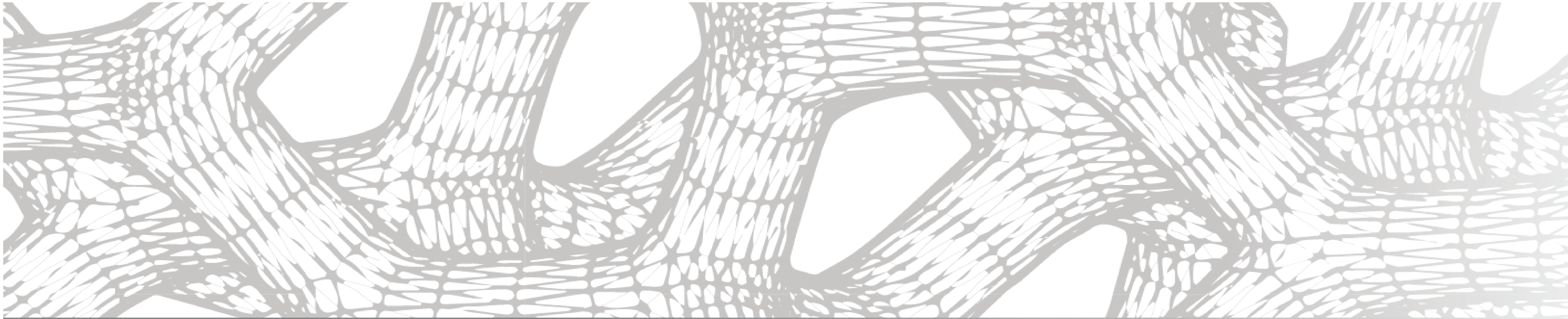
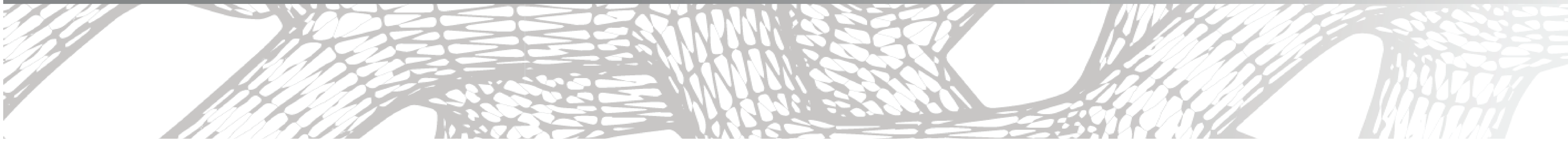


Application of hybrid design for additive manufacturing of metals on the example of Project T.O.S.T.

Combining topology optimization and lattice structures for structural lightweight designs

Philipp Manger (EAH Jena)
Thomas Töppel, Richard Kordass (Fraunhofer IWU, Dresden)

Formnext International exhibition and conference on the next generation of manufacturing technologies, 16.11.2017



AGENDA

- Short Introduction of the speakers
- Profile of the Fraunhofer IWU & Laser beam melting
- Background to Project T.O.S.T & study goals & design criteria
- Definition of Hybrid Design in this context
- **MAIN PART – Hybrid Design Workflow**
  - Step by step workflow on the example of the hanger of T.O.S.T.
- Results
  - About the workflow
  - Comparison to the benchmark trucks

Short introduction
Philipp Manger

- Precision engineering student at University of Applied Sciences in Jena, Germany
- Beside/before study working as Lead mechanical design engineer for Skatedeluxe OHG, ThyssenKrupp Presta AG and others
- Focusing on additive manufacturing, generative design and lattice structures

Richard Kordass

- 2014: M.Sc. in Mechanical Engineering
- Since 2015: Research Assistant at Fraunhofer Institute for Machine Tools and Forming Technology (IWU), Branch Additive Manufacturing Processes
- Focusing on LBM-Process Technology and optimization

Fraunhofer IWU in Profile

Profile of the Fraunhofer IWU

Fraunhofer IWU

- Part of the Fraunhofer Gesellschaft
- **Fraunhofer IWU:**
  - Research under the heading “Resource-Efficient Production“
  - 3 scientific fields:

Mechatronics and Lightweight Structures

- *Additive Manufacturing Technologies*

Forming Technology and Joining

Machine Tools, Production Systems and Machining

69 Institutes in Germany

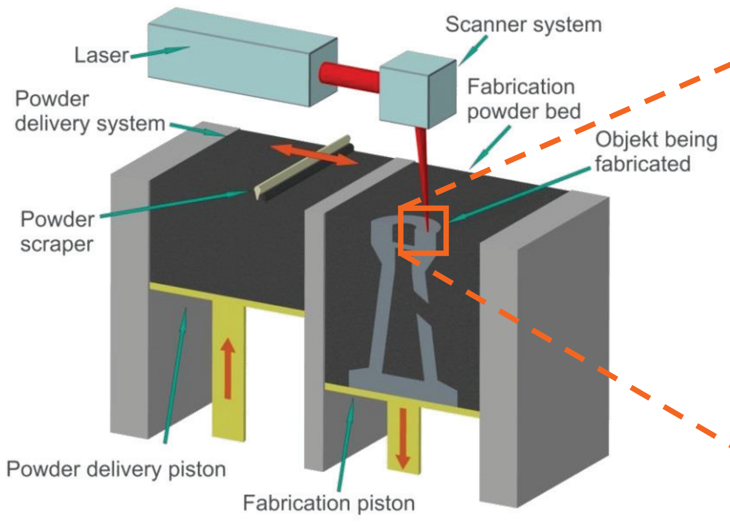
IWU Locations

Source: Fraunhofer IWU

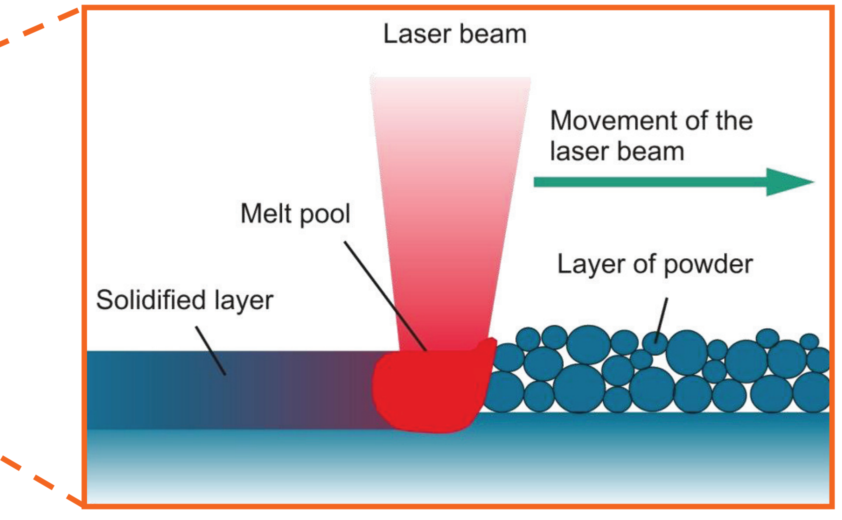
Additive Manufacturing – Laser Beam Melting (LBM)

Additive manufacturing – Laser Beam Melting process details

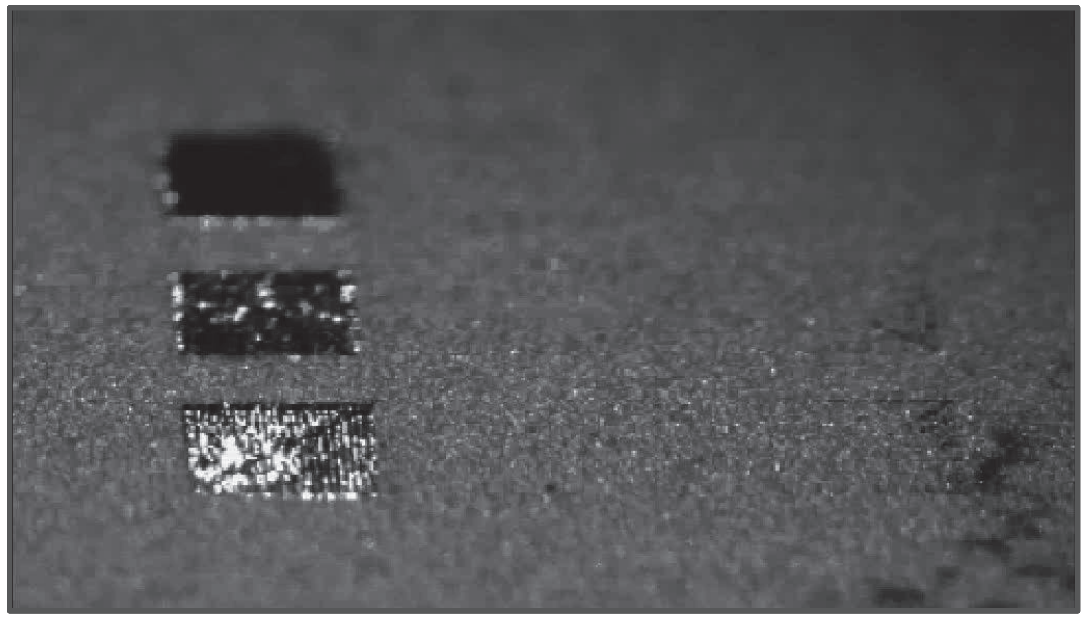
- Complete local melting of the metal powder to a 99.5 - 100 % **dense microstructure**
- **Direct, single step process**, creating parts out of **series-like metallic material** (+ removal of support structures and cleaning if necessary)



