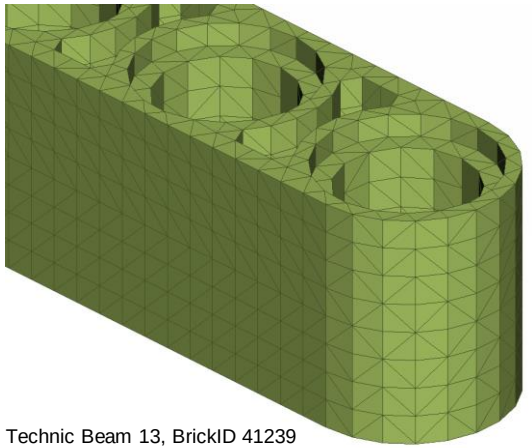
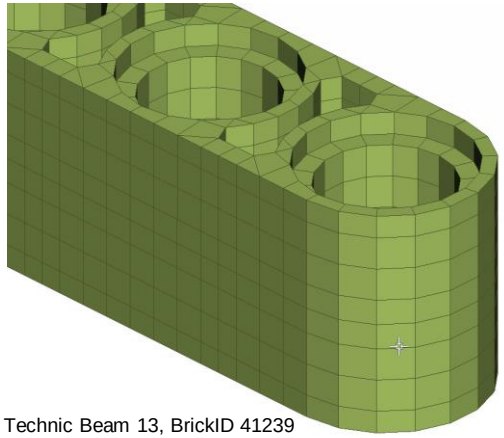
Meshing

- CAD Data for Porsche model and bricks are publically available
  (at ldraw.org by philo, at grabcad by dk)
- Meshed bricks maintained in brick library in LoCo
  - Each brick only meshed once
  - Improved bricks can instantly be used in all simulations
- CAD and ANSA files are kept together with solver files
- Meshing done in multiple location by different people
  - Thorsten *(Stuttgart, Germany)*
  - Pierre *(Versailles, France)*
  - Thomas *(Dublin, Ohio, USA)*
  - Marko *(Ingolstadt, Germany)*





Technic Beam 13, BrickID 41239
1mm Tetra mesh, **33123 elements**



Technic Beam 13, BrickID 41239
1mm Hexa mesh, **5124 elements**

Saves 800.000 elements in final simulation!

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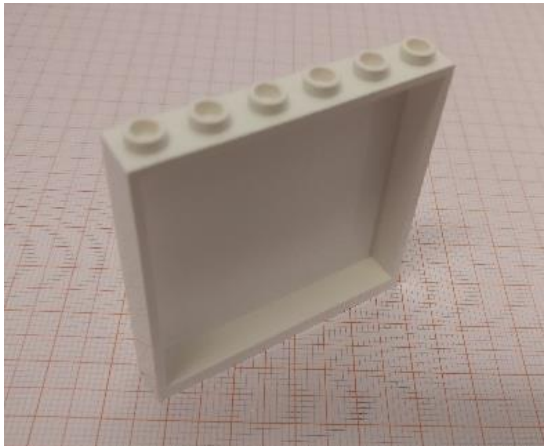
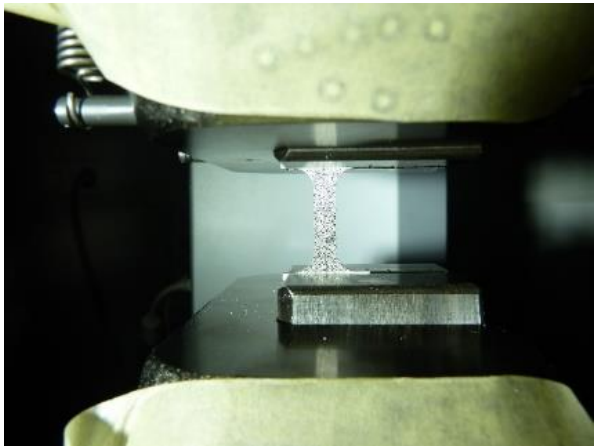
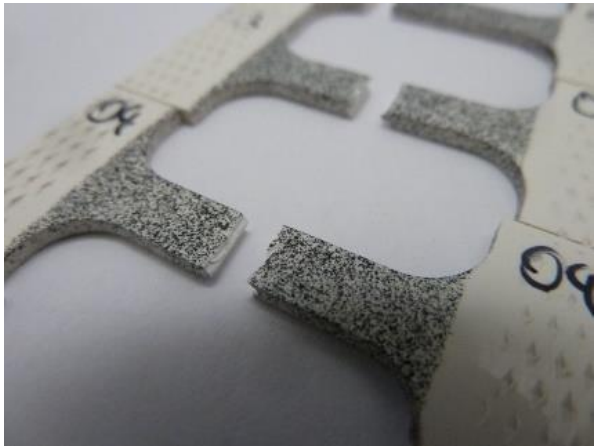
Material Data Calibration

- Tensile samples extracted from LEGO® bricks where tested at the DYNAmore materials test laboratory in Stuttgart



