

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

DYNAmore Express  
June 12

Thorsten Gerlinger<sup>(1)</sup>, David Koch<sup>(1)</sup>, Andre Haufe<sup>(1)</sup>,  
Nils Karajan<sup>(2)</sup>, Thomas Weckesser<sup>(2)</sup>,  
Pierre Glay<sup>(3)</sup>,  
Alexandru Saharnean<sup>(4)</sup>, Marko Thiele<sup>(4)</sup>

<sup>(1)</sup>DYNAmore GmbH  
<sup>(2)</sup>DYNAmore Corporation  
<sup>(3)</sup>DYNAmore France SAS  
<sup>(4)</sup>SCALE GmbH



# SCALE.model (LoCo)

SCALE.project  
Status.E

SCALE.model  
LoCo

SCALE.result  
CAVIT

SCALE.project  
Status.E

SCALE.sdm

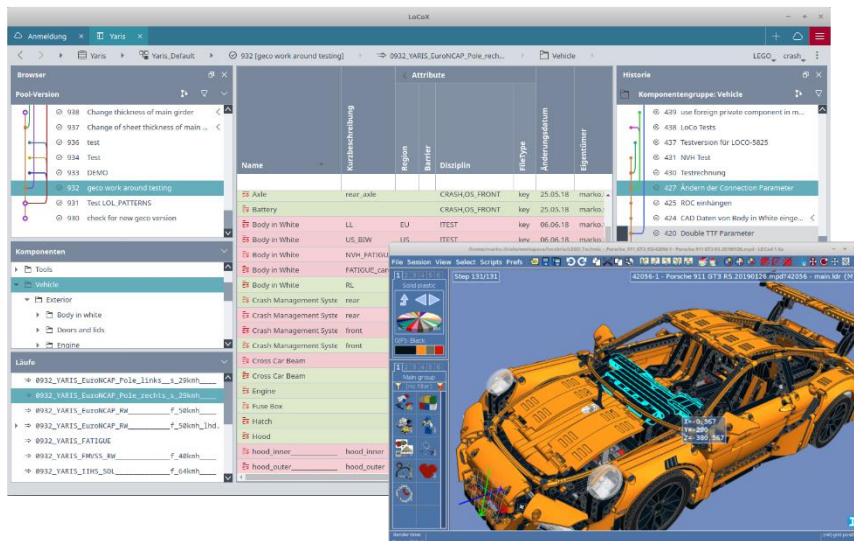
Requirements

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

# SCALE.result (CAViT)

SCALE.project  
Status.E

SCALE.model  
LoCo

SCALE.result  
CAViT

SCALE.project  
Status.E

SCALE.sdm

Requirements

Modelling

Solving

Results

Monitoring

The screenshot displays the CAViT web interface in a Chromium browser. The main content area shows a table of simulation scenarios with columns for 'Name' and 'Description'. The table lists various scenarios such as '0325\_AUDI\_QUATTRO\_1985.S1.H.f.w\_18kmh\_0\_deg\_25pct\_1bdyna', '0276\_1stAUDI\_QUATTRO\_vs\_2ndSCALECAR\_c\_17kmh\_0\_deg\_50\_1bdyna', and '0347\_SCALECAR\_2018.542.H.f.w\_25kmh\_0\_deg\_100pct\_1bdyna'. A 3D model of a vehicle is visible in the background. Below the table, there are sections for 'Attributes' and 'Description'.

## ■ 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)*

# What will happen?

We should be able to  
predict this with LS-DYNA®!

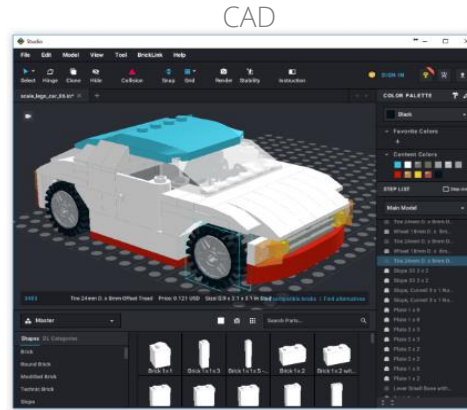


# 1<sup>st</sup> attempts to set up a virtual LEGO® Model

Prototype



Modeling in  
CAD



Physical Build

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/>

Rendering



# Working with CAD data in LoCo<sup>[1]</sup>

- 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

The screenshot displays the LoCoX software interface. On the left, a 'Pool-Version' browser shows a list of versions for a component, with version 140 selected. Below it, a 'Komponenten' tree shows a hierarchical structure of parts like 'car', 'exterior', 'platform', etc. In the center, a table lists components with columns for 'Komponententyp', 'Kurzbeschreibung', 'BRICKID', 'Disziplin', 'File Type', 'PartNumber', 'Version', and 'Änderungsdatum'. On the right, a 'Historie' panel shows a list of changes for a selected component. A callout box labeled 'Version control for project' points to the top of the interface. Another callout box labeled 'One file per part / brick' points to the 'BRICKID' column in the table. A third callout box labeled 'Version control for selected part group' points to the 'Historie' panel. In the foreground, a 3D CAD model of a LEGO assembly is shown in a window titled '/tmp/tmpBlm578/main.mpd - LDCad 1.6a'. The model is rendered in a blue environment with a grid. A callout box labeled 'Product structure rebuild from LDraw model' points to the 'Komponenten' tree. Another callout box labeled 'Opening and working with CAD assemblies from within LoCo' points to the 3D model window.

Version control for project

One file per part / brick

Version control for selected part group

Product structure rebuild from LDraw model

Opening and working with CAD assemblies from within LoCo

# Organizing the Meshing of CAD data with LoCo<sup>[1]</sup>

The image shows a screenshot of the LoCoX software interface. The top window displays a project browser with a tree structure under 'Bricks (517 - Bricks)'. Below it is a table with columns for 'Komponententyp', 'Kurzbeschreibung', 'BrickID', 'Solver', 'ElementSize', 'Disziplin', 'MeshingStep', 'BrickSize', 'Type', 'Presentation', and 'Erstellungsdatum'. The table lists various components like 'Technic\_Bus' and 'Isdyna' with their respective IDs and meshing steps.

A callout box points to the 'Bricks' folder in the browser, stating: "brick library mounted to project".

Another callout box points to the 'Historie' (History) window, stating: "versions of brick library or individual meshes".

The bottom window shows the ANSYS v18.1.0 64-bit interface with a 3D model of a meshed part. A callout box points to the model, stating: "Various representations of CAD geometry and meshed bricks".

A third callout box points to the 'Bricks' folder in the browser, stating: "Brick opened for meshing directly from LoCo".