Principle sketch of a laser melting machine



Schematic diagram of Selective Laser Melting

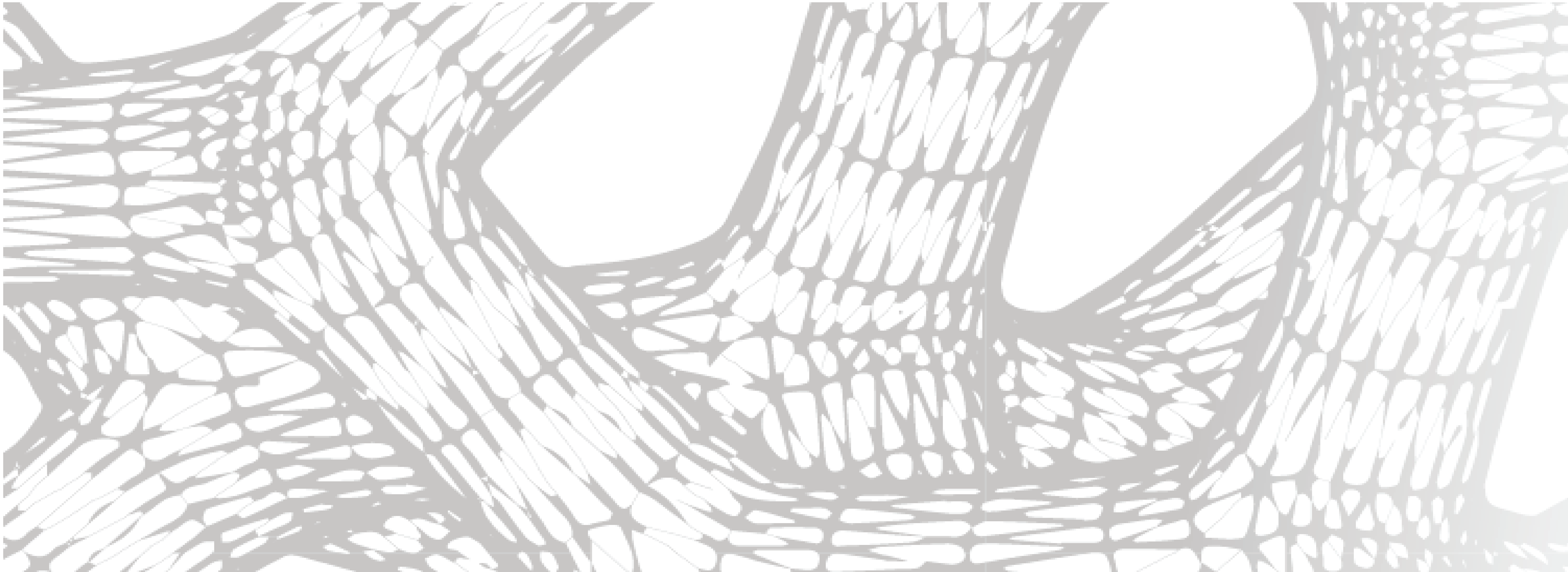


Additive manufacturing – Laser Beam Melting materials

Material	Condition	Tensile strength R_m [MPa]	Yield strength $R_{p0,2}$ [MPa]	Elongation A [%]	Hardness	Modulus of elasticity [GPa]
Tool steel [1] 1.2709 X3NiCoMoTi 18 9 5	heat-treated (490 °C)	2.040 - 2.180	1.870 - 1.940	3 - 5	54 - 56 [HRC]	
Tool steel (stainless) Corrax®	heat-treated (525 °C)	1.700	1.600	> 2	48 - 50 [HRC]	
stainless steel 1.4404 X2CrNiMo 17-12-2	as build	640	500	> 15	20 [HRC]	
Titanium [4] 3.7165 TiAl6V4	heat-treated	950 - 1.250	800 - 1.100	10 - 20	32 - 36 [HRC]	
Aluminium [2] 3.2381 AlSi10Mg	as build Annealed T6 heat-treated	353 - 482 221 - 260 281 - 320	210 - 295 126 - 160 222 - 262	2 - 7 10 - 18 5 - 10	95 - 119 [HB] 63 - 74 [HB] 85 - 101 [HB]	67 - 78 57 - 73 69 - 80
Inconel 718 [3] 2.4668 NiCr19NbMo	as build Annealed T6 heat-treated	929 - 1308 896 - 1080 1334 - 1545	583 - 945 549 - 922 924 - 1278	20.2 - 32.7 31.9 - 42.2 6.6 - 19.4	280 - 395 [HV 10] 273 - 320 [HV 10] 453 - 485 [HV 10]	128 - 232 142 - 257 149 - 242

further available Materials : CoCr, 17-4 PH, AlSi12, Hastelloy X

Characteristic values acc. to:
[1] VDI 3405 sheet 2
[2] VDI 3405 sheet 2.1
[3] VDI 3405 sheet 2.2
[4] VDI 3405 sheet 2.4 in prep.



Background to Project T.O.S.T

Background to Project T.O.S.T.

- Started as a private idea
- Presented the concept sketches to a few companies on Rapid.Tech 2016
- The **Fraunhofer IWU** then joined the project as partner
  - Helping with production knowhow and technology
  - research project about design for additive manufacturing in AGENT-3D
- Shortly after **Autodesk** supported me as well
  - Providing Netfabb Ultimate and Fusion 360
- So it fast developed to a case study about hybrid design
- T.O.S.T. is short for „**T**opology **O**ptimized **S**kateboard **T**rucks“

