

Virtual Product Development with an SDM System

Demonstrated by Playing with LEGO® Car Models as Examples

Marko Thiele,
Dr. Gordon Geissler

SCALE

IT-Solutions for CAE





The LEGO® Challenge

WHAT WILL
HAPPEN?



WE SHOULD BE ABLE TO PREDICT THIS
WITH SIMULATION!

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Setup in SDM-System

Goals

design a car that shall

- have a cool design
- be indestructible
- let the mini figure survive
- possesses good aerodynamics

Results

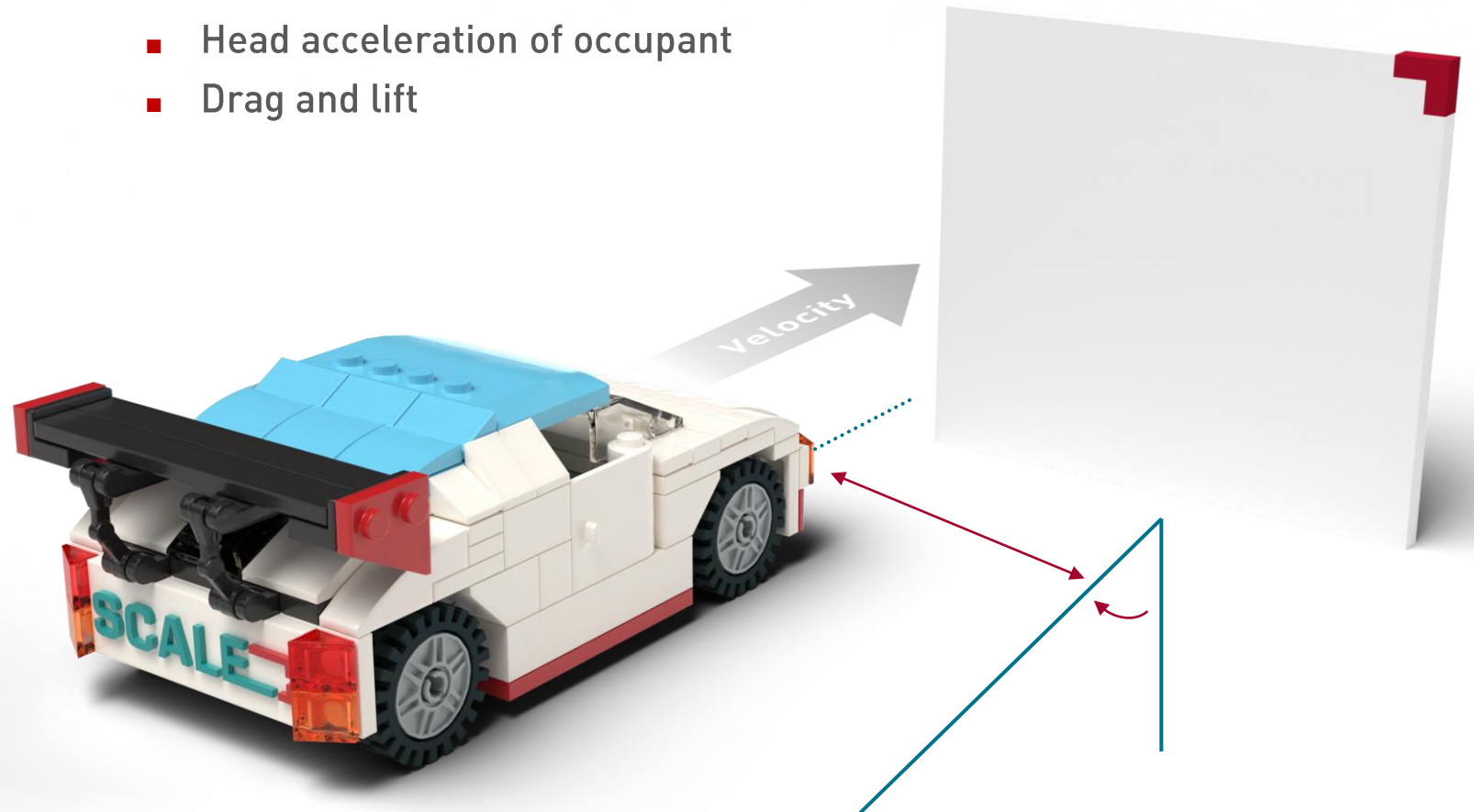
things that are to be monitored with respect to the goals

- Level of destruction
- Vehicle deceleration
- Head acceleration of occupant
- Drag and lift

Design & Test Parameters

things that we can vary

- Geometric build of car
- Speed
- Offset
- Angle of impact
- Angle of spoiler





Setup Requirements for the Project

Requirements

technical targets for the project

Structured by category, vehicle and velocity

- > CFD (8)
- ∨ Front Impact (16)
 - > AUDI_QUAT... (4)
 - > MERCEDES_... (4)
 - > RIVIAN_R1T (4)
 - ∨ SCALECAR (4)
 - ∨ 20 km/h (2)
 - Level of destruction (@20 km/h) Rating of destruction level for LEGO simulation models
 - ∞ < x < 20
 - 20 < x < 24
 - 24 < x < ∞
 - max. Acceleration (@20 km/h) max. Acceleration for LEGO simulation models
 - ∞ < x < 1200
 - 1200 < x < 1500
 - 1500 < x < ∞
 - > 30 km/h (2)