Komponententyp	Kurzbeschreibung	BrickID	Solver	ElementSize	Disziplin	MeshingStep	BrickSize	Type	Presentation	Erstellungsdatum
base	Technic_Bus	3713			CAD	00_import				
base	Technic_Bus	3713			CAD	00_import				
base	Technic_Bus	3713			CAD	00_import				
base	Technic_Bus	3713			CAD	01_cleanup				
base	Technic_Bus	3713	1mm		CAD	01_cleanup				
base	Technic_Bus	3713	1mm		CAD	01_cleanup				
base	Technic_Bus	3713	1mm		MESH	02_mesh				
base	Technic_Bus	3713	1mm		MESH	02_mesh				
base	Technic_Bus	3713	Isdyna	1mm	LEGO	03_solverfile				
base	Technic_Bus	3713	Isdyna	1mm	LEGO	03_solverfile				

# 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 !LDRW_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
```

transformation and rotation of brick

BrickID

meshed brick

```
#####
$ 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
Title 1_x_1_with_Groove 6558_lmm03_key
$# idnoff ideoff idpoff idmoff idsoff idloff iddooff
20115000 20115000 20115000 0 20115000 20115000 20115000
$# idroff
20115000
$# fctmas fcttim fctlen fcttem incout
$# tranid
20115001
$
```



# Job assembly and control through LoCo... 1<sup>st</sup> 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_
└── [Context Menu]
    ├── Lokal aufbauen
    ├── Remote aufbauen
    ├── Anrechnen
    ├── Run-Konfiguration entfernen
    ├── Run-Konfiguration duplizieren
    ├── Bild hinzufügen...
    └── Tags
```

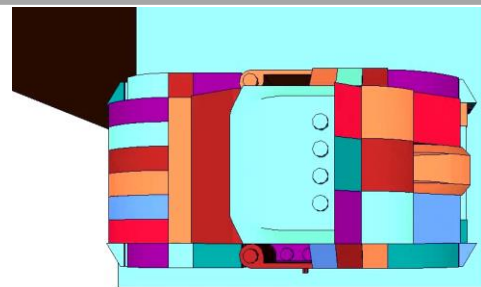
Flexible grouping of runs by their properties

Setup of multiple different scenarios

Setup of multiple cars

Job submit directly in GUI

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

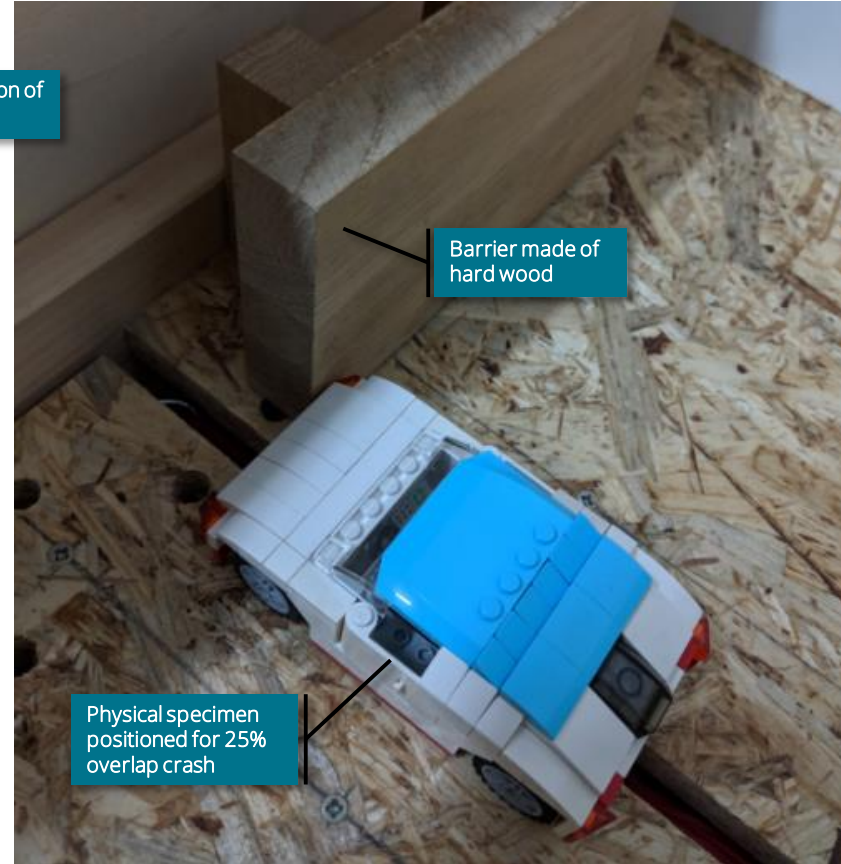
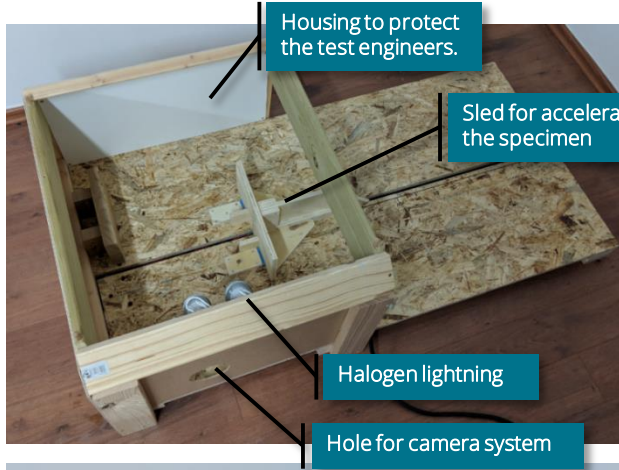


Slot 0: 0138\_FEM\_scale\_car\_w\_17kmh\_0\_grad\_25\_2mm - State 1 at time 0.000000

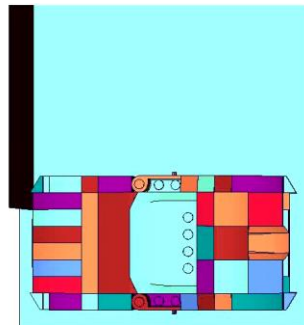
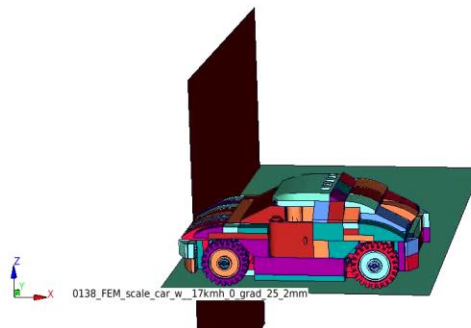


# Wooden slingshot crash test sled

- 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



# 1<sup>st</sup> 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

Slot 0: 0138\_FEM\_scale\_car\_w\_17kmh\_0\_grad\_25\_2mm

# Organizing Teamwork with aid of LoCo and



## DYNAmore Corporation USA

- Niils (LS-DYNA®)
- Thomas (Meshing)

## DYNAmore France SAS

- Pierre (Meshing, LS-DYNA®)

## SCALE GmbH Dresden

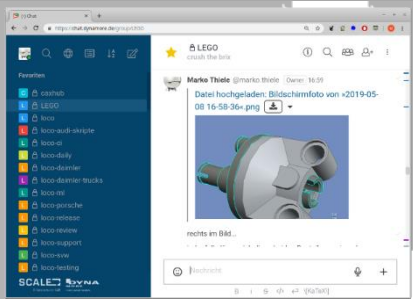
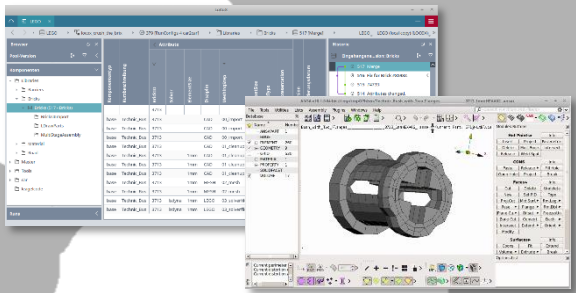
- David (Software)
- Peter (Process, Submitting to HPC)

## SCALE GmbH Ingolstadt

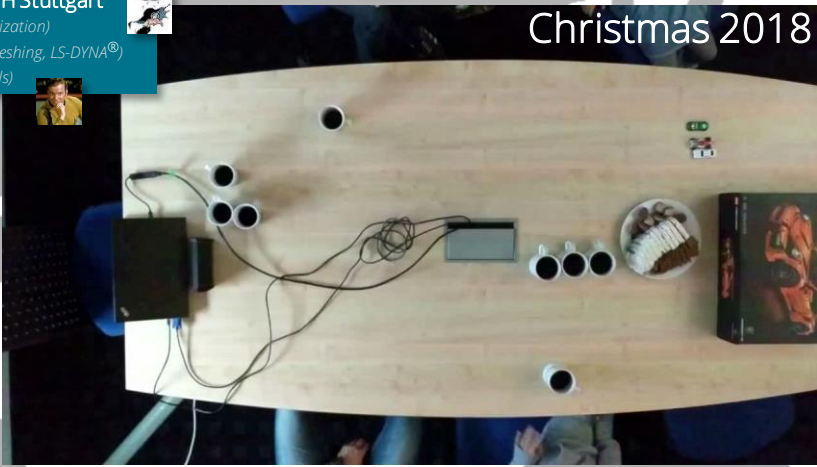
- Alexandru (Model, LoCo)
- Marko (LEGO® CAD, Process, LoCo, ...)