PROJECT T.O.S.T

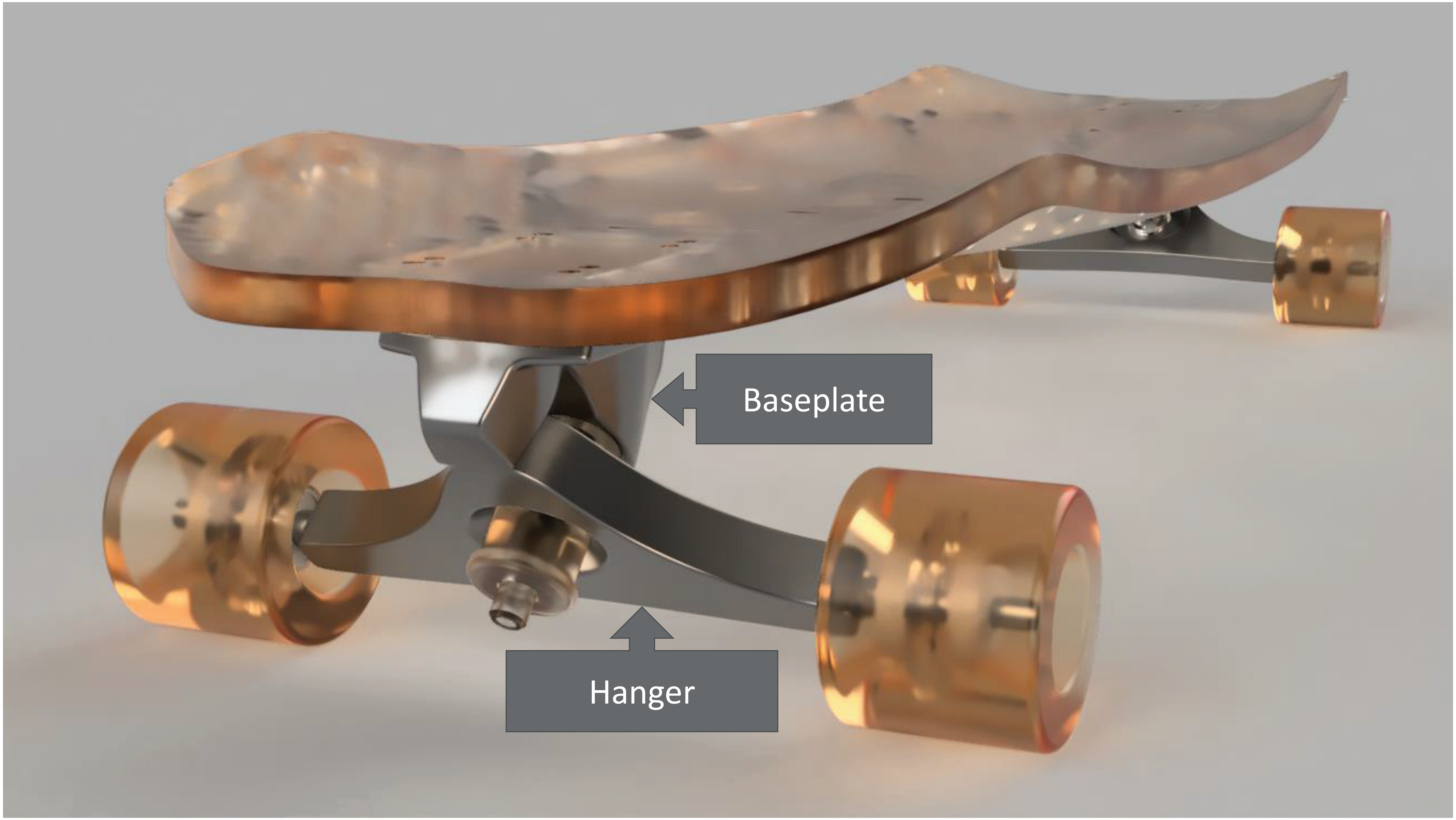
GEFÖRDERT VOM

zwanzig20 PARTNERSCHAFT FÜR INNOVATION

Bundesministerium für Bildung und Forschung

AUTODESK® NETFABB®

AUTODESK® FUSION 360™


Baseplate
Hanger

Study goals

- demonstrably illustrate a new approach to lightweight designs by combining organic and lattice structures
- development of a end-to-end workflow, using different new software tools for generative design in interaction with the laser beam melting

Design criteria

- same — or higher — stiffness and less weight compared with trucks currently available on the market
- Less parts (hanger and axle out of one material)

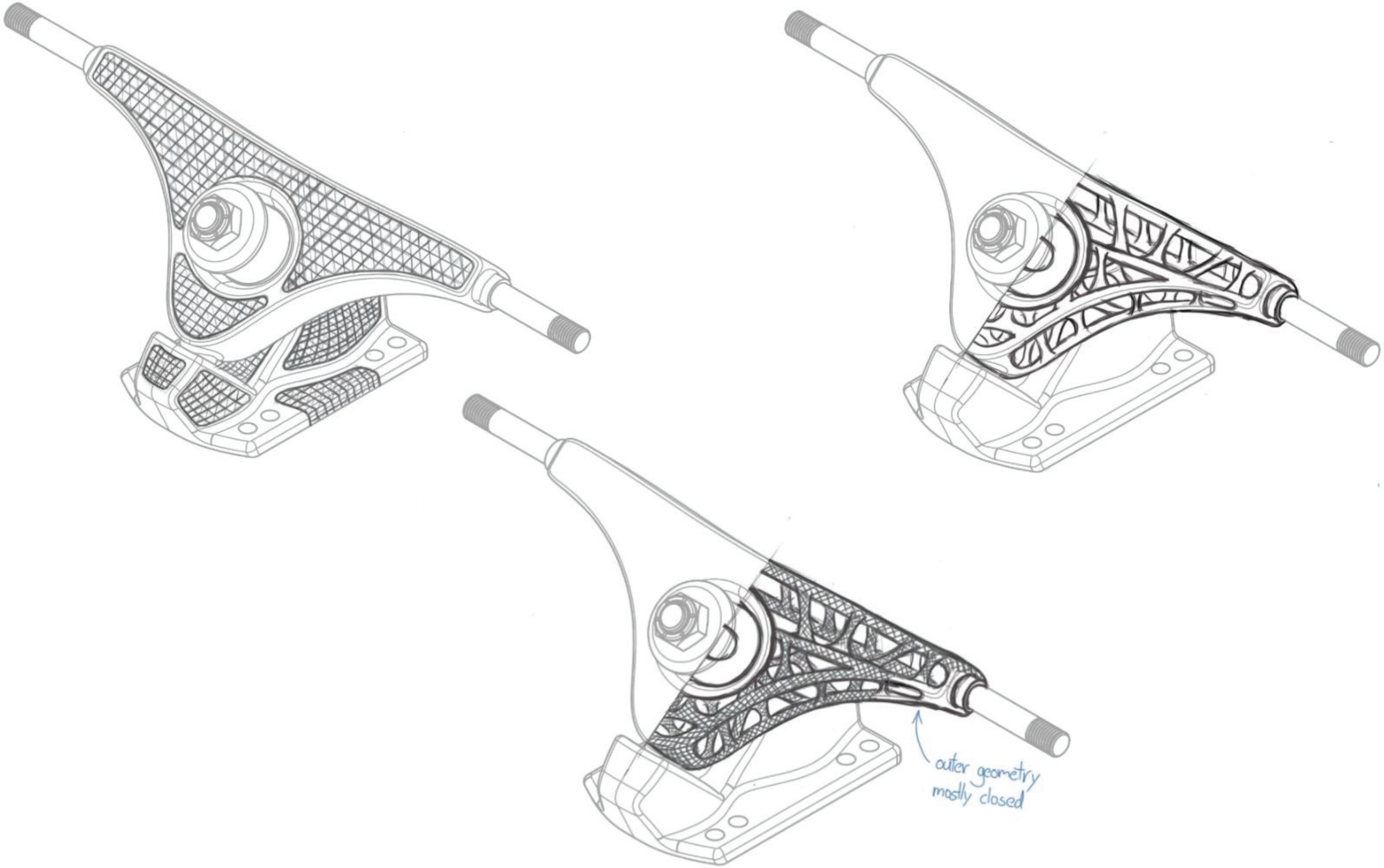
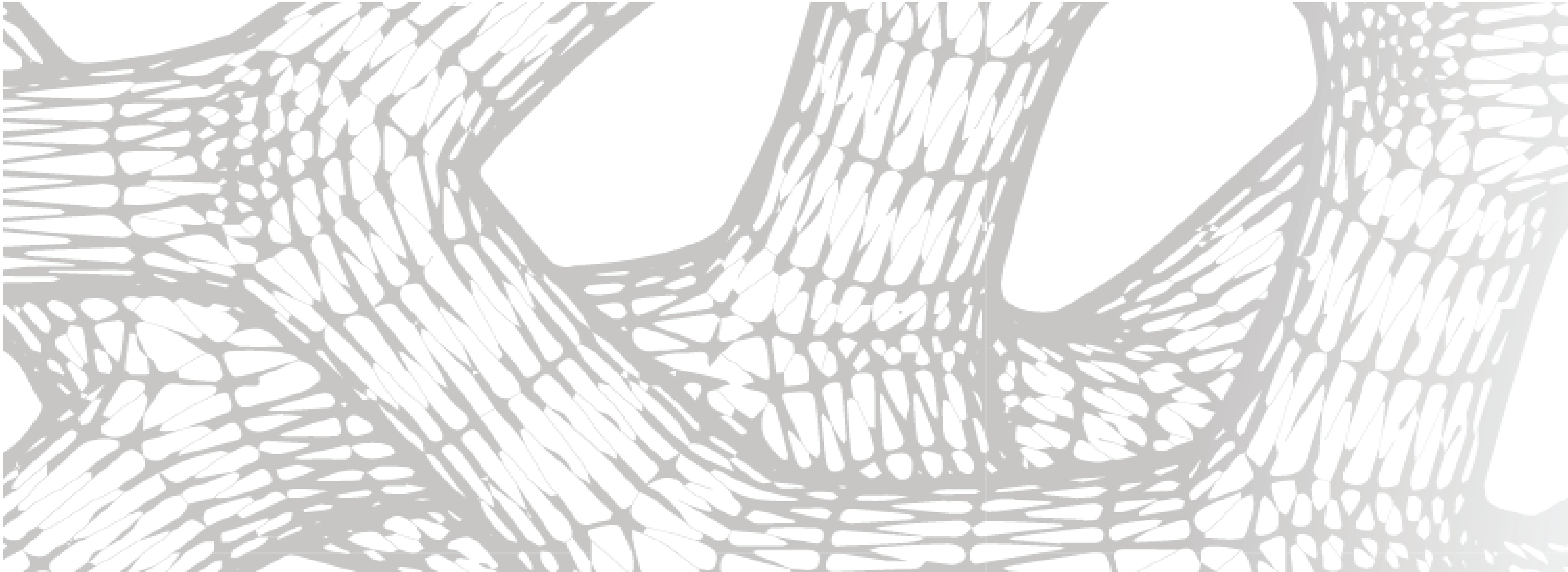


Photo Credit

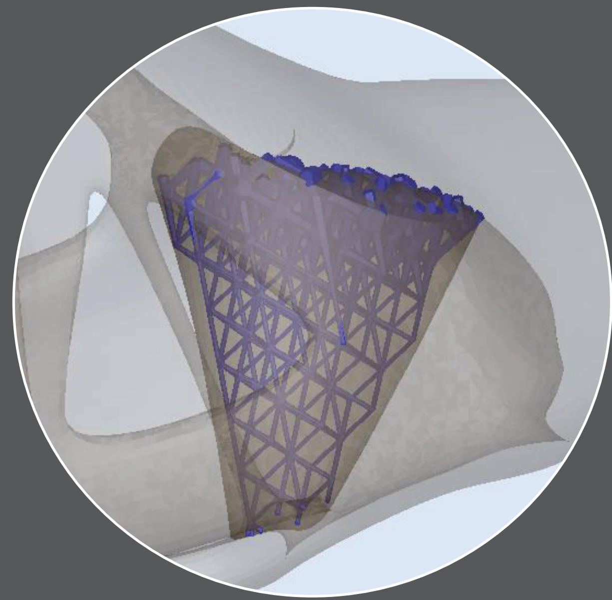


What means “Hybrid Design” in this context?