Thresholds for level of destruction

Thresholds for acceleration

Milestones

definition of all project milestones and targets



Monitoring

transparent project status at any time

Assessment

individual assessment by users

Project Status

aggregated on each level of requirements

∨ CFD (8)	yellow
∨ 30 km/h (4)	yellow
> MERCEDES_SLS_AMG (2)	green
∨ SCALECAR (2)	yellow
Drag (@30 km/h)	0.41 yellow
Lift (@30 km/h)	0.32 green
> 40 km/h (4)	yellow
∨ Front Impact (16)	green
∨ 20 km/h (8)	green
> AUDI_QUATTRO (2)	yellow
> MERCEDES_SLS_AMG (2)	green
> RIVIAN_R1T (2)	yellow
∨ SCALECAR (2)	green
Level of destruction (@20 km/h)	22.62 green
max. Acceleration (@20 km/h)	1738.03 red

Aggregated status

User assessment

Manage CAD data in the SDM-System [1]



- CAD data in the SDM-system *imported, versioned, managed*
- Product structure *disassembled into groups to allow teamwork*
- Integrated CAD tools *can be opened and worked with directly*
- Teamwork *changes automatically synced to all team members*

Version control for project

One file per part / brick

Version control for a selected part group

Product structure rebuild from LDraw model

Opening and working with CAD assemblies from within SCALE.sdm

Komponententyp	Kurzbeschreibung	BrickID	Disziplin	FileType	PartNumber	Version	Änderungsdatum
brick	platform_26	3004	CAD,LEGO	ldr	250	2	06.12.18
brick	platform_27	3004	CAD,LEGO	ldr	251	2	06.12.18
brick	platform_07	3005	CAD,LEGO	ldr	7	10	06.12.18
brick	platform_06	3005	CAD,LEGO	ldr	6	10	06.12.18



[1] C. Knebler, 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

Meshing of CAD Data [1]



LoCoX

LEGO

lococx_crush_the_brix

379 [RunConfigs 4 car2car]

Libraries

Bricks

517 [Merge]

LEGO LEGO (local copy) (LOCOX)

Browser

Pool-Version

Komponenten

Libraries

Barriers

Bricks

Bricks (517 - Bricks)

Bricks4Import

LDrawParts

MultiStageAssembly

Material

Road

Master

Tools

car

leagelcode

Runs

Attribute

Komponententyp	Kurzbeschreibung	BrickID	Solver	ElementSize	Disziplin	MeshingStep	setsize	Type	presentation	ion	erungsdatum
base	Technic_Bus	3713			CAD	00_import					
base	Tec				AD	00_import					
base	Tec				AD	01_cleanup					
base	Tec				AD	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					

Brick library mounted to project

Historie

Eingehangene...sion: Bricks

- 517 Merge
- 516 Fix for Brick #85984
- 515 #4733
- 514 Attributes changed.

ANSYS v18.1.0 64-bit (/tmp/tmpOPhbn/Technic_Bush_with_Two_Flanges...3713_1mmHEXA02_ansa)