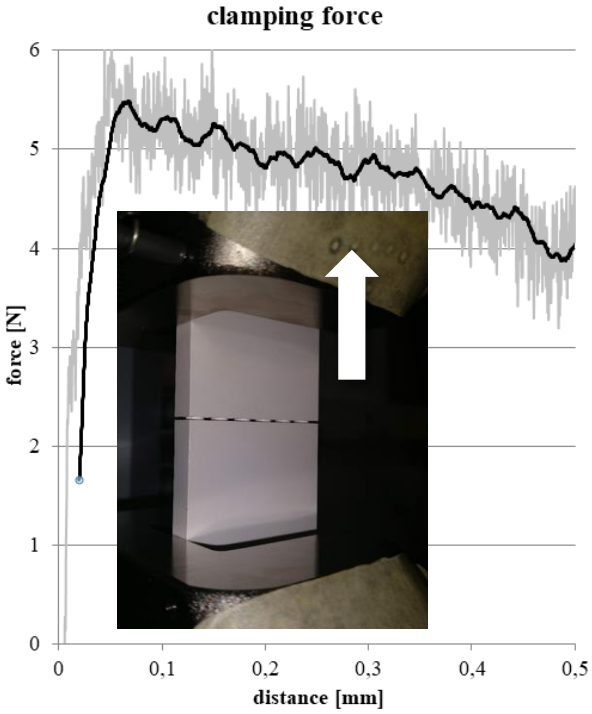




- Samples taken from brick #59349, specimen extraction by milling
- Tensile tests with digital image correlation (DIC)
- Yield curve via reverse engineering
- **`MAT_24`** material card created

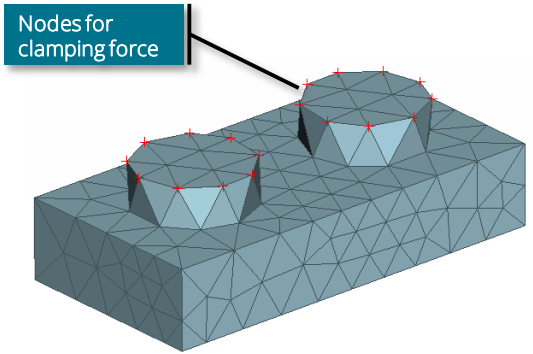
Calibration of Clamping Forces

- Experiment to measure clamping forces

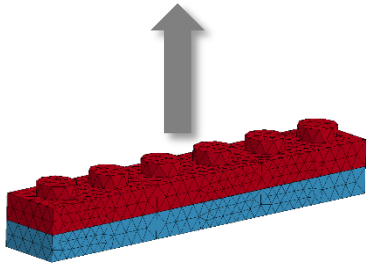


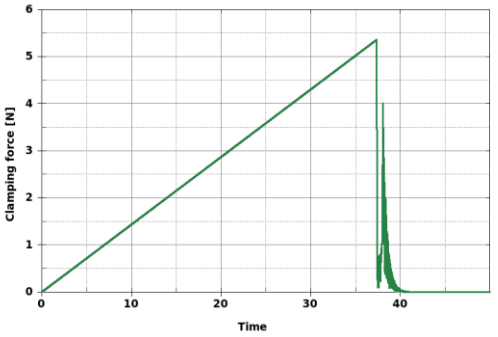
- Modeling in LS-DYNA® by ***CONTACT_TIEBRAKE_NODES_ONLY**

```
*CONTACT_TIEBREAK_NODES_ONLY
$      cid                                                          title
$     ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         7002      1001         4         2
$       fs        fd        dc        vc       vdc    penchk        bt        dt
                                              20.0
$      sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
                          -0.15     -0.15
$     nflf      sflf       nen       mes
    1.45E-4   3.0E-5
```



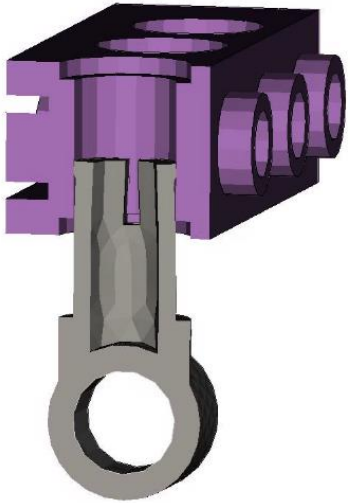
- Calibration by inverse parameter identification



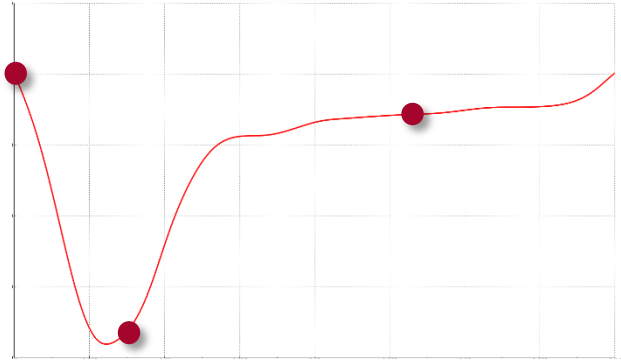


Validation of friction parameters

- The Porsche LEGO® set 42056 is a technic set.
- Connections are mainly created through pins
- Friction to pull out pins greatly influences overall model behavior.