Hybrid Design means here to use optimization software to "copy nature" on different levels

Topology optimization for skeleton like organic forms
(Level 1)

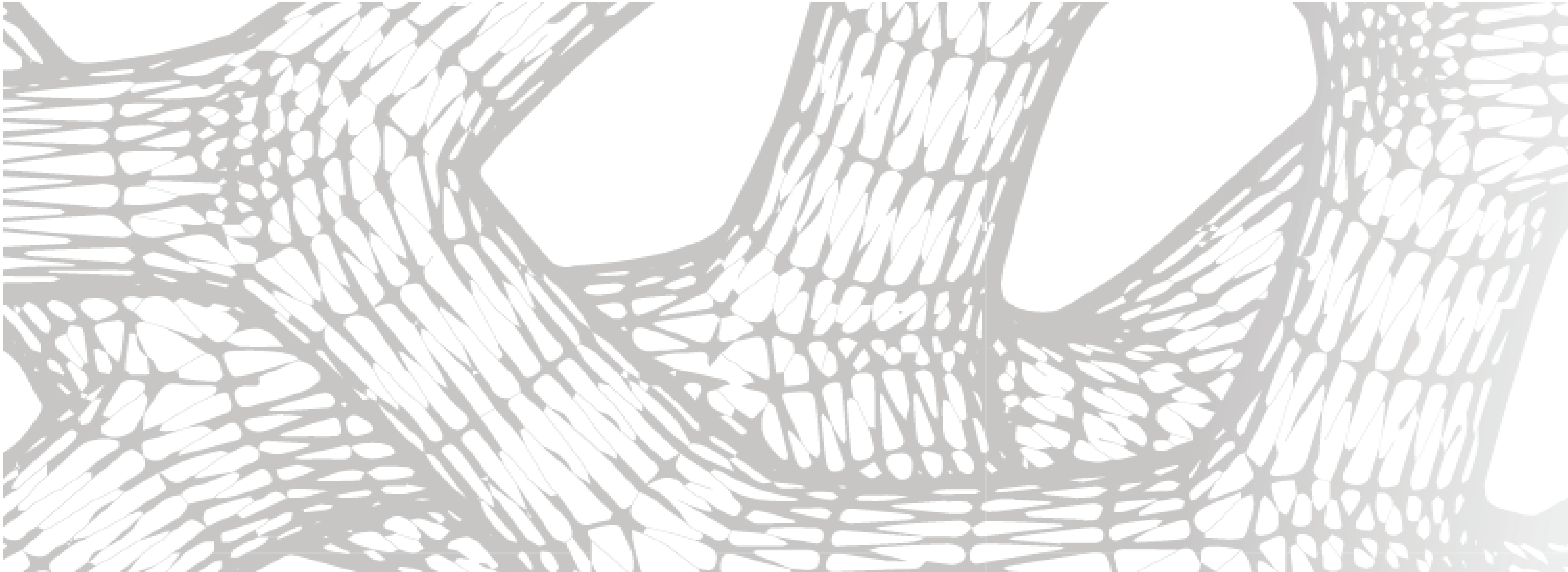
Lattice structure for the inside of these forms like in bones
(Level 2)



Include "Design for Additive Manufacturing"
(Level X)

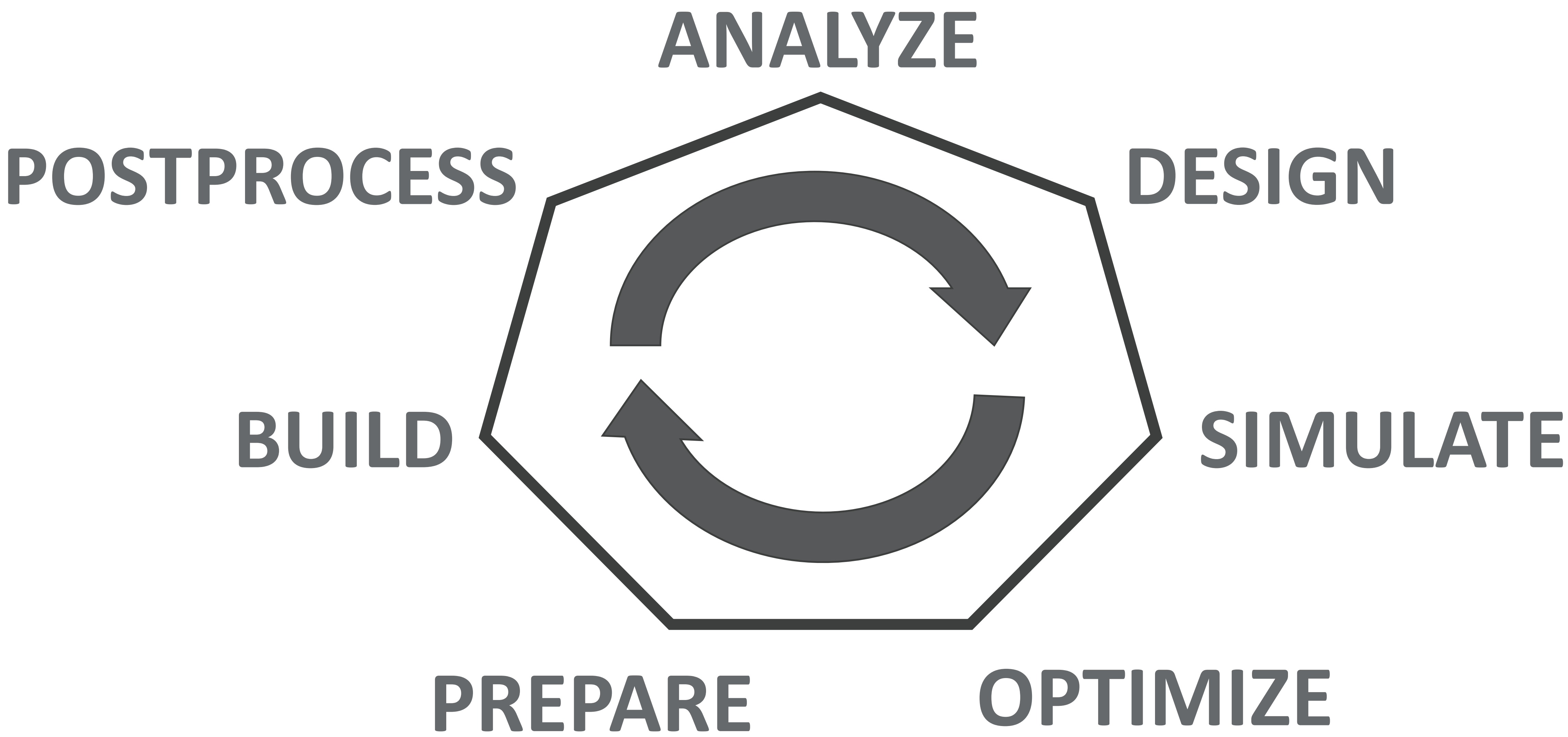
Photo Source: https://static.turbosquid.com/