File Tools Utilities Lists Assembly Plugins Windows Help

Database

Name	Numbe
ANSAPART	1
EDGE	
ELEMENT	260
GEOMETRY	9
GRID	520
MATERIAL	1
PROPERTY	1
SOLIDFACET	
VOLUME	17

Bush_with_Two_Flanges...3713_1mmHEXA02_ansa

Current Part: 3713-LtBluis

Hot Points

Insert Project Parametric

Delete Mult.Proje. Intersect

Release Weld Spot

CONS

Paste Release Fill Hole

Open Hole Project Break

Faces

Cut Delete Undelete

New Set PID Topo

Proj.Cut Mid.Surf. Rm.Log

Fuse Flange Rm.Dbl

Plane Cu. Offset Freeze/Un

Zone Cut Convert Dach

Intersect Extend Orient

Modify

Surfaces

Coons Fit Extend

Volume Extrude Break

Options List

Current perimeter

Current distortion

Current distortion

ENT PID

40°

ENT

ANSA PRE PROCESSOR

Various representations of CAD geometry and meshed bricks

Versions of brick library or individual meshes

Brick opened for meshing directly from SDM-system

[1] C. Knebler, 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



Setup of Load Cases and Solving

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_QUATT
 - 0381_AUDI_QUATT

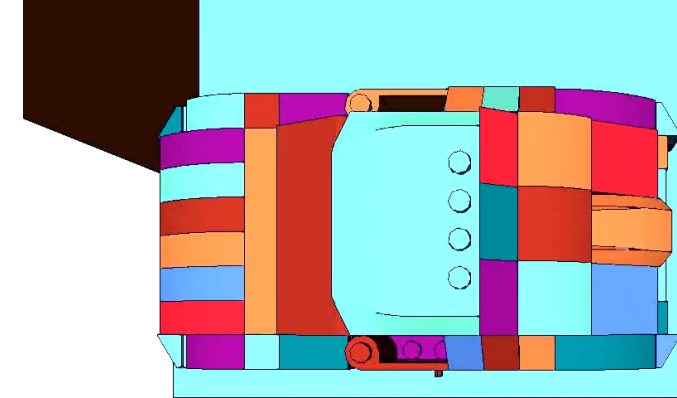
Jobs

Filter

- 0042_1st-PORSCHE_60.0kmh_0.0_deg_0....TI_0.0_kmh_270.deg_-1145off_-_04fa
 - Simulation Job: Solving: 59.12ms of 130.1ms computed KIN=46.7%, INT=2.6% [Job](#)
- Simulation Job
 - Solving: 59.12ms of 130.1ms computed KIN=46.7%, INT=2.6% [Job Folder Log](#)

Annotations:

- Flexible grouping of runs by their properties
- Setup of multiple different scenarios
- Setup of multiple cars
- Job Monitoring



Job submit

ON-PREMISE

CLOUD

SCALE

HLRIS

rescale



Simulation Results compared to Test

The screenshot displays the CAVIT software interface for a simulation of a LEGO car model. The main window shows a table of simulation results with columns for Name, Vehicle Speed, Overlap, Angle, OLC, and level of detail. Two items are selected: '0607_SCALECAR_DOE_00_17.0k...' and 'SCALECAR_PHYSICAL_MARKO_R...'. Below the table, there are tabs for Attributes, Photos, Videos, Documents, Channels, and Measure Data. A filter is applied to 'SCALECAR_PHYSICAL_TEST', showing two video thumbnails. On the right, a 'Report' window is open, displaying a legend with two entries: '0607_SCALECAR_DOE_00_17.0kmh_0.0_deg_25.0pct_w_20221001T100740_70217marko.thiele' (green square) and 'SCALECAR_PHYSICAL_TEST' (red square). Below the legend, there are three comparison views: 'Top View', 'Left View', and 'Global Energy Curves'. Each view shows a simulation image on the left and a corresponding test photograph on the right. The 'Global Energy Curves' view shows a line graph for 'Total Energy' with a peak value of 1.71.

Star	Name	Vehicle Speed	Overlap	Angle	OLC	level of des...
☆	SCALE					
☆	0601_SCALECAR_8stud_f_w_...	30.0	25.0	0.0		53.0303
☆	0588_SCALECAR_8stud_f_w_...	30.0	25.0	-30.0		48.4848
☆	0541_SCALECAR_DOE_00_17.0k...	17.0	25.0	0.0		1.5385
☆	0587_SCALECAR_8stud_f_w_...	30.0	25.0	0.0		46.2121
☆	0587_SCALECAR_8stud_f_w_...	30.0	25.0	-30.0		48.4848
☆	0607_SCALECAR_8stud_f_w_...	35.0	25.0	0.0		55.3030
★	0607_SCALECAR_DOE_00_17.0k...	17.0	25.0	0.0	966.1	16.6667
☆	0607_SCALECAR_8stud_f_w_...	30.0	25.0	0.0	1514.4	40.1515
☆	0607_SCALECAR_8stud_f_w_...	20.0	25.0	0.0		18.1818
★	SCALECAR_PHYSICAL_MARKO_R...	17.0	25.0	0.0	966.1	16.6667
☆	0607_SCALECAR_8stud_f_w_...	30.0	25.0	0.0		43.1818
☆	0607_SCALECAR_8stud_f_w_...	17.0	25.0	0.0	957.5	11.3636
☆	0588_SCALECAR_8stud_f_w_...	30.0	25.0	0.0		46.2121
☆	0607_SCALECAR_DOE_26_22.2k...	22.3	25.7	-9.372	1108.6	19.6970
☆	0607_SCALECAR_DOE_30_24.0k...	24.1	30.0	-18.201	1202.9	19.6970
☆	0607_SCALECAR_DOE_25_23.9k...	24.0	30.4	-7.415	1267.8	21.2121
☆	0607_SCALECAR_DOE_27_23.8k...	23.8	31.1	-1.257	1347.9	22.7273

- Simulations correlated with test videos
- Parameters for validation
 - Friction
 - Clamping force
 - DTSTIF
- Basis to start more complex challenges

Model created by collaboration with SDM



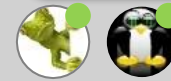
DYNAmore Corporation USA

- **Nils** (LS-DYNA®)
- **Thomas** (meshing)



SCALE GmbH Dresden

- **David** (software)
- **Peter** (process, submitting to HPC)



DYNAmore France SAS

- **Pierre** (meshing, LS-DYNA®)



SCALE GmbH Ingolstadt

- **Alexandru** (model)
- **Marko** (LEGO® CAD, process, model, ...)