## DYNAmore GmbH Stuttgart

- Andre (Organization)
- Thorsten (Meshing, LS-DYNA®)
- David (Materials)

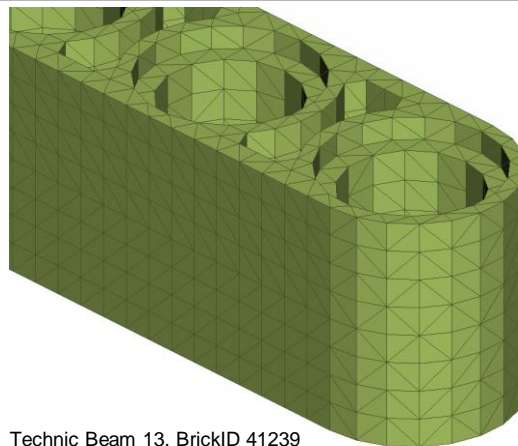


Christmas 2018



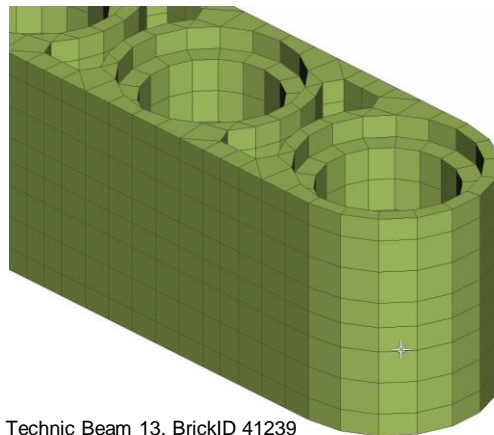
# Meshing

- CAD Data for Porsche model and bricks are publicly 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*)

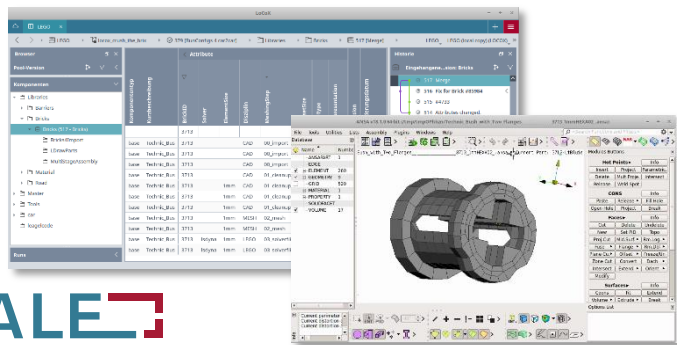


Technic Beam 13, BrickID 41239  
1mm Tetra mesh, **33123 elements**

Saves 800.000  
elements in final  
simulation!

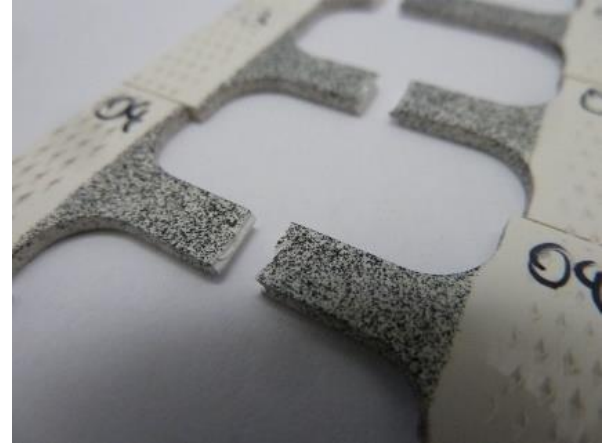
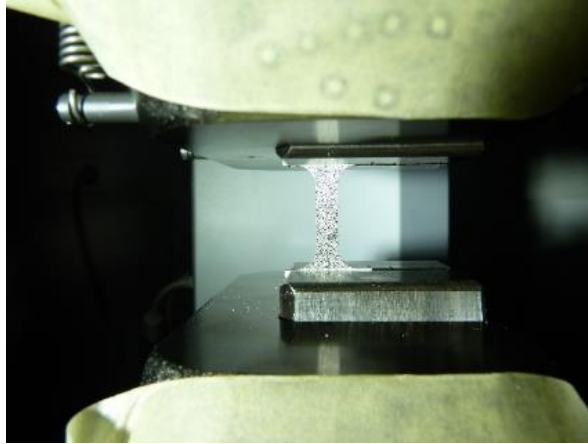
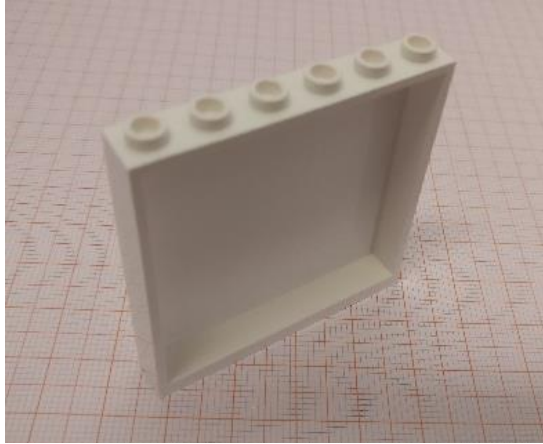


Technic Beam 13, BrickID 41239  
1mm Hexa mesh, **5124 elements**



# Material Data Calibration

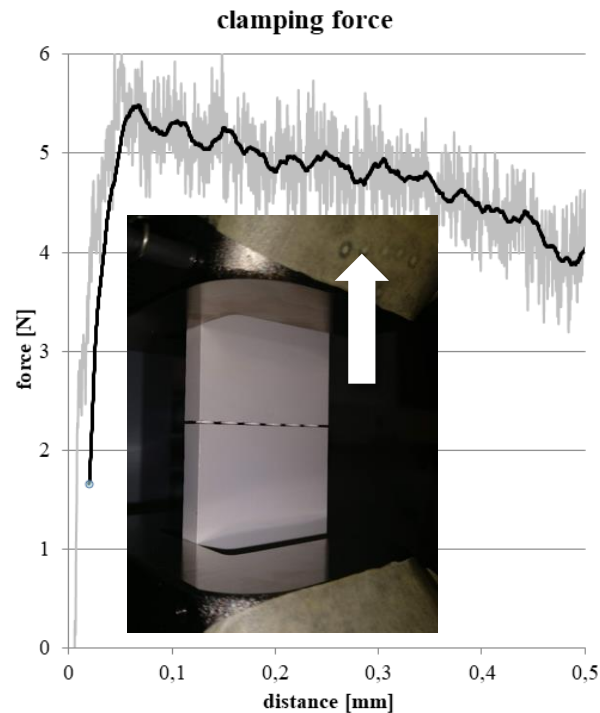
- Tensile samples extracted from LEGO® bricks where tested at the DYNAmore materials test laboratory in Stuttgart