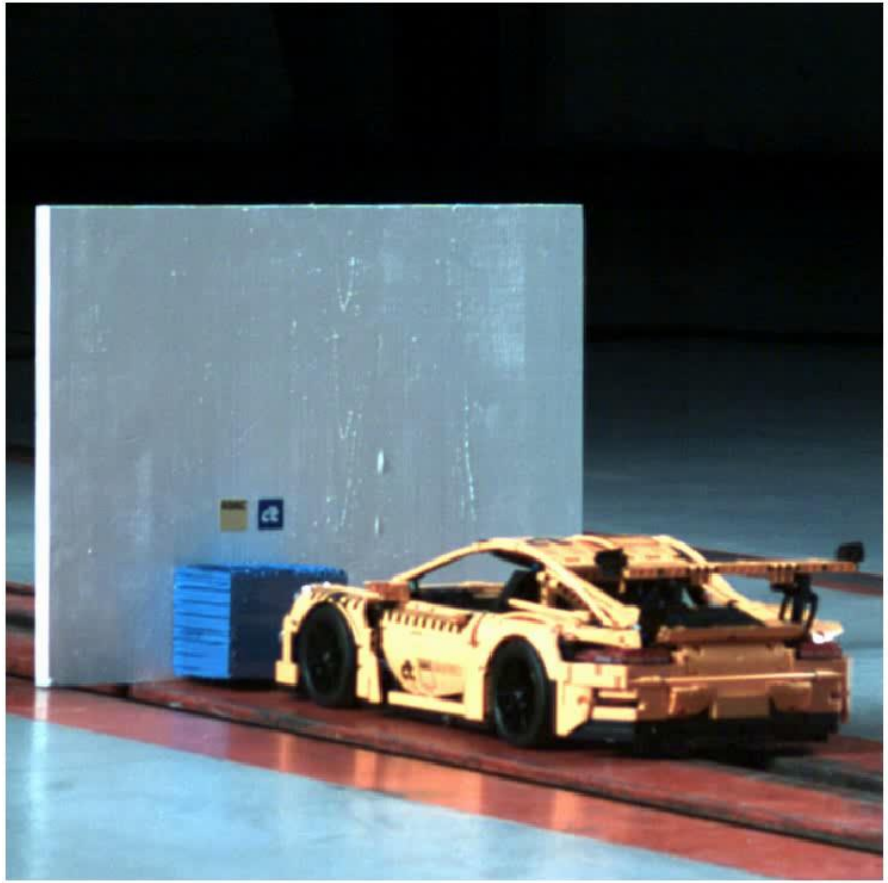
Physical experiments have been conducted to determine the pull out forces.
Parameters for friction have been calibrated by inverse parameter identification.

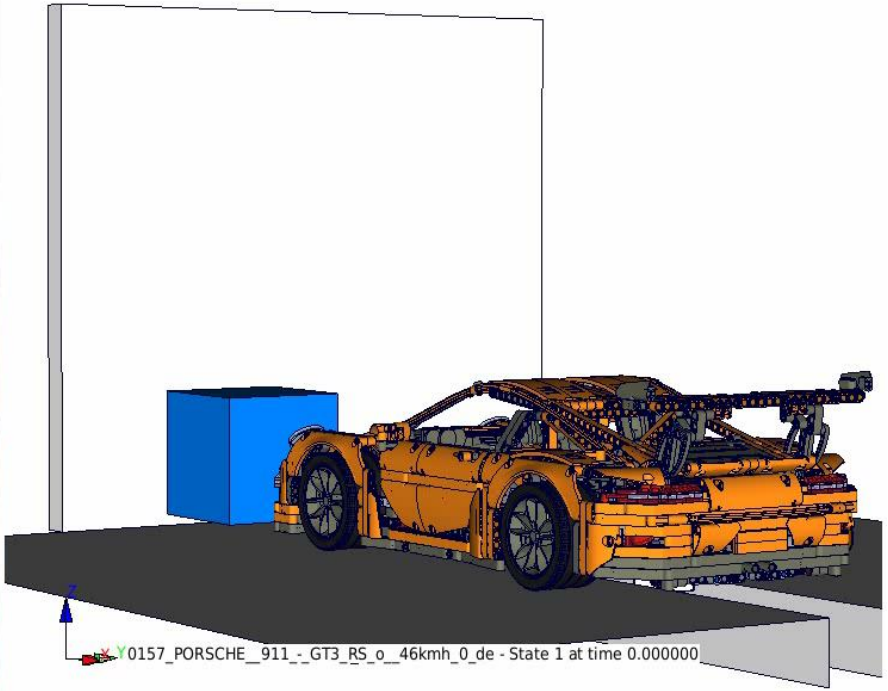


Simulation results

- 2704 Parts *(Bricks)*
- 19.5M elements
- 120ms
- 192CPU
- 22h runtime

Simulation compared to test videos http://ct.de/cash





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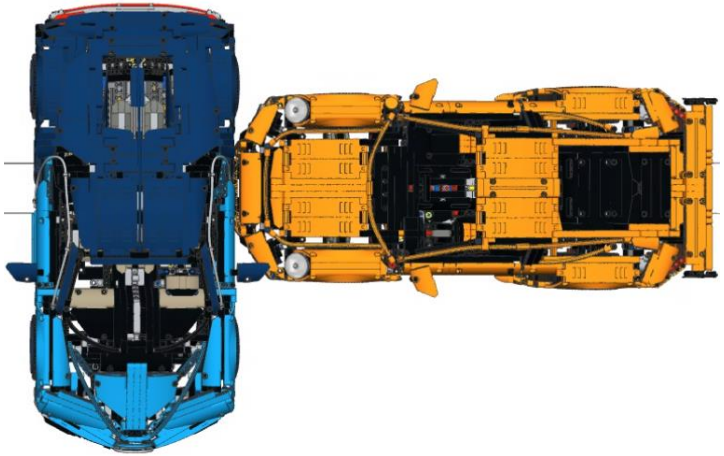
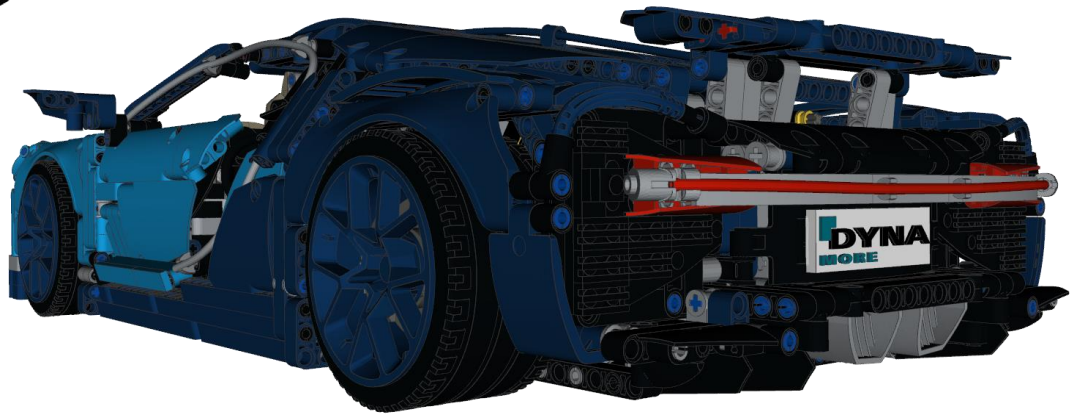
The challenge … #legowette