DYNAmore GmbH Stuttgart

- **Andre** (organization)
- **Thorsten** (meshing, LS-DYNA®)
- **David** (materials)



Porsche:
2704 bricks
182 different bricks

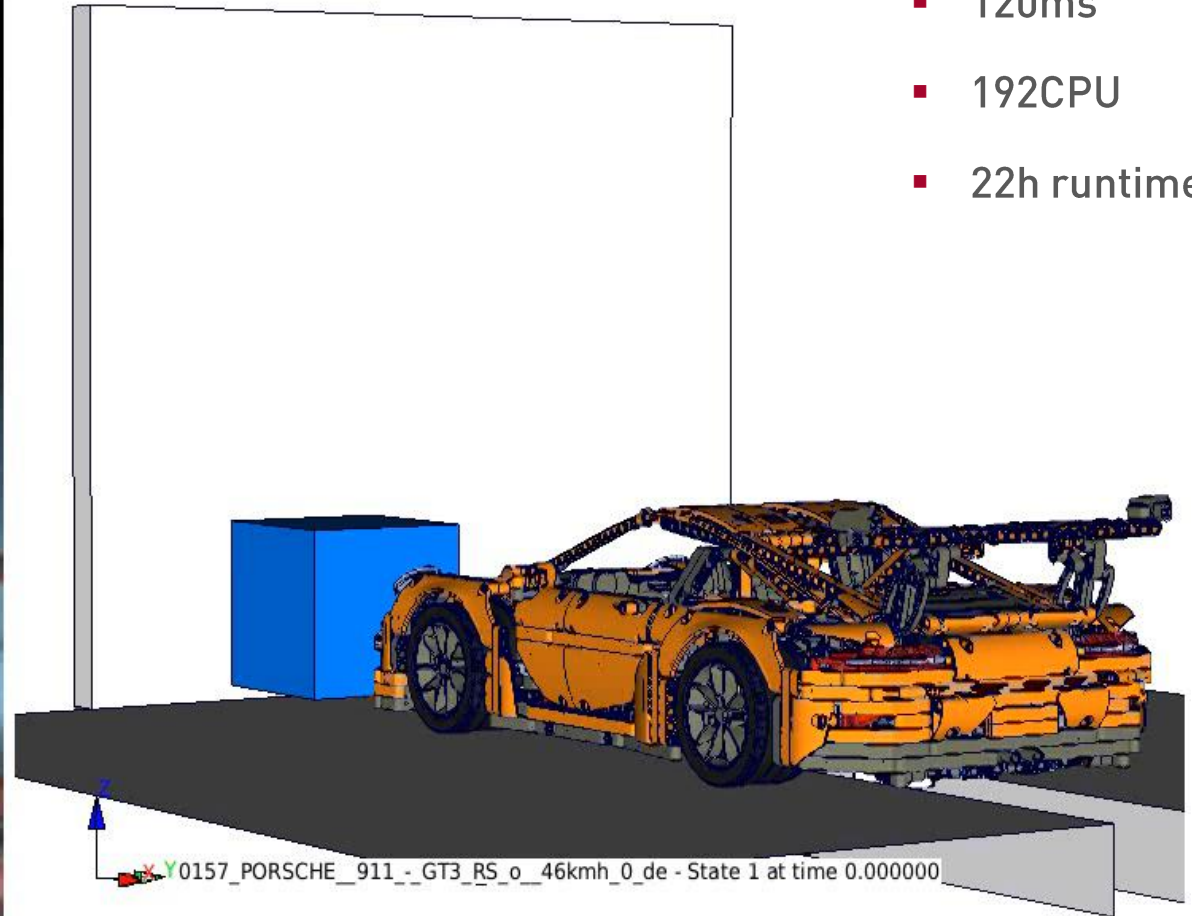
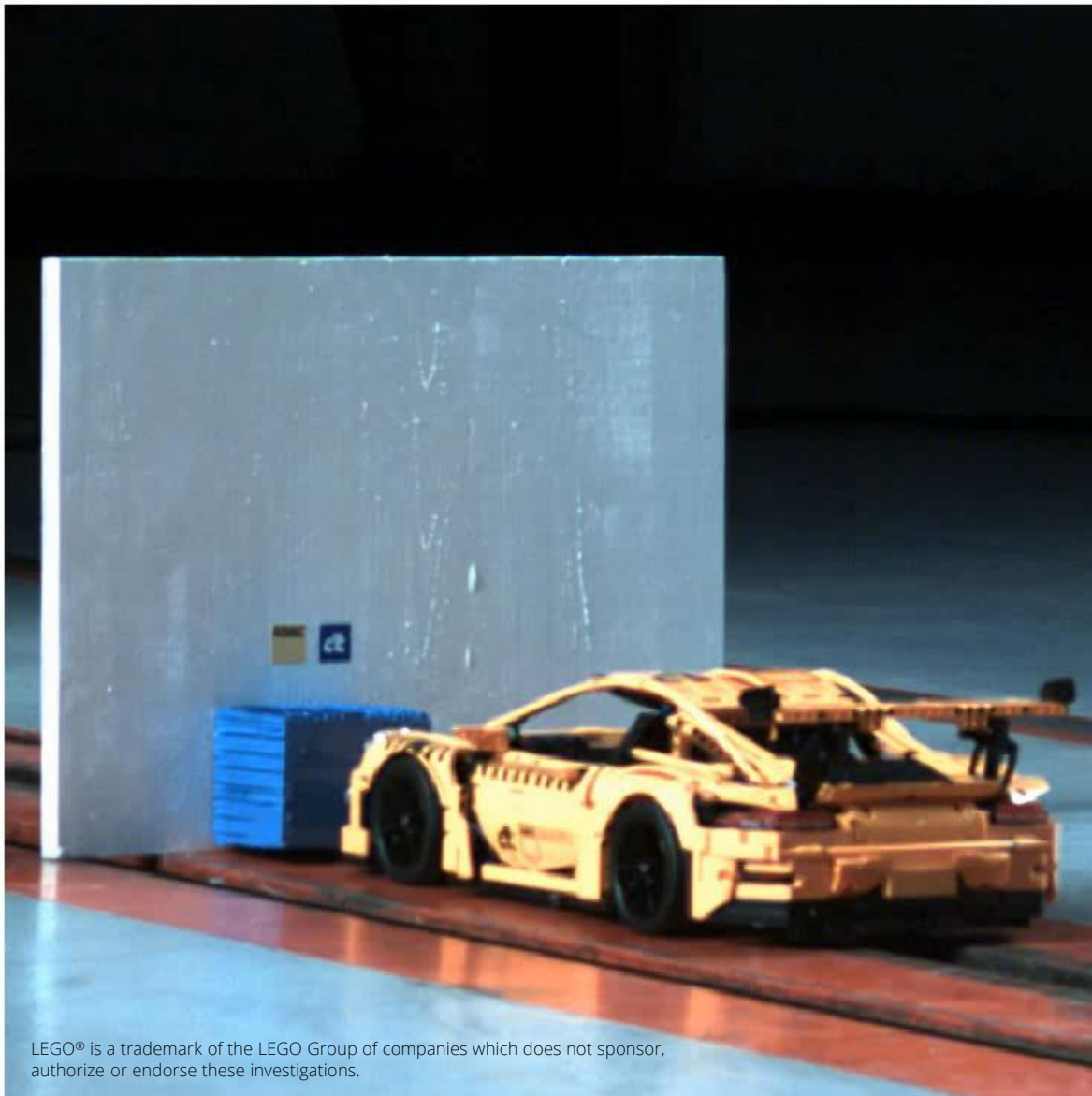