- 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

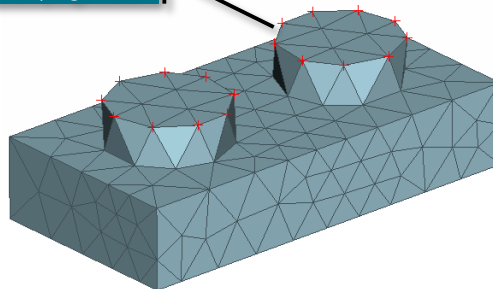
- Experiment to measure clamping forces



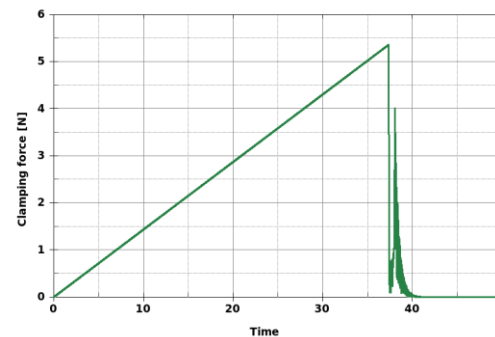
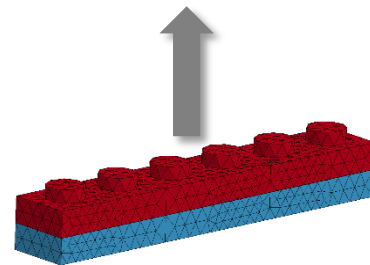
- Modeling in LS-DYNA® by  
\*CONTACT\_TIEBRAKE\_NODES\_ONLY

```
*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
$      sfs        sfm        sst        mst        sfst        sfmt        fsf        vsf
$      nflf       sflf       nen        mes
$      1.45E-4   3.0E-5
```

Nodes for clamping force



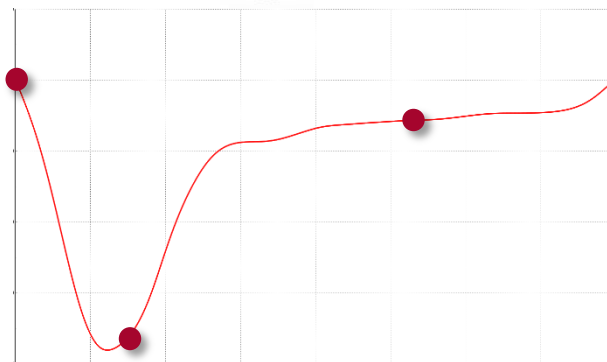
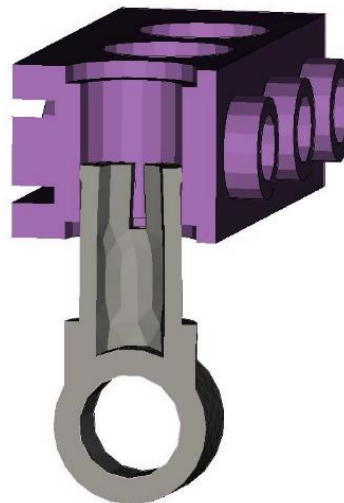
- Calibration by inverse parameter identification



# 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.

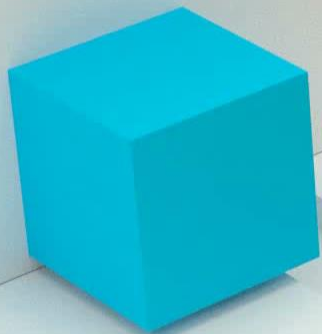
Physical experiments have been conducted to determine the pull out forces. Parameters for friction have been calibrated by inverse parameter identification.



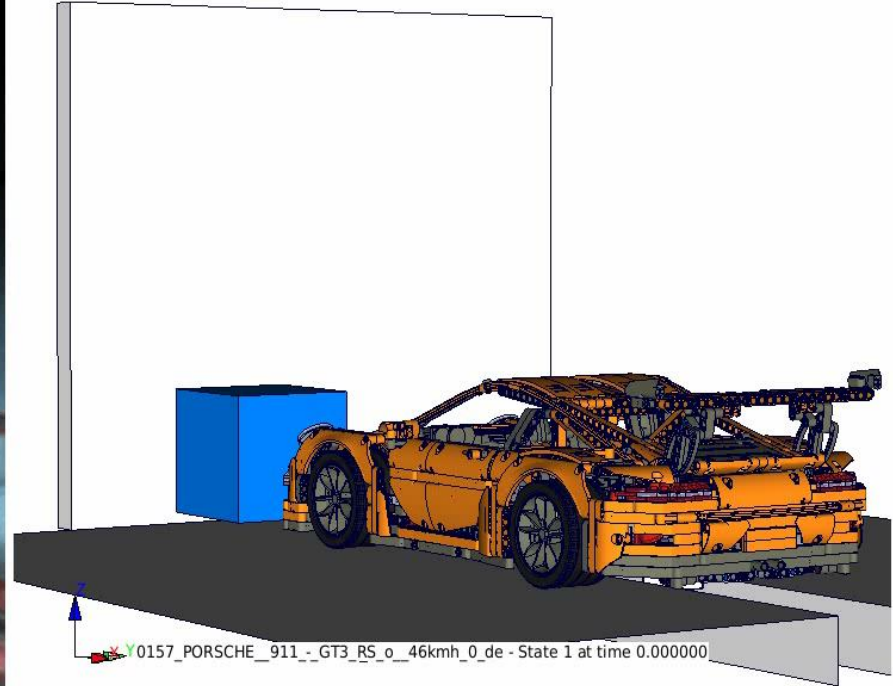
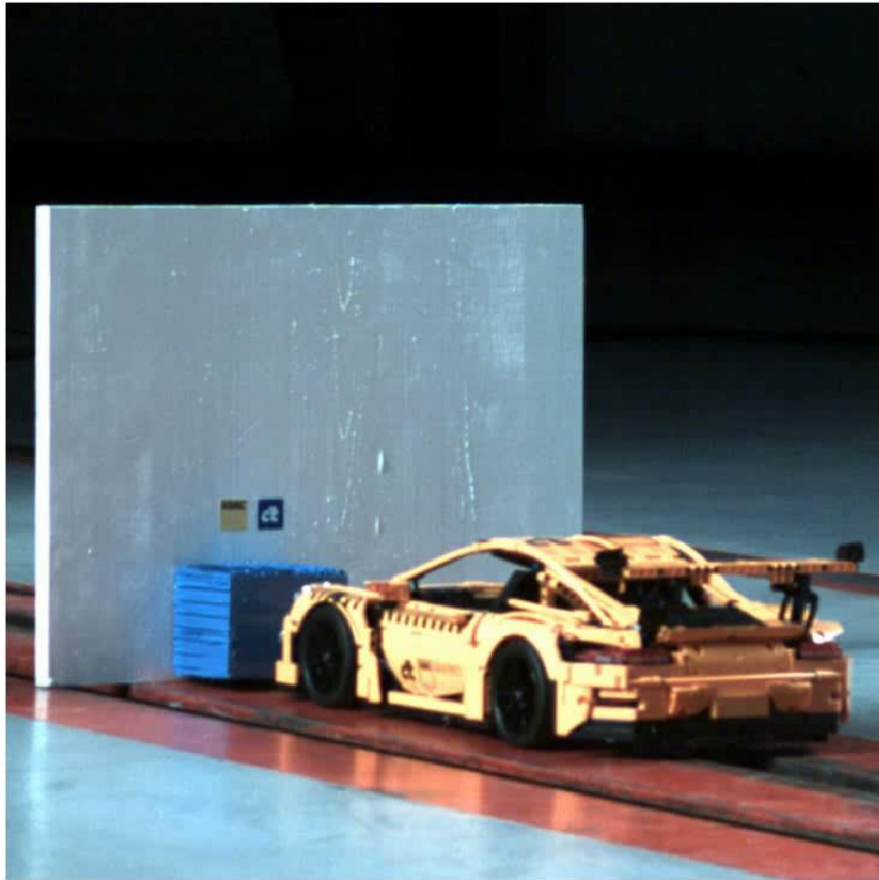