Photo Source: https://images.fineartamerica.com/

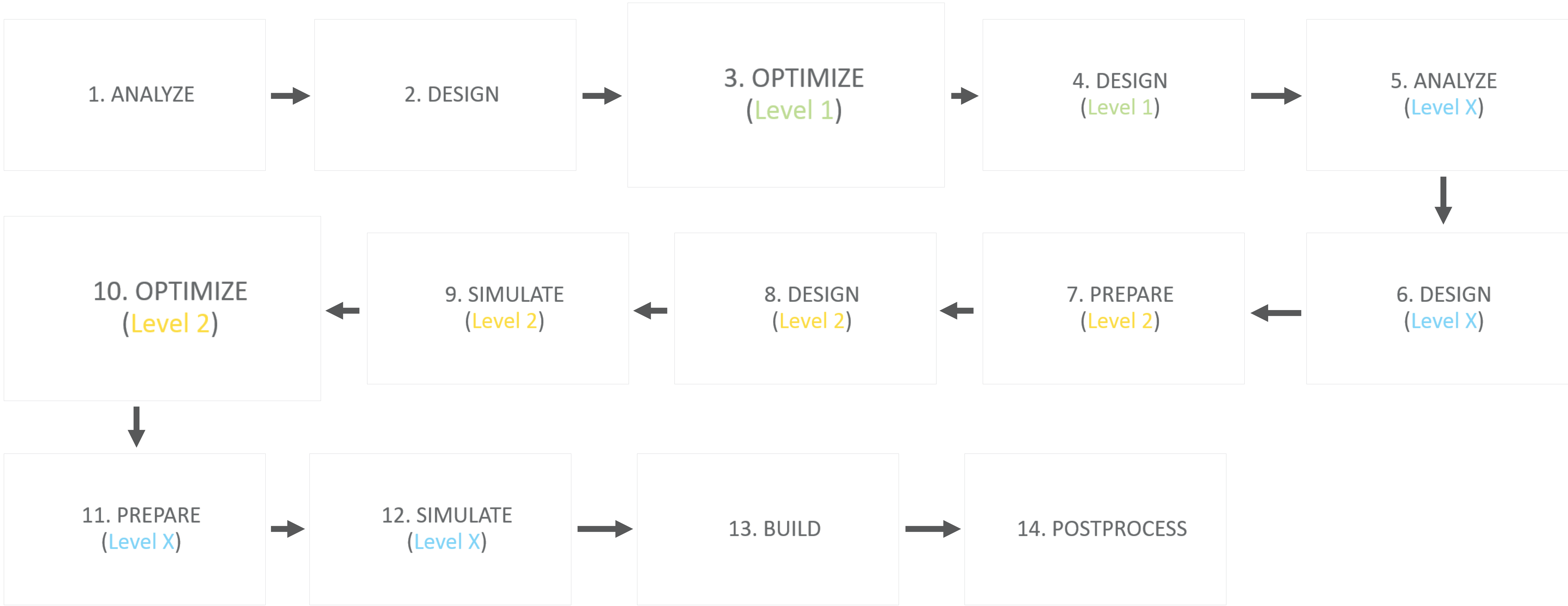


MAINPART - Hybrid design workflow

Seven points of AM product development
- A common workflow



Seven points of AM product development
- The actual workflow while designing the hanger



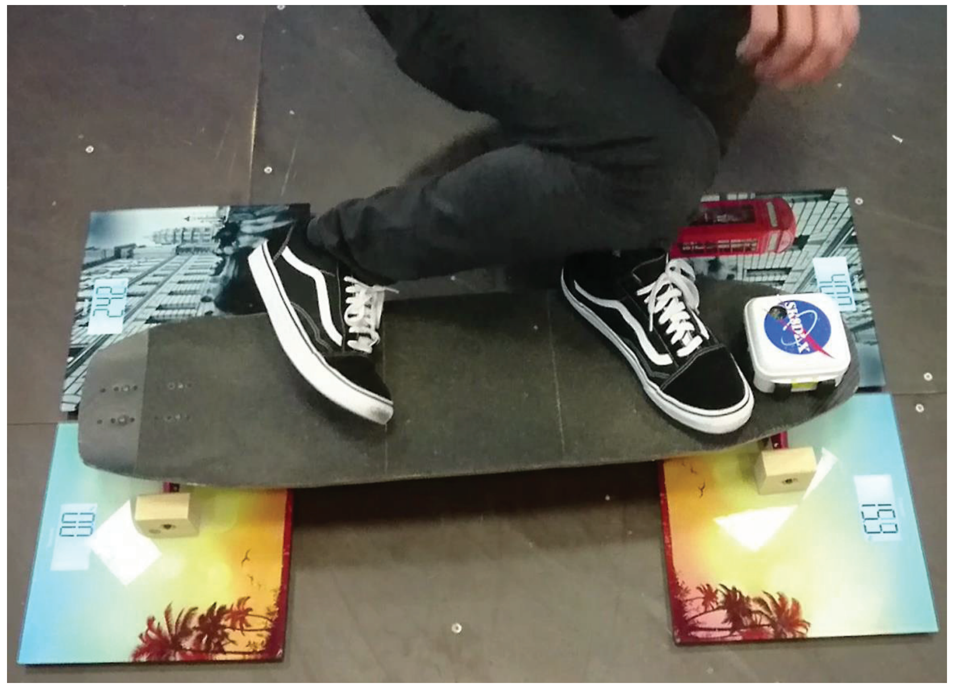
1. ANALYZE

ANALYZE – Collect the approaching load cases

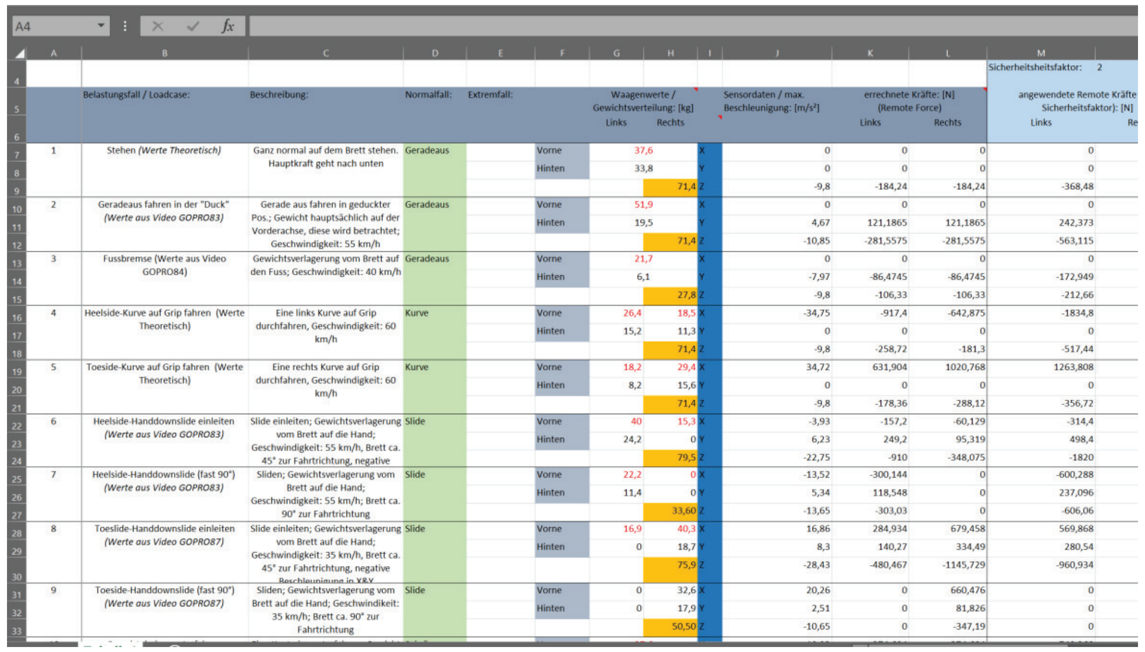
ANALYZE – Force determination for these load cases via a sensor box and weight distribution