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Simulation Results



- 2704 parts (bricks)
- 19.5M elements
- 120ms
- 192CPU
- 22h runtime





Simulation Results

- 2704 parts (bricks)
- 19.5M elements
- 120ms
- 192CPU
- 22h runtime



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The LEGO® Challenge

#legowette



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Simulation Results

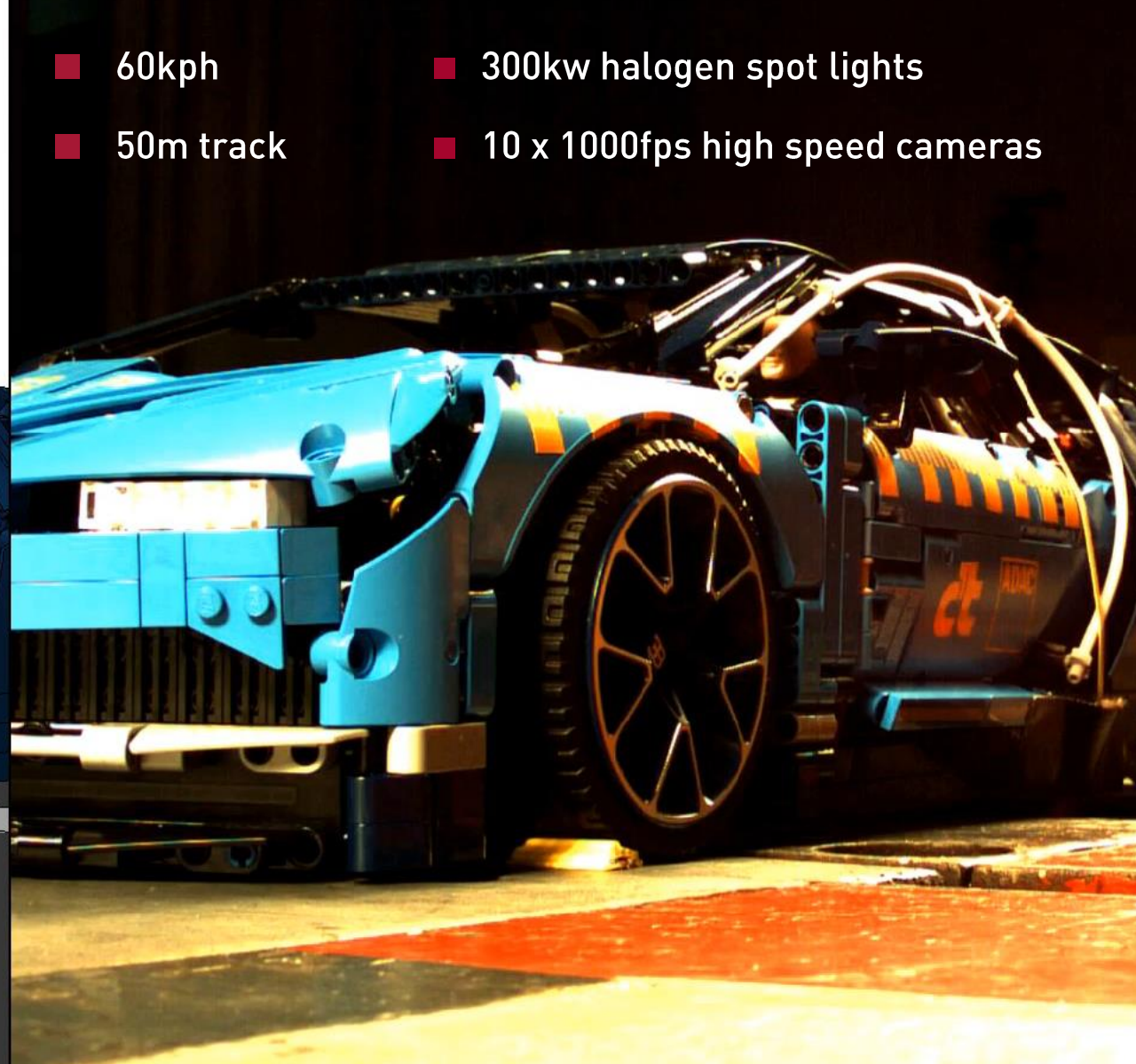
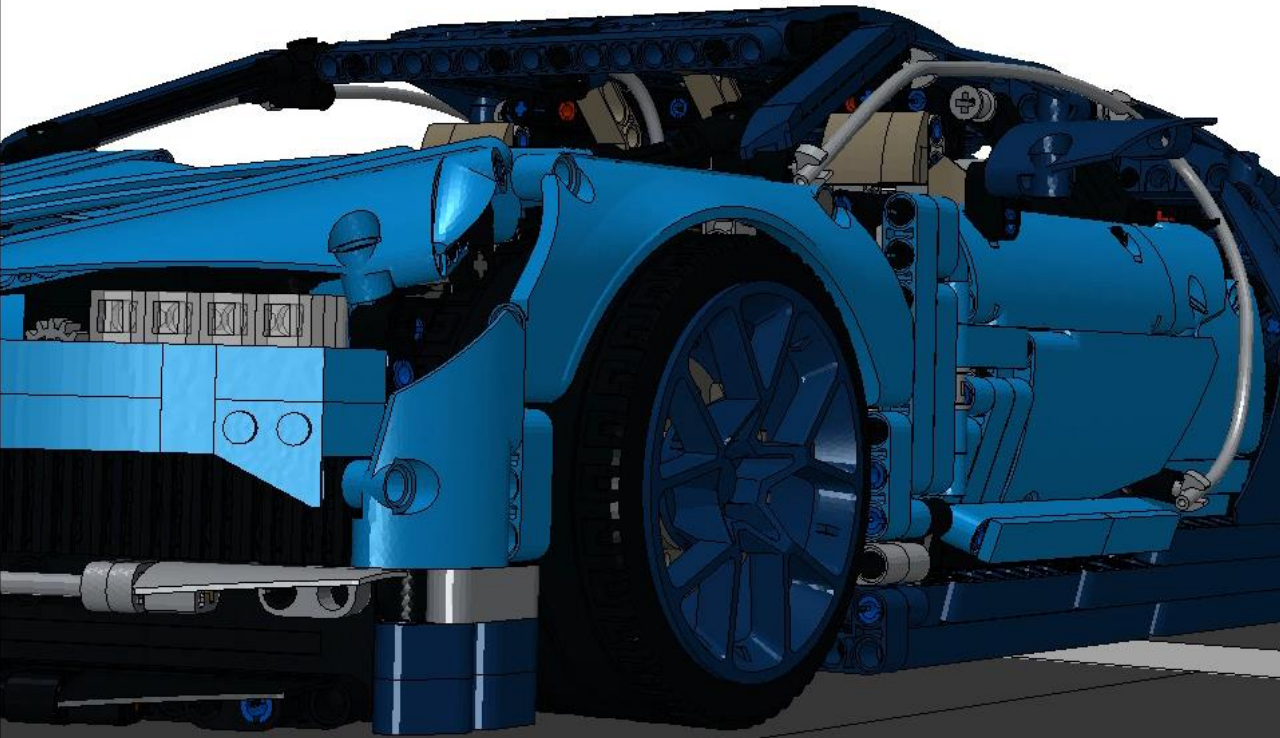
- 6303 parts (bricks)
- 45.8M elements
- 130ms
- 192CPU
- 54h runtime