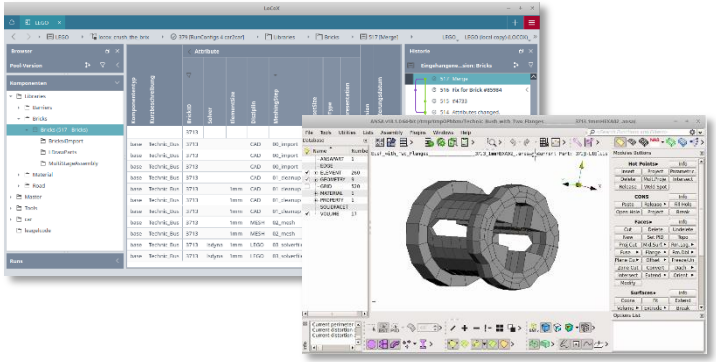
- Car 2 Car – Crash
- Velocity: 60kph
- Prediction of results prior to real crash!



Simulation Models

Porsche: 2704 Bricks
182 different bricks

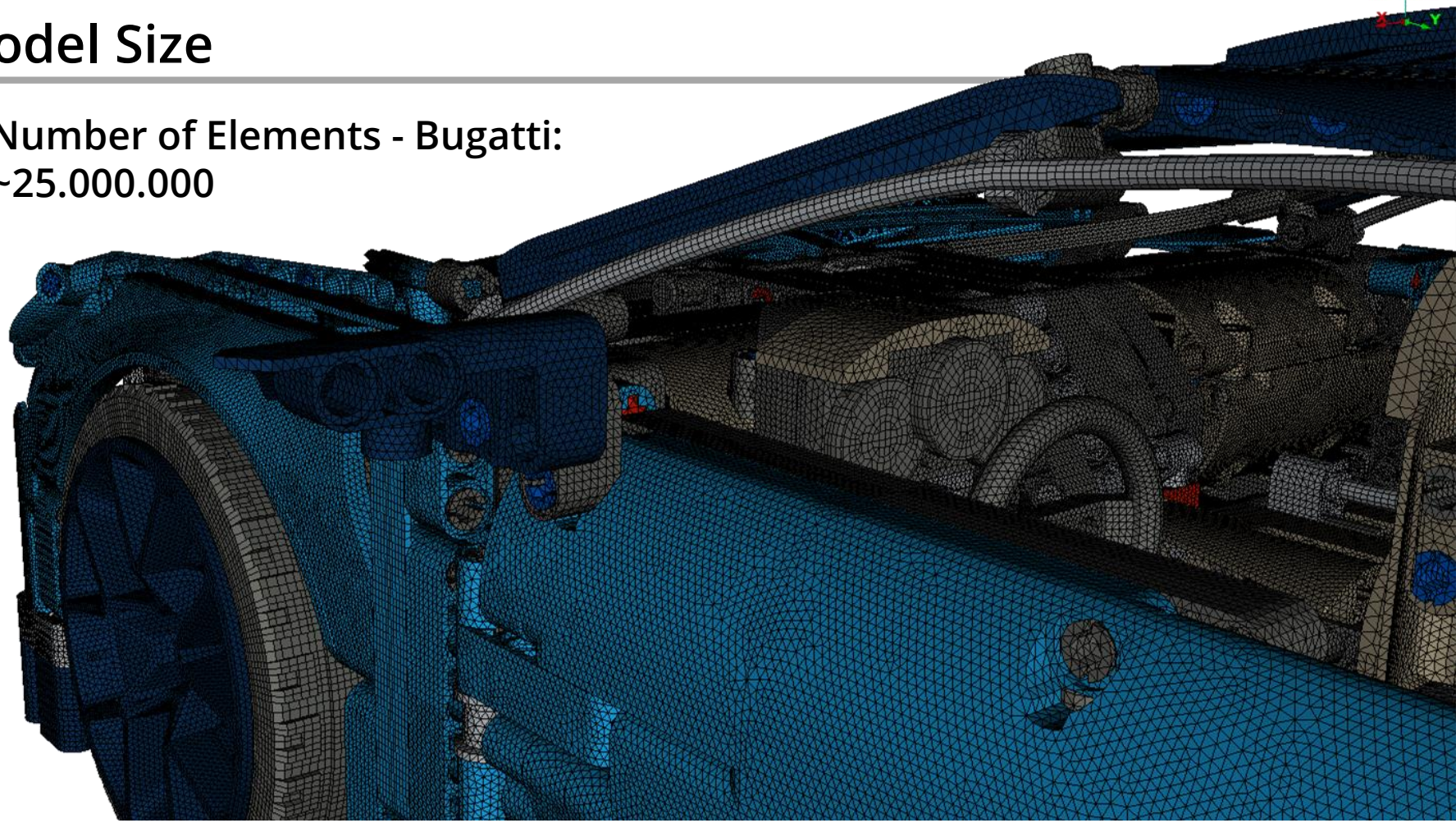




Bugatti: 3599 Bricks