a

m



F = m*a



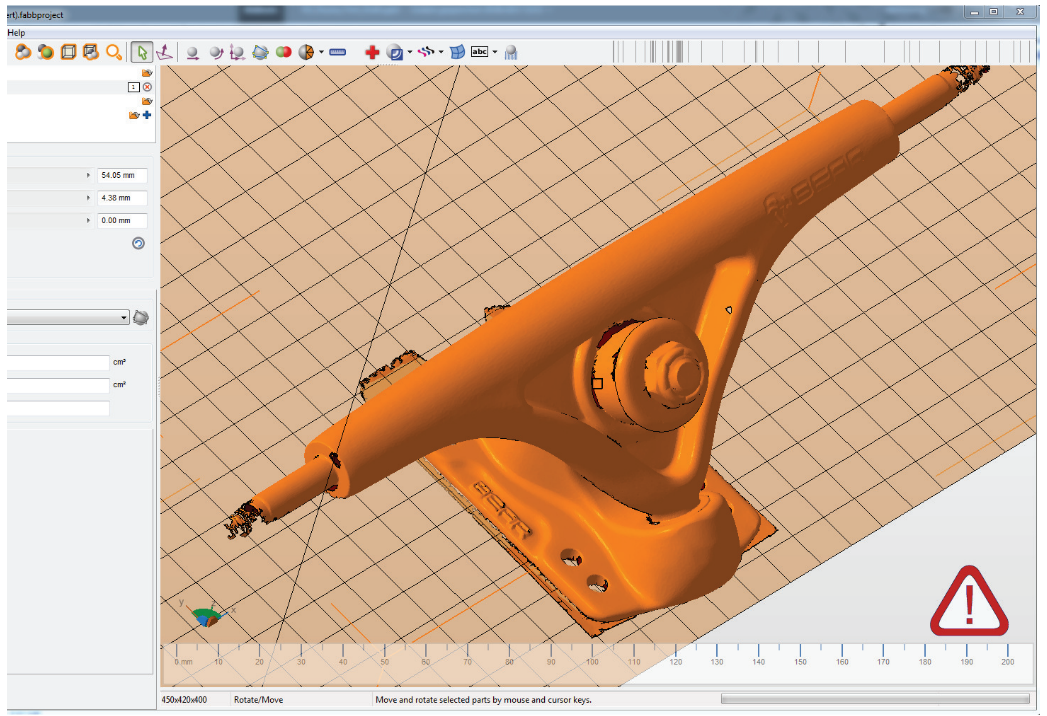
A	B	C	D	E	F	G	H	I	J	K	L	M
												Sicherheitsheitsfaktor: 2
	Belastungsfall / Loadcase:	Beschreibung:	Normalfall:	Extremfall:		Waagenwerte / Gewichtsverteilung: [kg] Links	Rechts		Sensordaten / max. Beschleunigung: [m/s²]	errechnete Kräfte: [N] (Remote Force) Links	Rechts	angewendete Remote Kräfte Sicherheitsfaktor): [N] Links
1	Stehen *(Werte Theoretisch)*	Ganz normal auf dem Brett stehen. Hauptkraft geht nach unten	Geradeaus		Vorne	37,6		X	0	0	0	0
					Hinten	33,8		Y	0	0	0	0
							71,4	Z	-9,8	-184,24	-184,24	-368,48
2	Geradeaus fahren in der "Duck" *(Werte aus Video GOPRO83)*	Gerade aus fahren in geduckter Pos.; Gewicht hauptsächlich auf der Vorderachse, diese wird betrachtet; Geschwindigkeit: 55 km/h	Geradeaus		Vorne	51,9		X	0	0	0	0
					Hinten	19,5		Y	4,67	121,1865	121,1865	242,373
							71,4	Z	-10,85	-281,5575	-281,5575	-563,115
3	Fussbremse (Werte aus Video GOPRO84)	Gewichtsverlagerung vom Brett auf den Fuss; Geschwindigkeit: 40 km/h	Geradeaus		Vorne	21,7		X	0	0	0	0
					Hinten	6,1		Y	-7,97	-86,4745	-86,4745	-172,949
							27,8	Z	-9,8	-106,33	-106,33	-212,66
4	Heelside-Kurve auf Grip fahren (Werte Theoretisch)	Eine links Kurve auf Grip durchfahren, Geschwindigkeit: 60 km/h	Kurve		Vorne	26,4	18,5	X	-34,75	-917,4	-642,875	-1834,8
					Hinten	15,2	11,3	Y	0	0	0	0
							71,4	Z	-9,8	-258,72	-181,3	-517,44
5	Toeside-Kurve auf Grip fahren (Werte Theoretisch)	Eine rechts Kurve auf Grip durchfahren, Geschwindigkeit: 60 km/h	Kurve		Vorne	18,2	29,4	X	34,72	631,904	1020,768	1263,808
					Hinten	8,2	15,6	Y	0	0	0	0
							71,4	Z	-9,8	-178,36	-288,12	-356,72
6	Heelside-Handdownslide einleiten *(Werte aus Video GOPRO83)*	Slide einleiten; Gewichtsverlagerung vom Brett auf die Hand; Geschwindigkeit: 55 km/h, Brett ca. 45° zur Fahrtrichtung, negative	Slide		Vorne	40	15,3	X	-3,93	-157,2	-60,129	-314,4
					Hinten	24,2	0	Y	6,23	249,2	95,319	498,4
							79,5	Z	-22,75	-910	-348,075	-1820
7	Heelside-Handdownslide (fast 90°) *(Werte aus Video GOPRO83)*	Sliden; Gewichtsverlagerung vom Brett auf die Hand; Geschwindigkeit: 55 km/h; Brett ca. 90° zur Fahrtrichtung	Slide		Vorne	22,2	0	X	-13,52	-300,144	0	-600,288
					Hinten	11,4	0	Y	5,34	118,548	0	237,096
							33,60	Z	-13,65	-303,03	0	-606,06
8	Toeslide-Handdownslide einleiten *(Werte aus Video GOPRO87)*	Slide einleiten; Gewichtsverlagerung vom Brett auf die Hand; Geschwindigkeit: 35 km/h, Brett ca. 45° zur Fahrtrichtung, negative	Slide		Vorne	16,9	40,3	X	16,86	284,934	679,458	569,868
					Hinten	0	18,7	Y	8,3	140,27	334,49	280,54
							75,9	Z	-28,43	-480,467	-1145,729	-960,934
9	Toeside-Handdownslide (fast 90°) *(Werte aus Video GOPRO87)*	Sliden; Gewichtsverlagerung vom Brett auf die Hand; Geschwindikeit: 35 km/h; Brett ca. 90° zur Fahrtrichtung	Slide		Vorne	0	32,6	X	20,26	0	660,476	0
					Hinten	0	17,9	Y	2,51	0	81,826	0
							50,50	Z	-10,65	0	-347,19	0

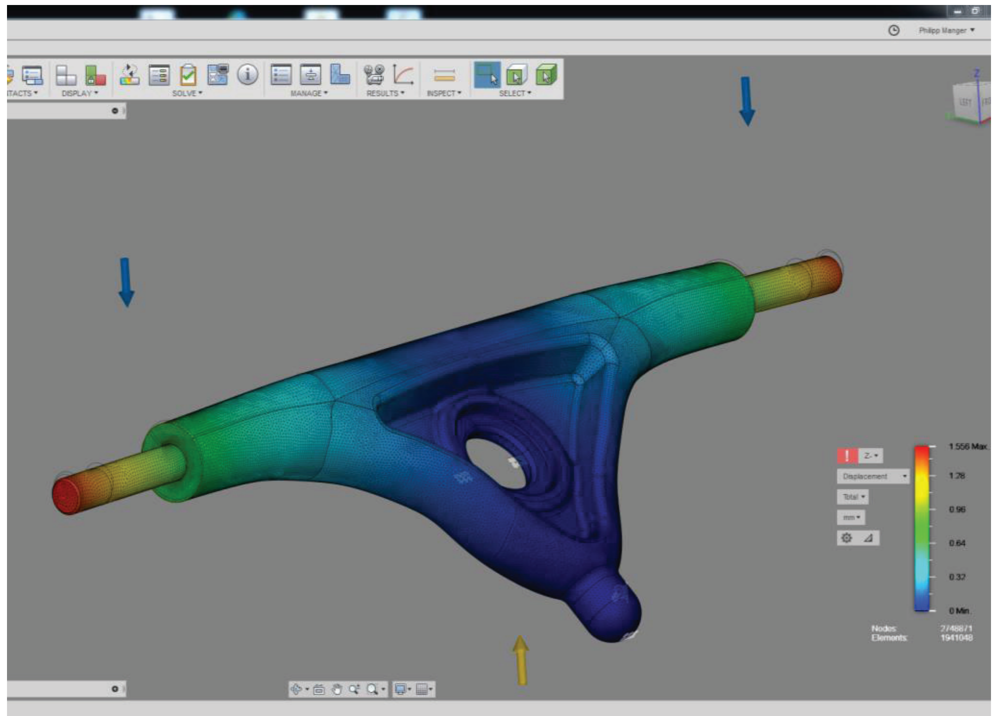
➢ This Data was used for the topology optimization