# Simulation results

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

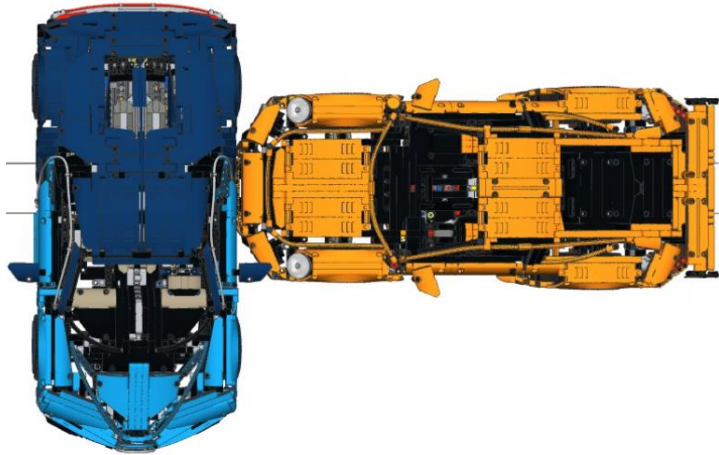


# Simulation compared to test videos <http://ct.de/cash>



# The challenge ... #legowette

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



Anyone can copy! 😊

Can you do Bugattis?

How about a bet?



Hi, we prepared something. Would that be interesting for c't?

LOL 14:03

Nachmachen kann ja jeder ;) 14:03

Könnt ihr auch Bugattis? 14:03

Wir können alles 🤔👍 14:04 ✓

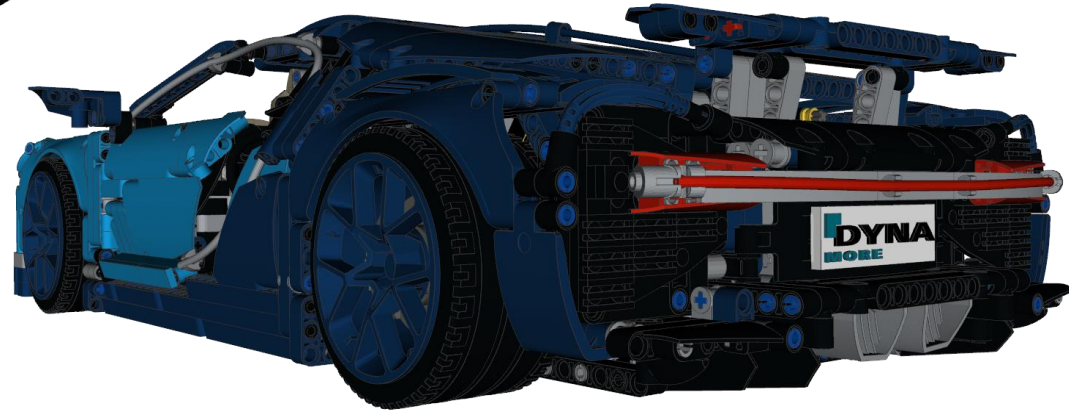
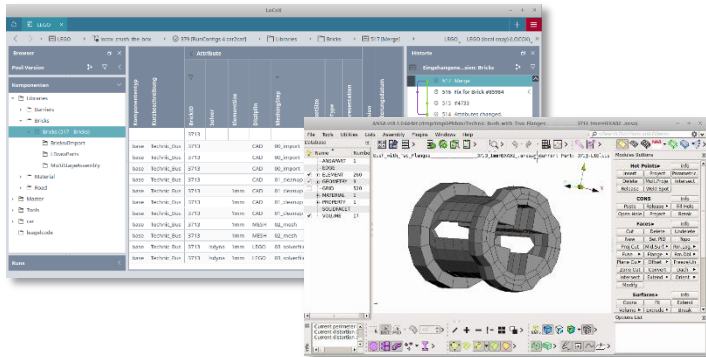
Wie wärs mit ner Lego-Wette? ;) 14:04

Yeah, we can do anything 😊👍

# Simulation Models



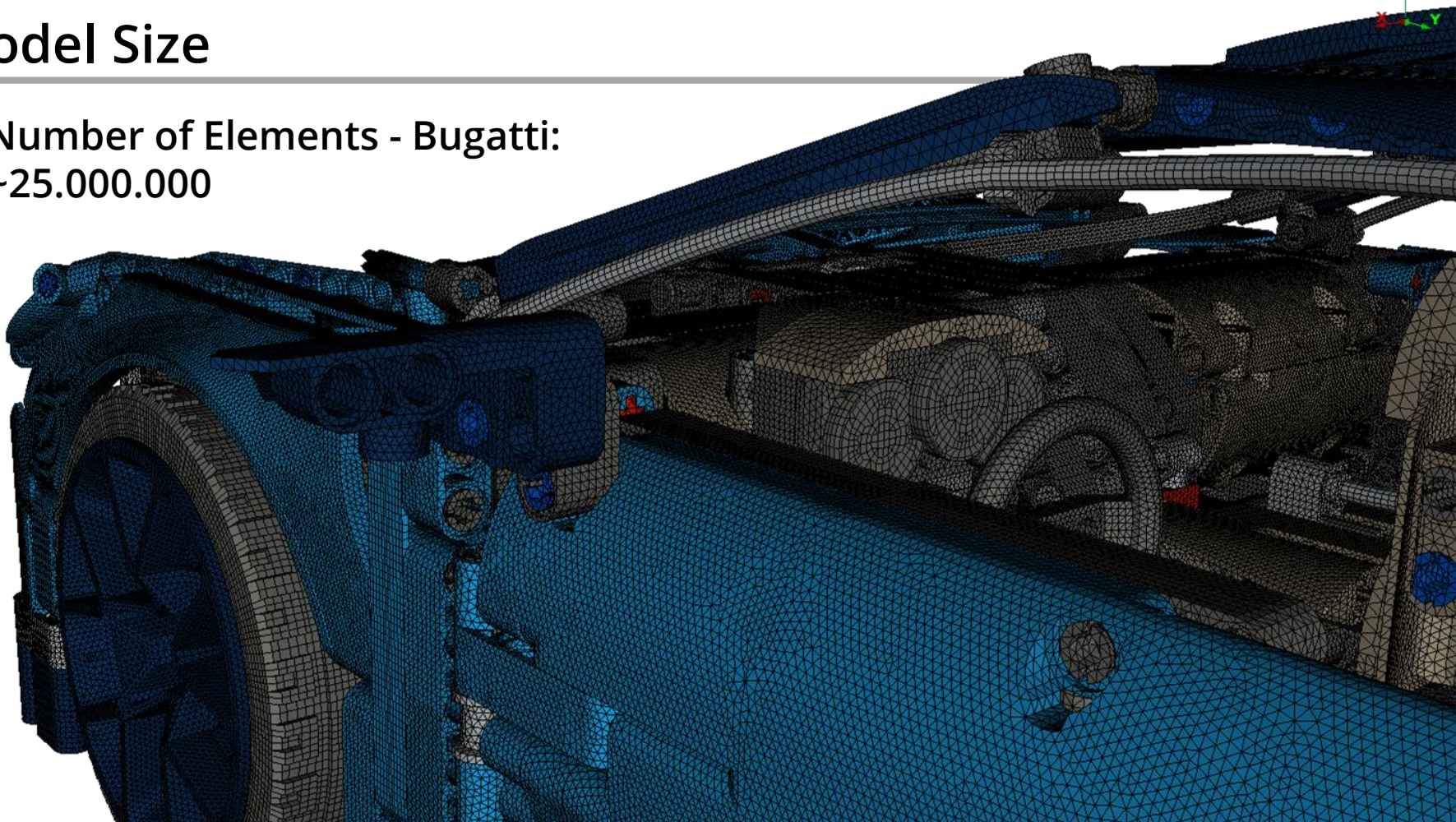
Porsche: 2704 Bricks  
182 different bricks