74 additional bricks to be meshed

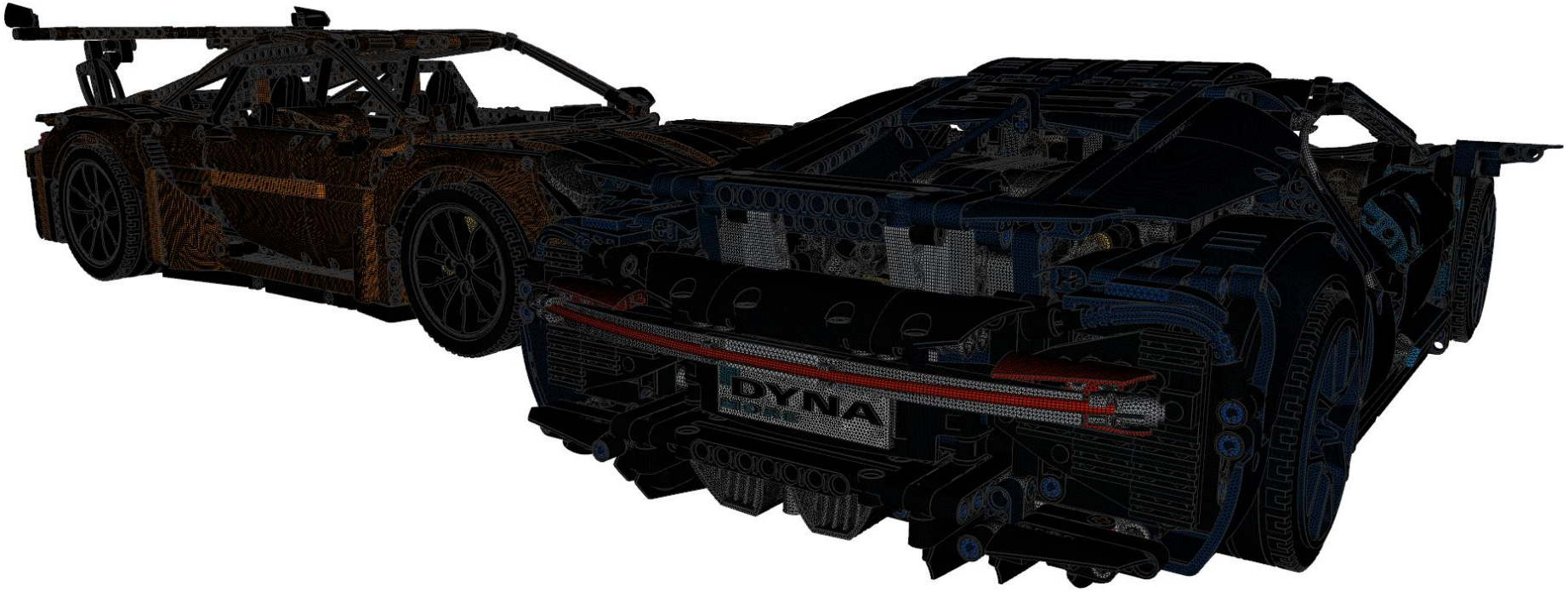
Model Size

- Number of Elements - Bugatti: ~25.000.000

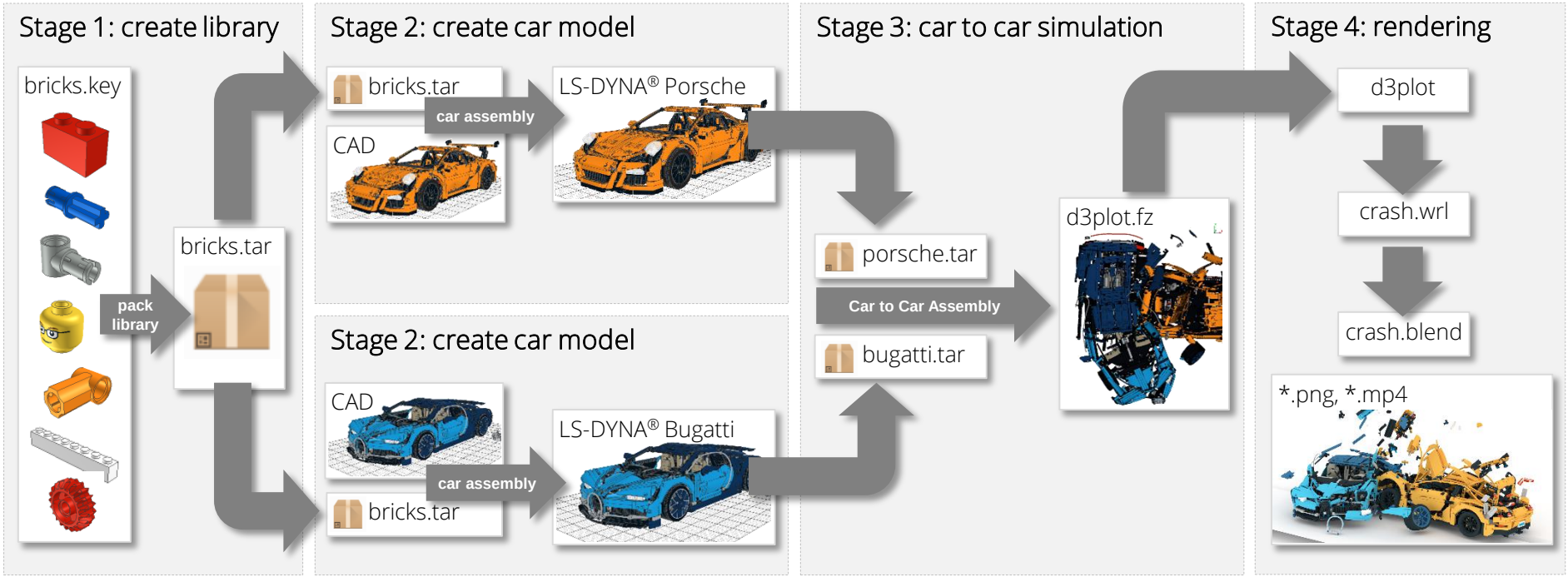


Model Size

- Number of Elements - total: ~45.800.000



Car to Car Crash Setup using Multi Stage Assembly in LoCo