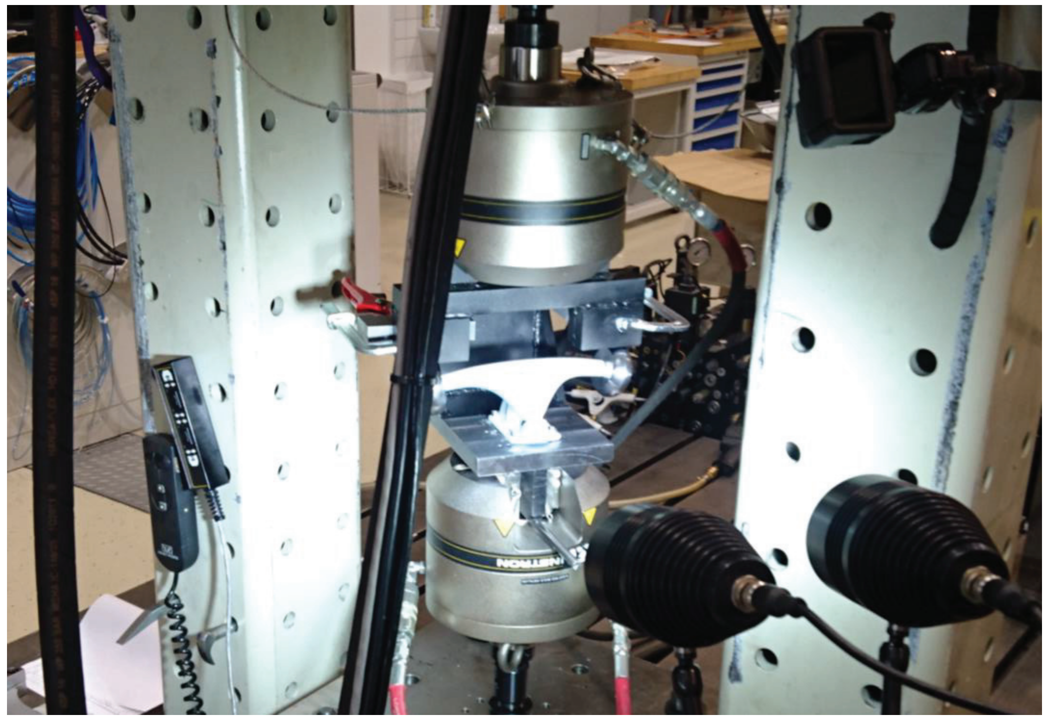

40
50
30
60
N
W
E
20
70
S
103°
10
0
57
KPH
0.1 G
SPEED TRACKER

ANALYZE – Comparison to currently available trucks through 3D Scans and experimental tests

- As benchmark a conventionally manufactured truck was chosen.



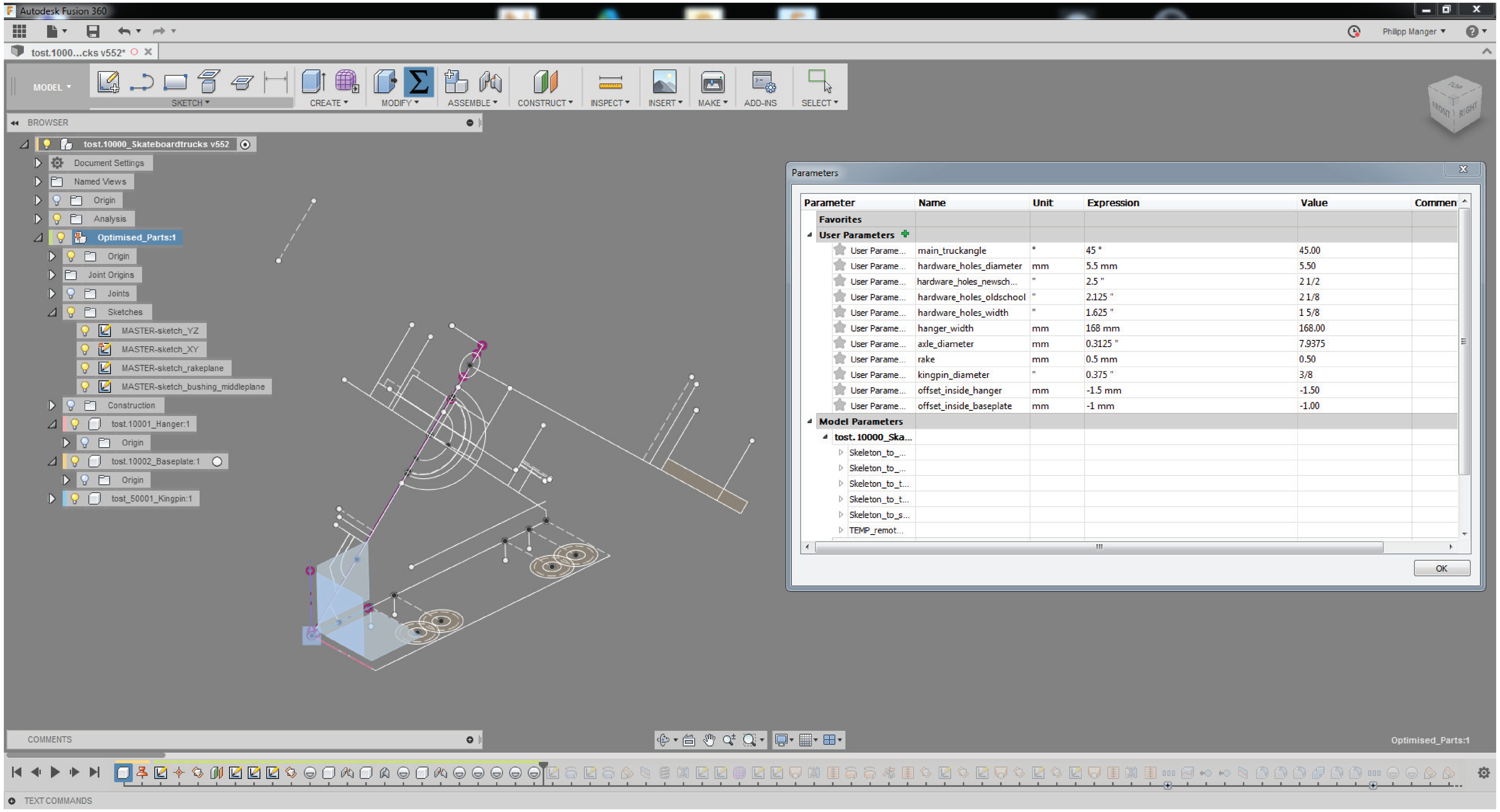




- <u>This Data was used to check the overall stiffness after the creation of the lattice</u>

2. DESIGN

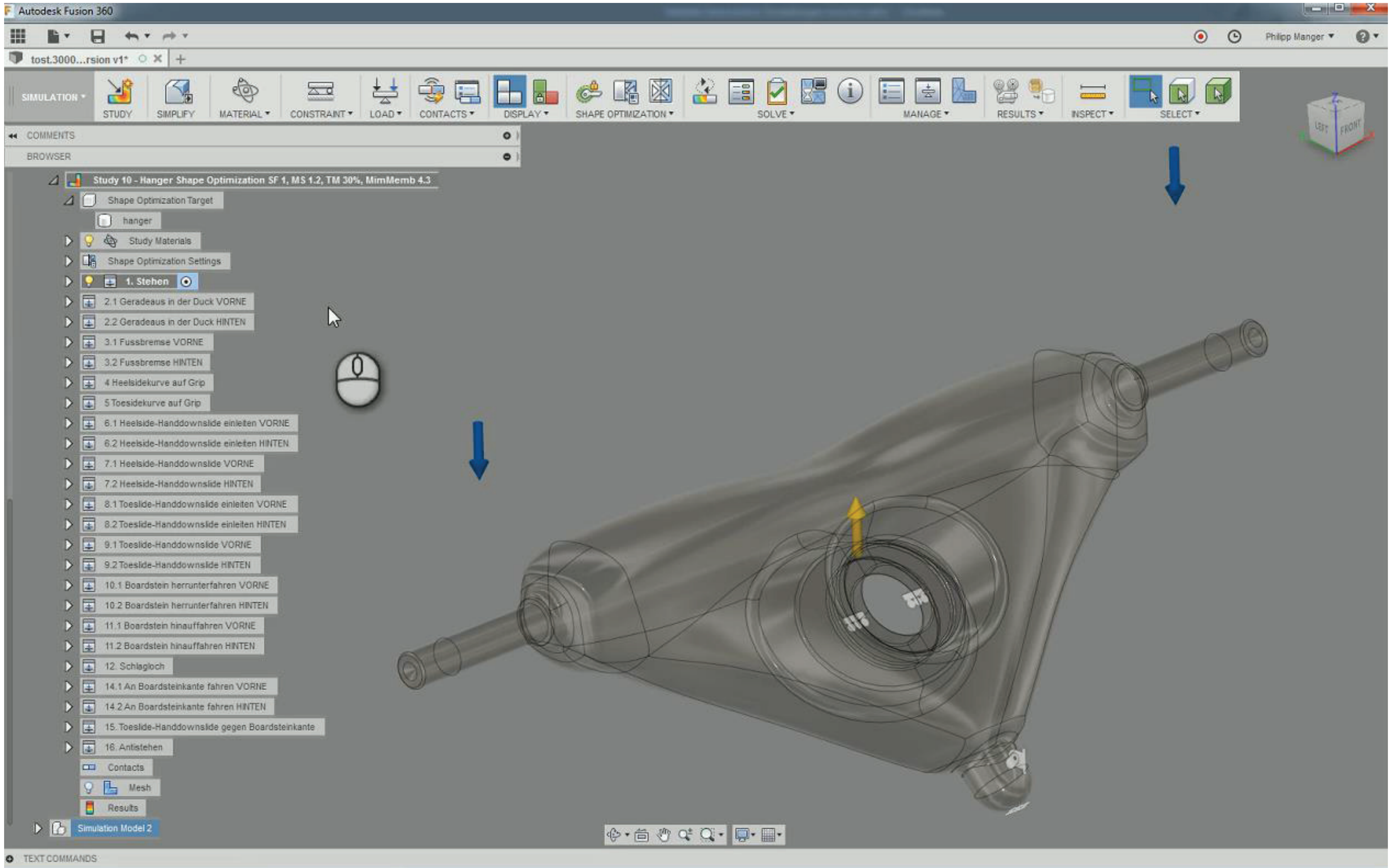
DESIGN – Creating a parametric geometry & design space / Start for the topology optimization