Bugatti: 3599 Bricks  
74 additional bricks to be meshed

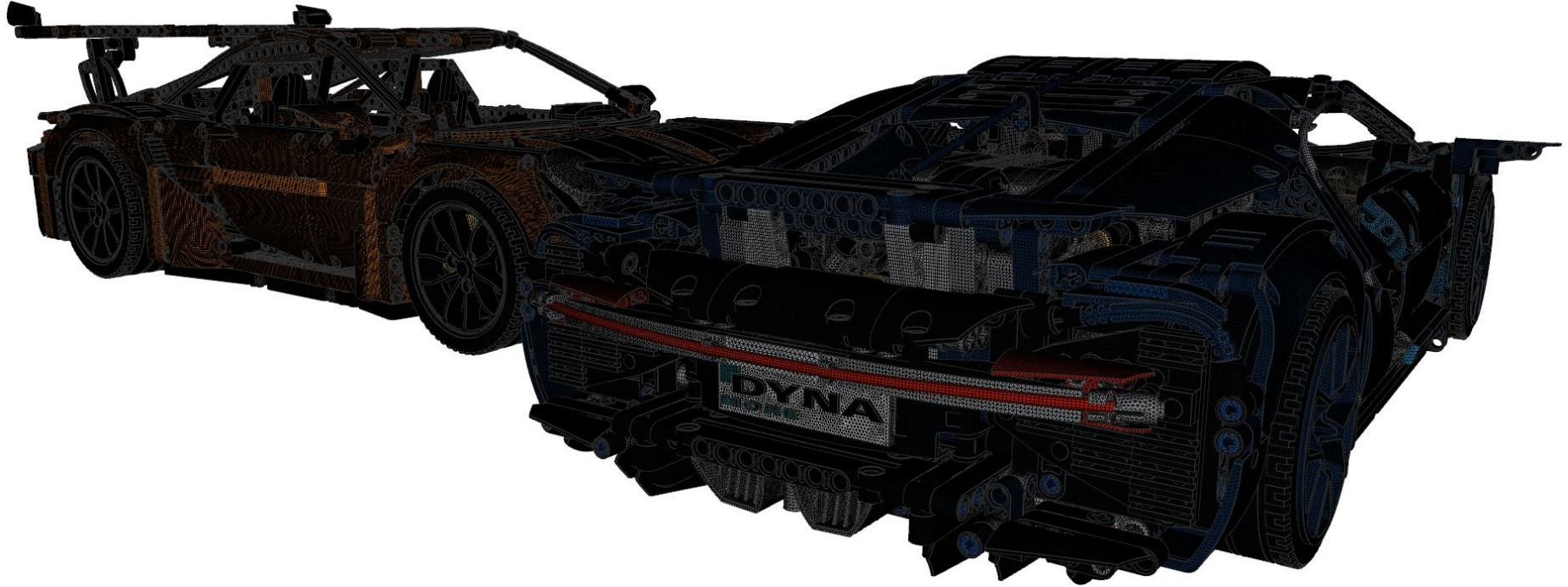
# Model Size

- Number of Elements - Bugatti:  
~25.000.000

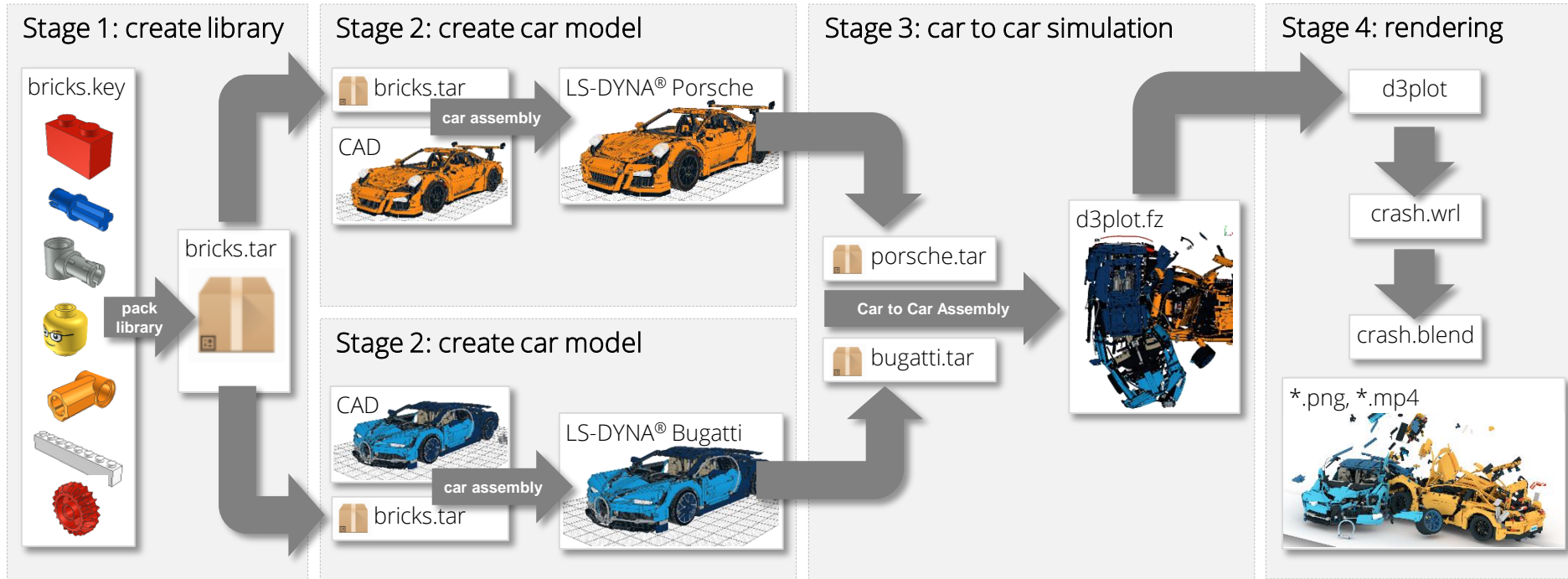


# Model Size

- Number of Elements - total: ~45.800.000



# Car to Car Crash Setup using Multi Stage Assembly in LoCo



# Simulation Results

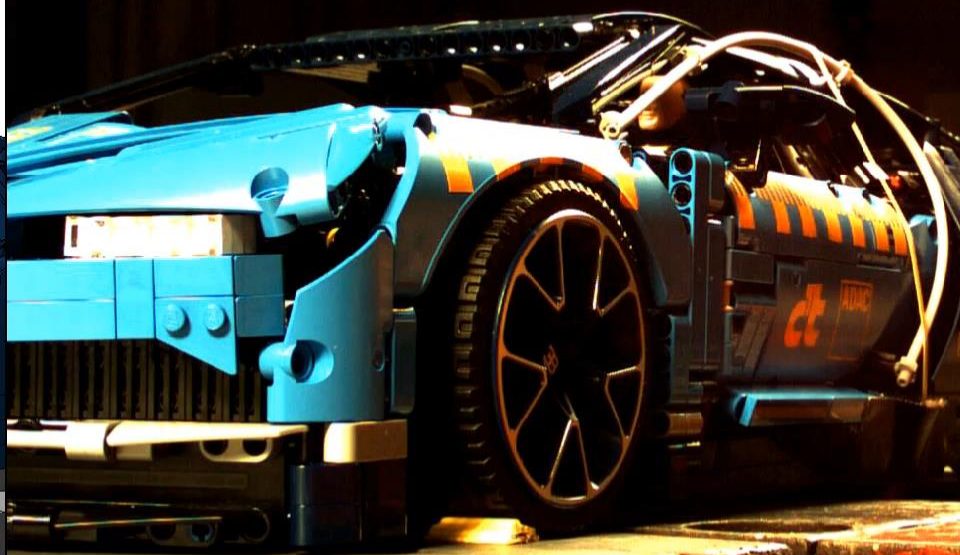
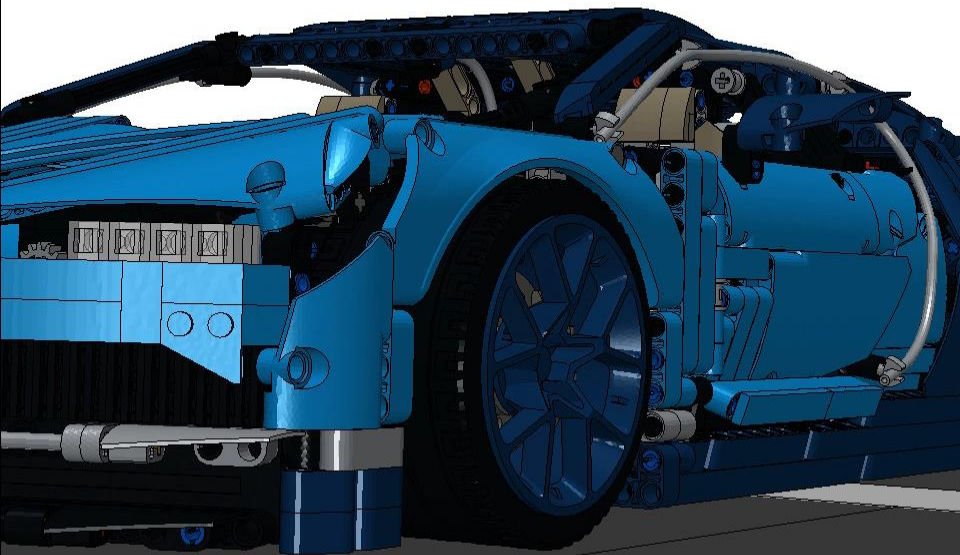
- 6303 Parts (*Bricks*)
- 45.8M elements
- 130ms
- 192CPU
- 54h runtime