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Simulation Results



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

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Data Analysis



- **DOE and data-analysis**

setup easy within SDM-System

- **Input**

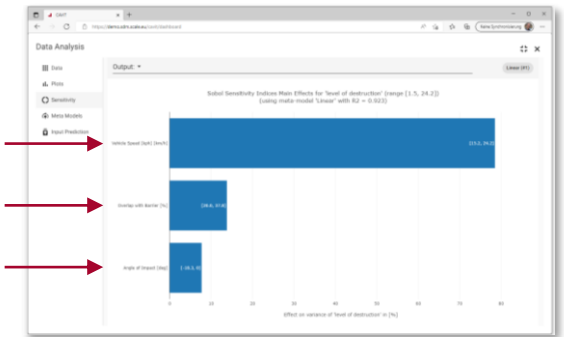
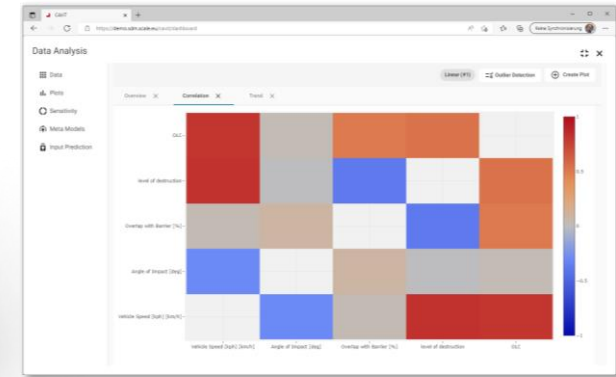
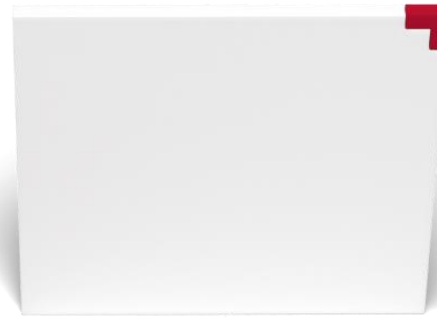
- Speed
 - Offset
 - Angle

- **Output**

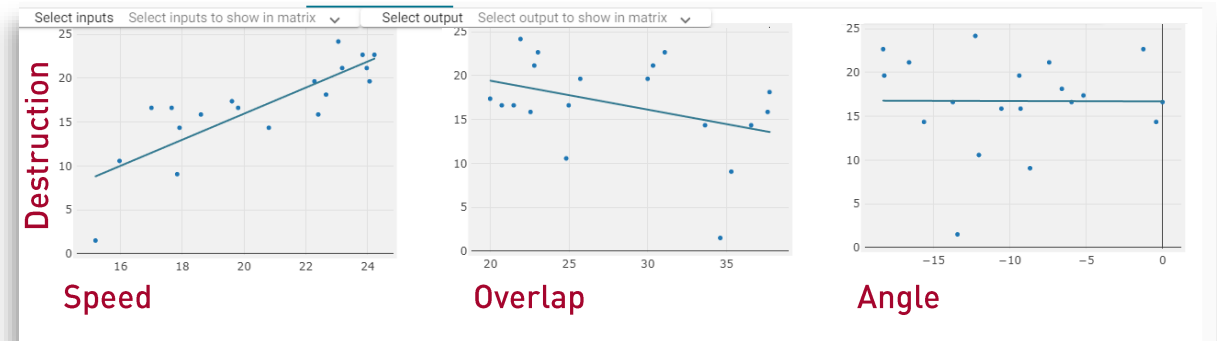
- Level of destruction
 - Deceleration

- **Analysis**

correlation, trends, meta-models



Destruction





Discipline – Car 2 Car Crash

- **Separate project & discipline**
car to car crash as simulation discipline
- **Parameterization**
velocity, angle, offset, ...
 - DOE studies
 - Data analysis
- **Multi-stage-assembly**
references individual car projects as input



Discipline – CFD



- Using same geometry as crash
separate simulation discipline
- Fully automatized
runs directly after changing CAD geometry
 - Snappy hexmesh
 - OpenFOAM
- Postprocessing
automatic extraction
 - Paraview
 - Images, videos, key-results, ...
 - Data cached remotely
accessible through VDI workstation

The screenshot displays the SCALE result software interface for a 'LEGO CFD' simulation. The dashboard includes a list of simulation cases, a 'Key Values' table, and 'Convergence Plots'.

Key Values Table:

Test Name	Velocity	Spoiler Angle	Overall Lift	Overall Drag
0685_SCALECAR_8stud__20kmh_0_deg_CFD_2434	20.00	0°	-0.01	-0.02

Convergence Plots: A line graph showing the convergence of various parameters over iterations. The y-axis is labeled 'NOVALUE' and ranges from 10⁻⁶ to 1. The x-axis represents iterations from 0 to 200. The legend includes U_{x,0}, U_{y,0}, U_{z,0}, ϵ_0 , k₀, and p₀.