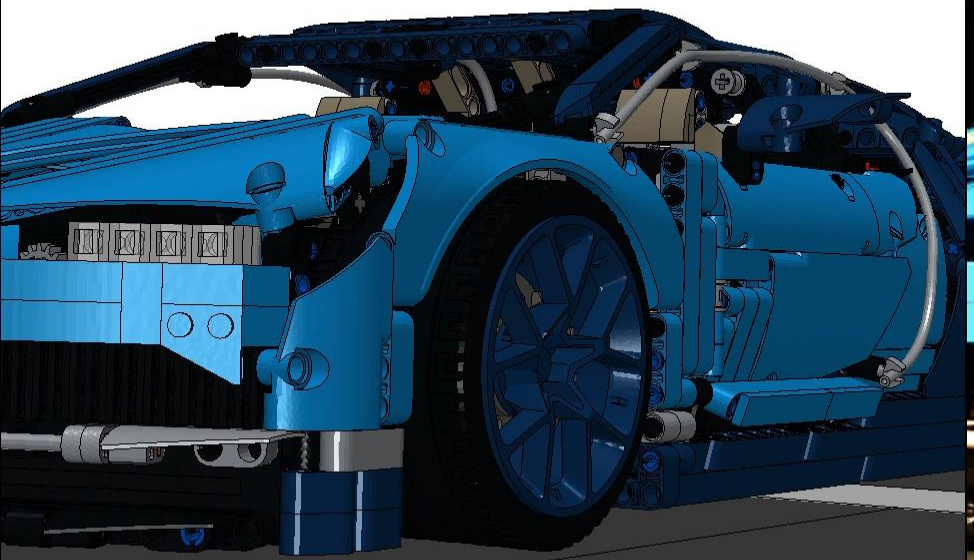
Simulation Results

- 6303 Parts *(Bricks)*
- 45.8M elements
- 130ms
- 192CPU
- 54h runtime

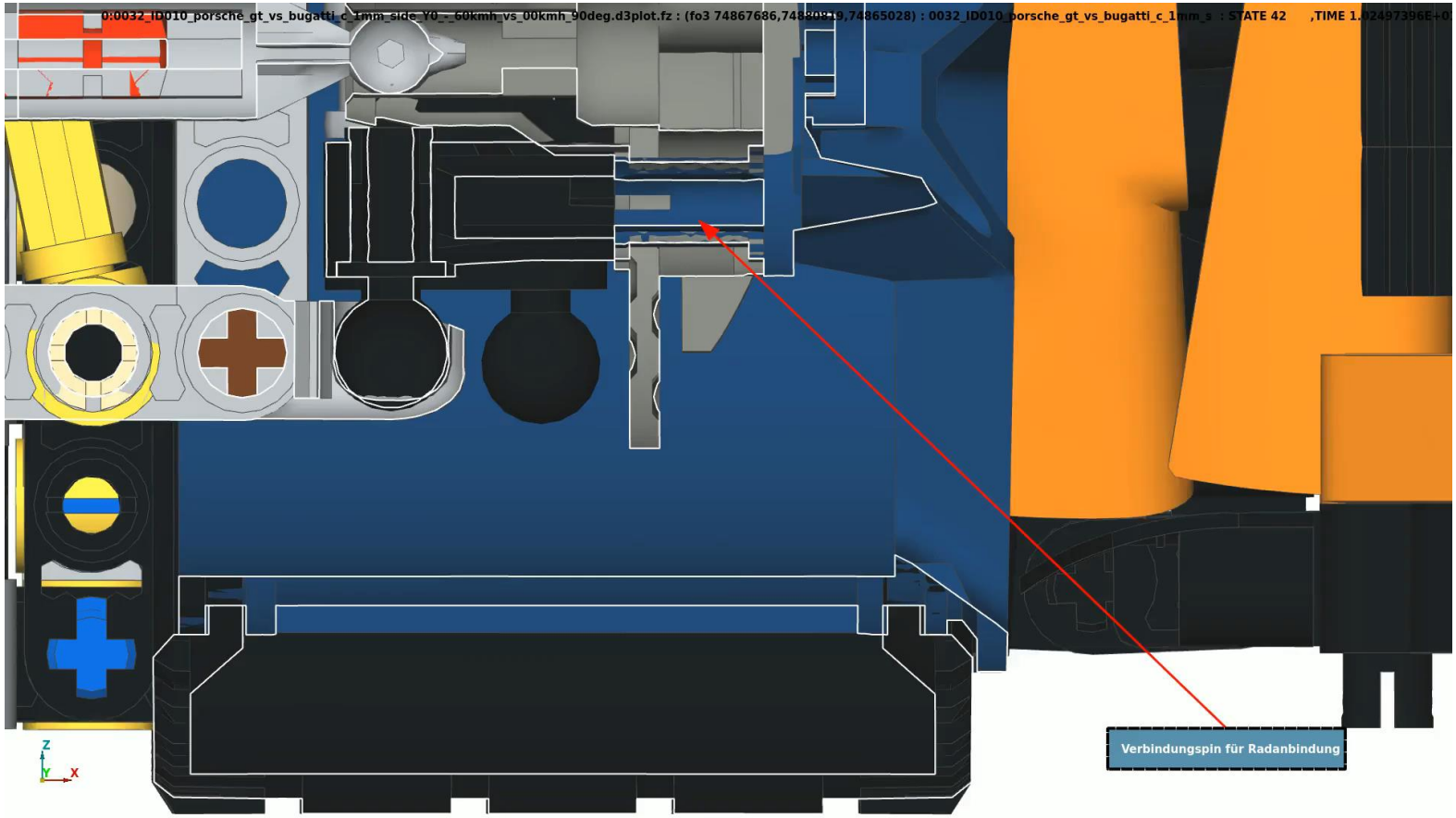
The real crash by c't magazin für computer technik and ADAC compared to Simulation