# The real crash by magazin für computer technik and **ADAC** compared to Simulation

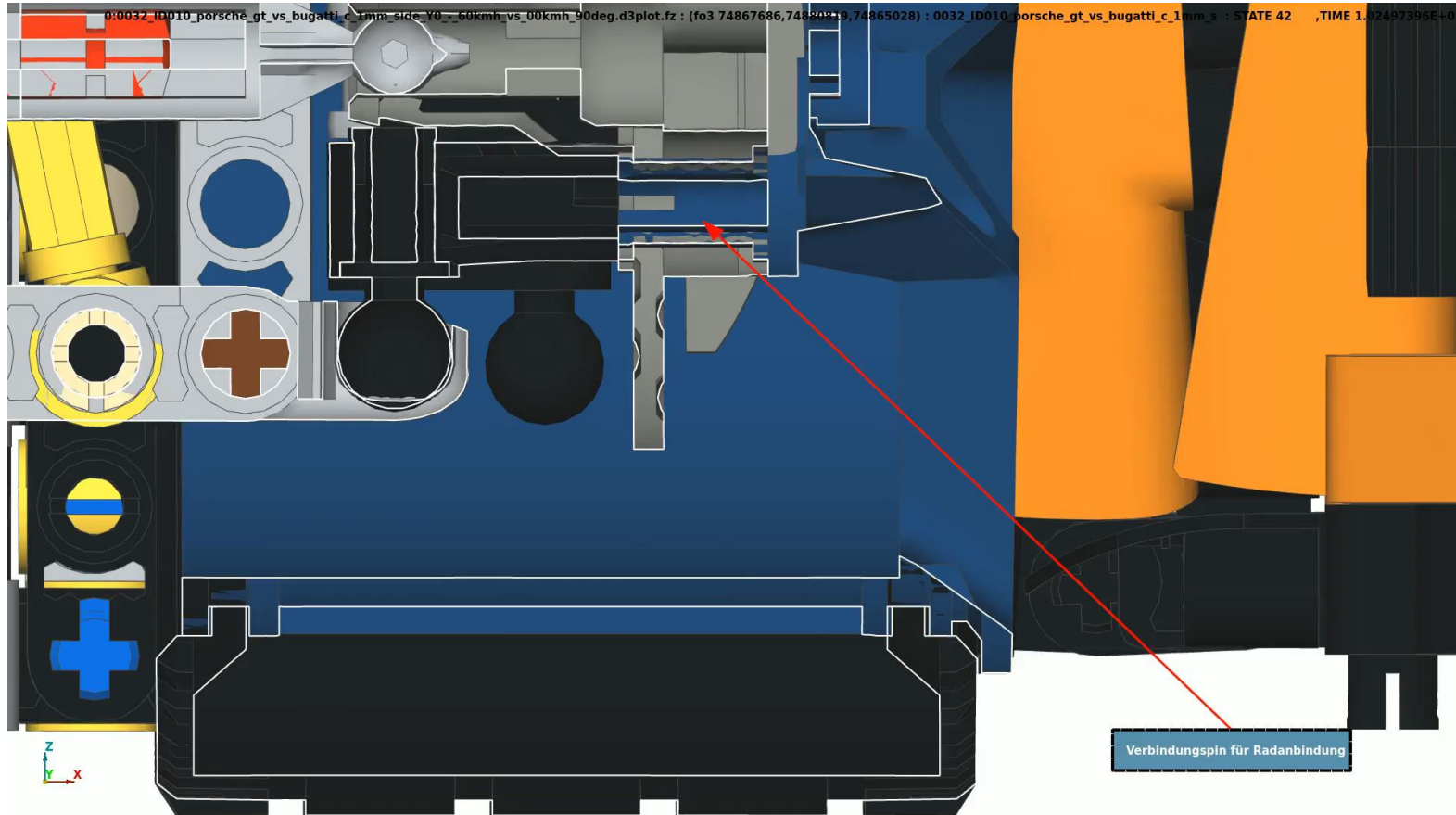
<http://ct.de/cash>



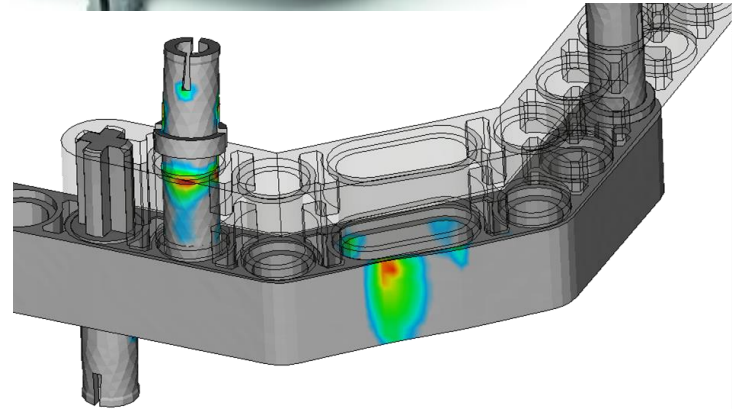
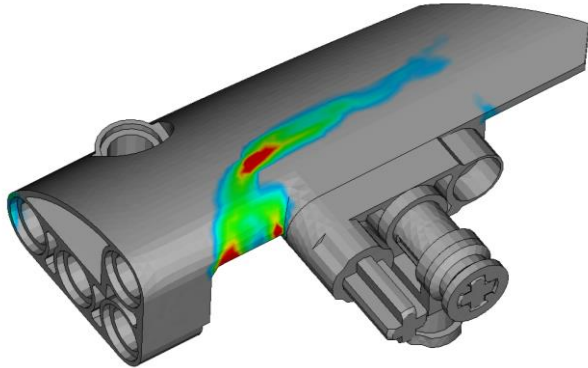
- 60kph
- 300kw halogen spot lights
- 50m track
- 10 x 1000fps high speed cameras

LEGO® is a trademark of the LEGO Group of companies which does not sponsor, authorize or endorse these investigations.  
© 2019 Copyright by DYNAmore GmbH, SCALE GmbH

# Detail of left front wheel from Bugatti



# Damage on LEGO Parts



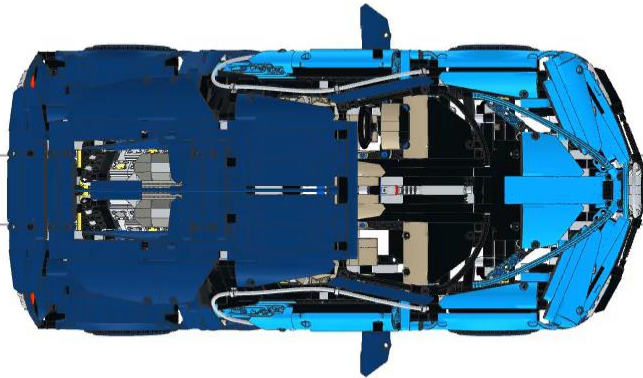
evaluation of plastic strains

# 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

The screenshot displays the CAVIT web interface in a Chromium browser. The main content area shows a table of simulation results with columns for Name and File size. A sidebar on the left contains project and scenario filters. A video player window is open in the foreground, showing a 3D model of a truck.

**Projects**

- Audi Quattro
- SCALECar

**Scenarios**

- Front (11 / 11)
- Europa (0 / 0)