Discipline – Rendering

■ Simulation of light

setup and automated within SDM-System



LS-DYNA®

■ Preprocess



■ Blender

for studio and lighting setup

■ *.blend files

managed in SDM-system

simulation

input

convert

■ Solving

*.blend

■ d3plot.fz from LS-DYNA

converted to 1TB blender in ~1 week

■ Solver: Blender

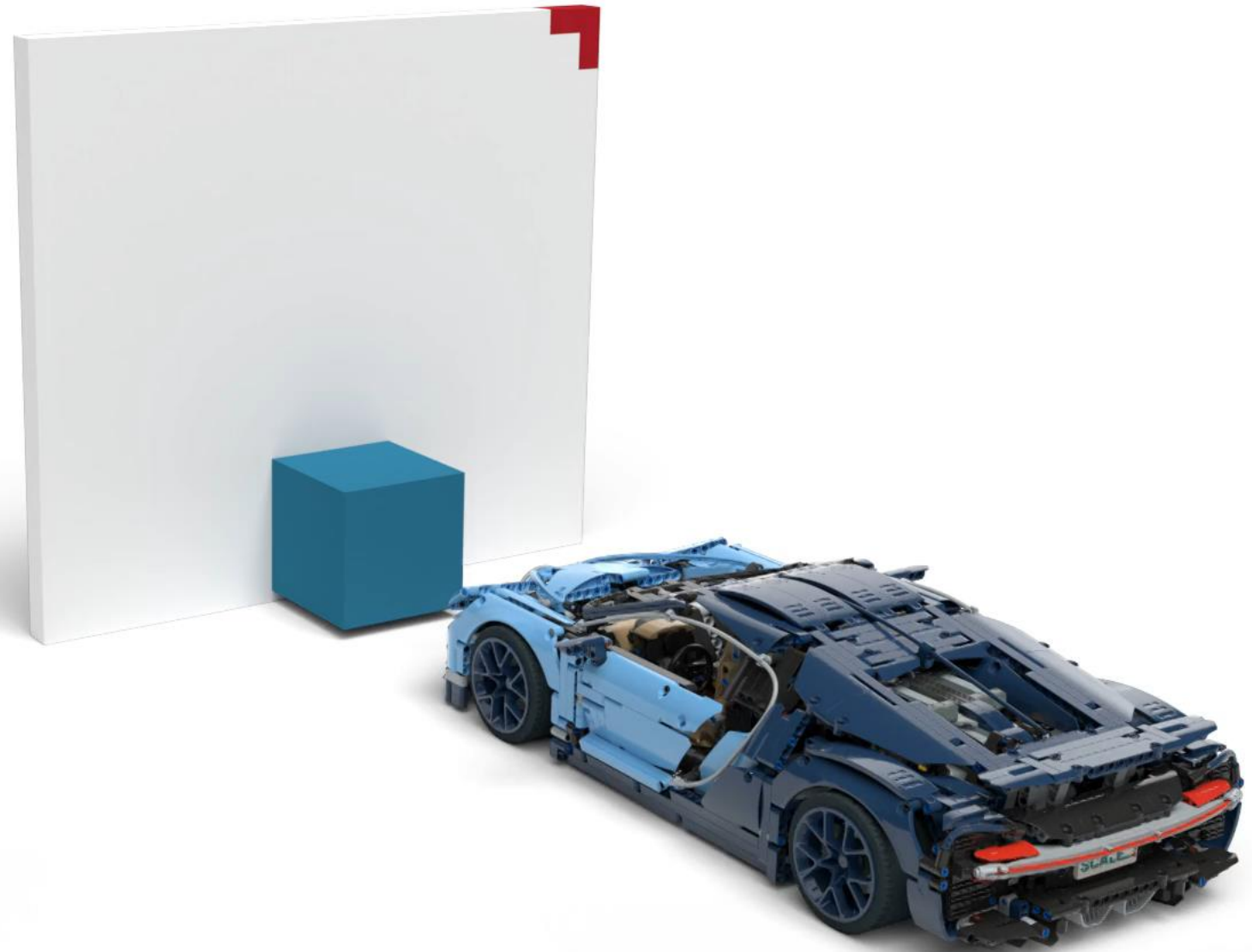
~2 day on 64CPU for 911 frames

BLENDER

■ Camera perspectives as load cases



■ Videos as results



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What's Next

- More models
 - Technic #42115 @ xmas
 - 8 stud wide MOCs
- More simulation disciplines
 - Powertrain
 - Multi body dynamics (MBD)
 - Water splashing (SPH)
 - ...
- More fun with simulation...
- Free models for HPC benchmarking and ...

models are licensed [CC BY-NC-SA 4.0](https://creativecommons.org/licenses/by-nc-sa/4.0/) and can be provided for noncommercial use, reach out to info@scale.eu





SO LONG, AND THANKS

FOR ALL THE FISH



<https://www.linkedin.com/company/scale-gmbh/>

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