http://ct.de/cash

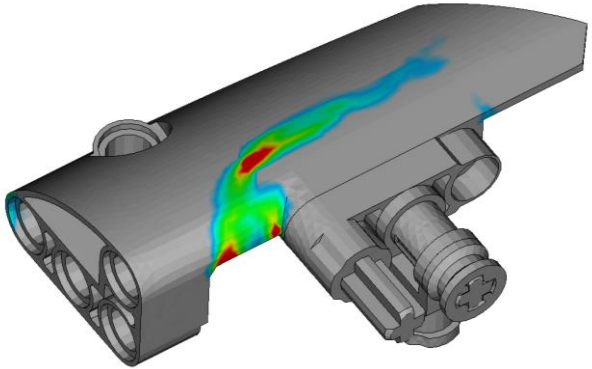
- 60kph
- 50m track
- 300kw halogen spot lights
- 10 x 1000fps high speed cameras

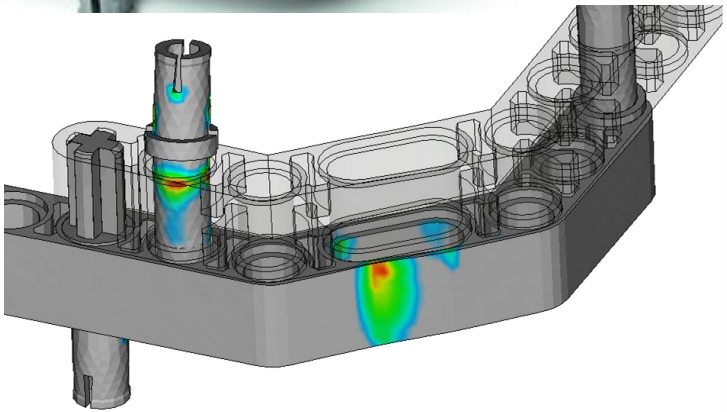


Detail of left front wheel from Bugatti



Damage on LEGO Parts





evaluation of plastic strains

Any other Crash Scenario is possible with Simulation

Bugatti 40km/h

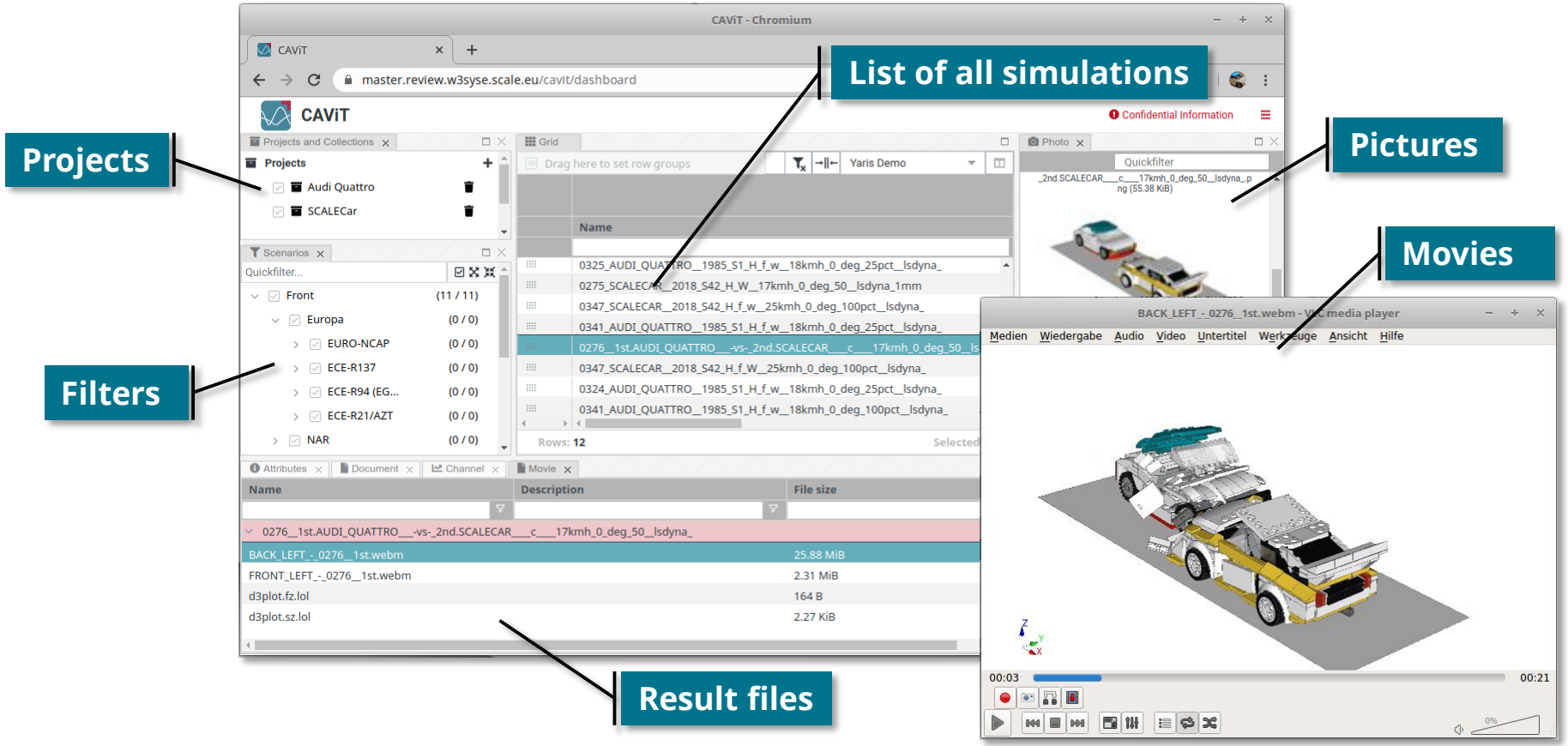
LEGO® Technic 42083

VS.

Porsche 46km/h

LEGO® Technic 42056

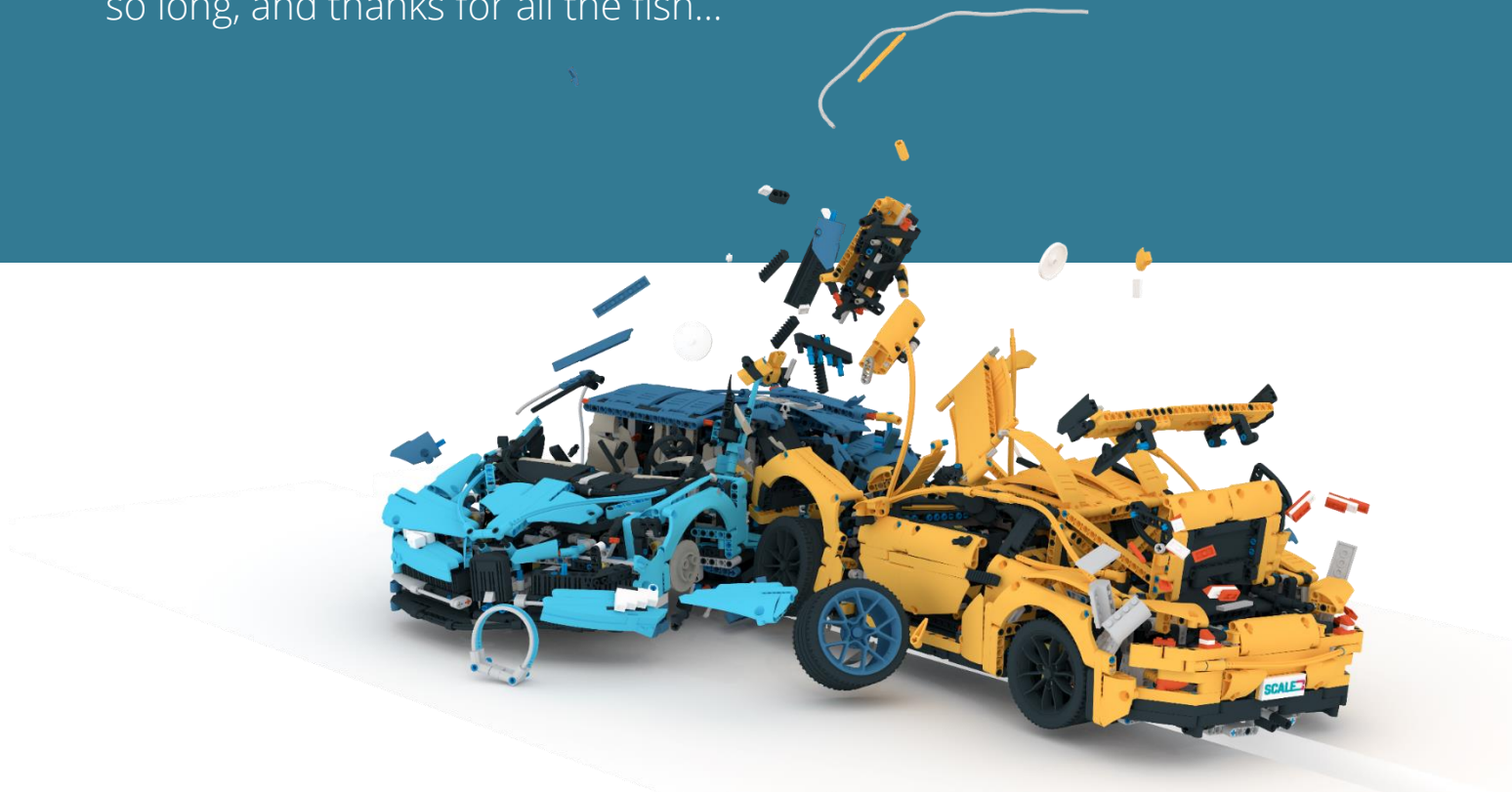
Web Interface for accessing Results



What's next...

- LEGO Technic #**42115**
- Demo and Benchmark for LOCOX and CAViT development
  - Acceptable performance for setups with many parts/components
  - Usability, ease of use
  - Complete Process from CAD to Result
  - Early access to our next gen products “locox crush the brix challenge”
    want to participate?, loco-support@scale.eu
- Use for class examples and education...
- Teaching the fun of physics...

so long, and thanks for all the fish...



The real thing at 60kph… 3 , 2 , 1 … BOOM