  - EURO-NCAP (0 / 0)
  - ECE-R137 (0 / 0)
  - ECE-R94 (EG... (0 / 0)
  - ECE-R21/AZT (0 / 0)
  - NAR (0 / 0)

**List of all simulations**

Name	File size
0325_AUDI_QUATTRO_1985_S1_H_f_w_18kmh_0_deg_25pct_Isdyna_	
0275_SCALECAR_2018_S42_H_W_17kmh_0_deg_50_Isdyna_1mm	
0347_SCALECAR_2018_S42_H_f_w_25kmh_0_deg_100pct_Isdyna_	
0341_AUDI_QUATTRO_1985_S1_H_f_w_18kmh_0_deg_25pct_Isdyna_	
0276_1st_AUDI_QUATTRO_-vs_-2nd_SCALECAR_c_17kmh_0_deg_50_Is	
0347_SCALECAR_2018_S42_H_f_w_25kmh_0_deg_100pct_Isdyna_	
0324_AUDI_QUATTRO_1985_S1_H_f_w_18kmh_0_deg_25pct_Isdyna_	
0341_AUDI_QUATTRO_1985_S1_H_f_w_18kmh_0_deg_100pct_Isdyna_	

**Filters**

**Pictures**

**Movies**

**Result files**

Name	Description	File size
0276_1st_AUDI_QUATTRO_-vs_-2nd_SCALECAR_c_17kmh_0_deg_50_Isdyna_		
BACK_LEFT_-0276_1st.webm		25.88 MiB
FRONT_LEFT_-0276_1st.webm		2.31 MiB
d3plot.fz.lol		164 B
d3plot.sz.lol		2.27 KiB

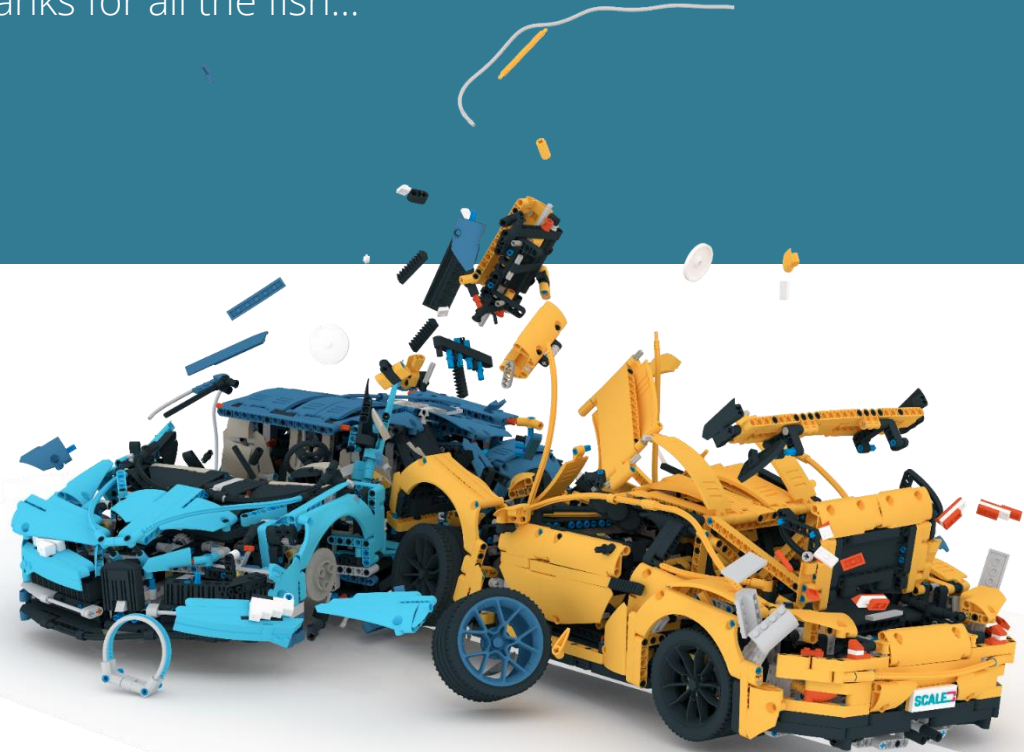
# What's next...

- 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](mailto: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