3. OPTIMIZE
(Level 1)

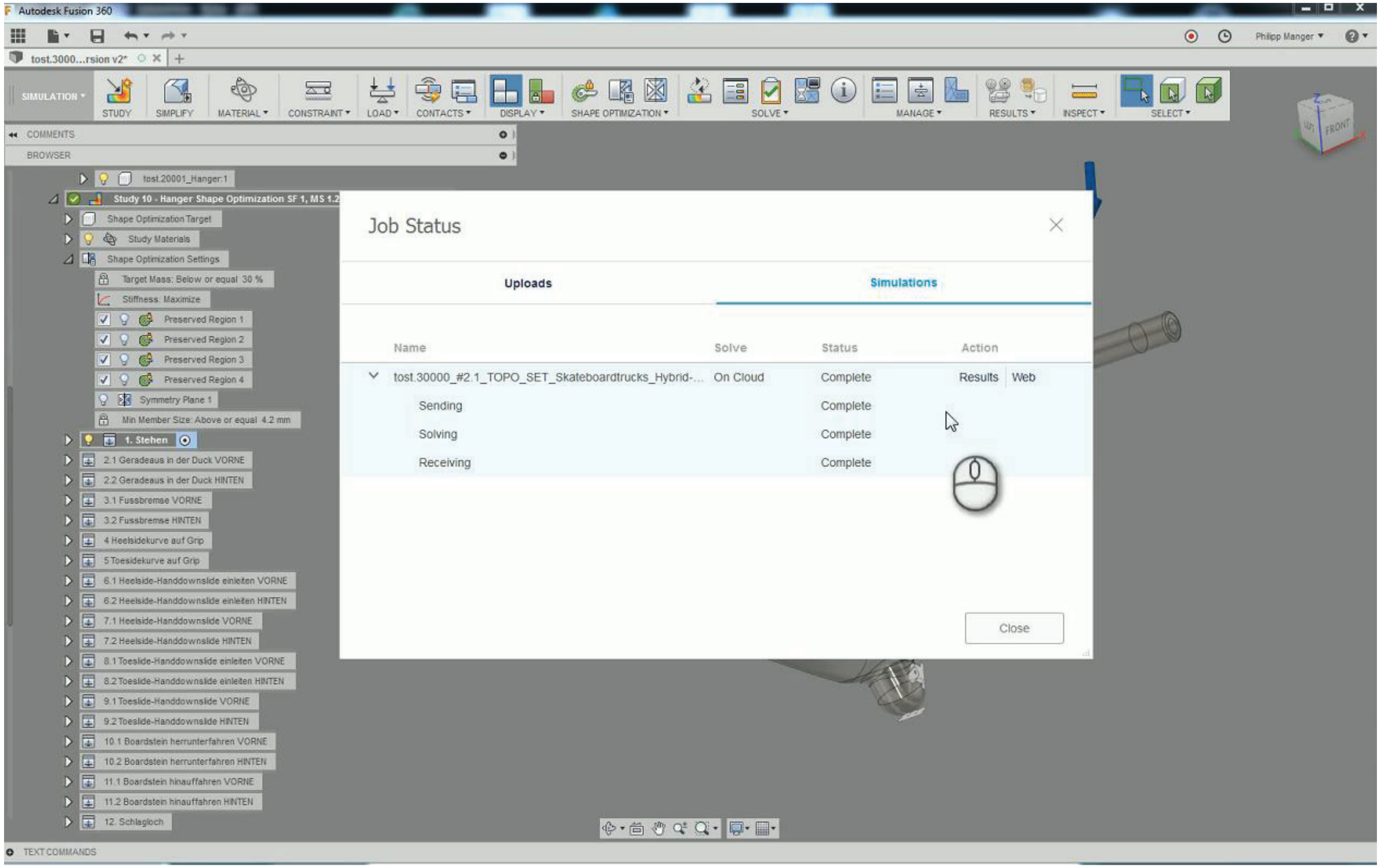
OPTIMIZE – Set up a shape optimization study from the collected load cases / Use of cloud solving

LEVEL 1



OPTIMIZE – Promote result from the shape optimization study

LEVEL 1

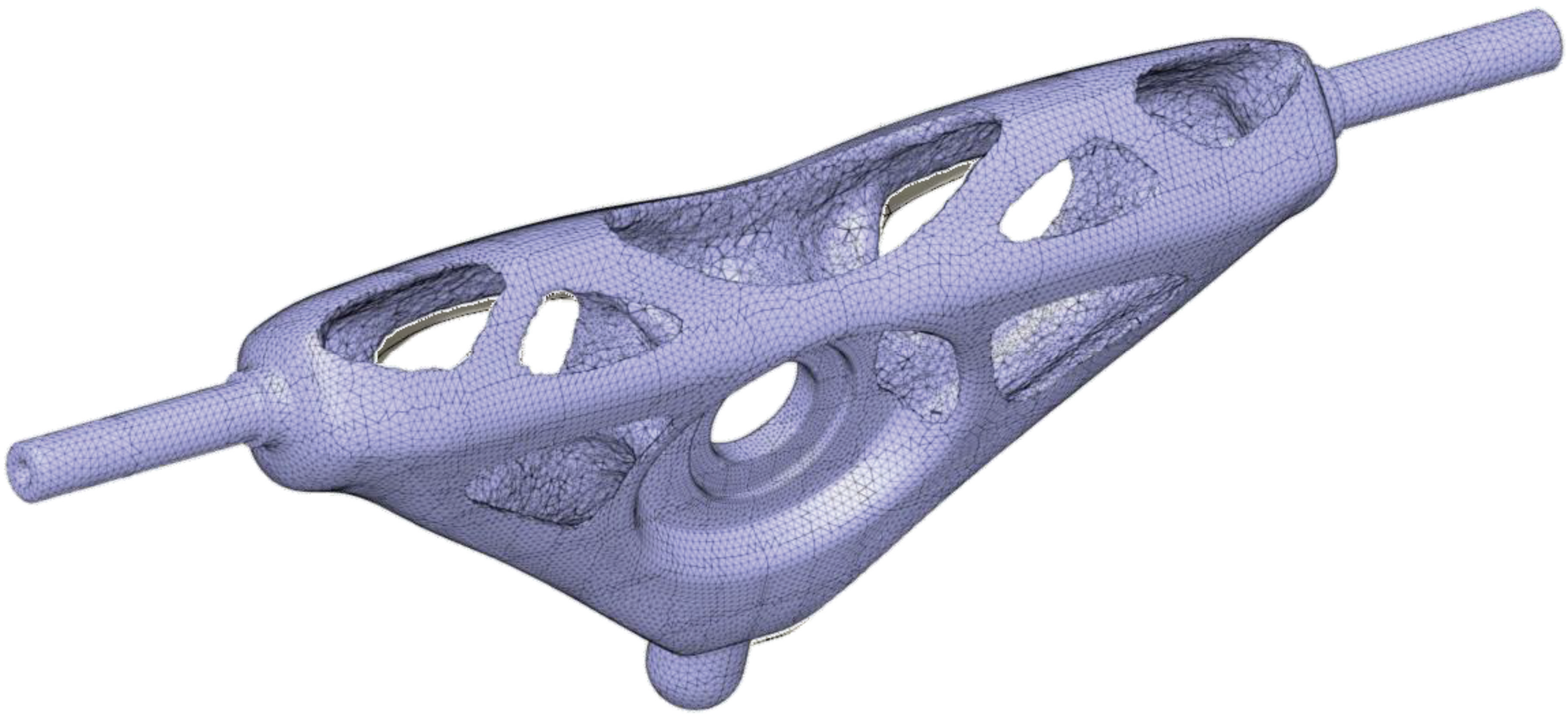


4. DESIGN

(Level 1)

DESIGN – Modifying the body according the result of the topology optimization

LEVEL 1



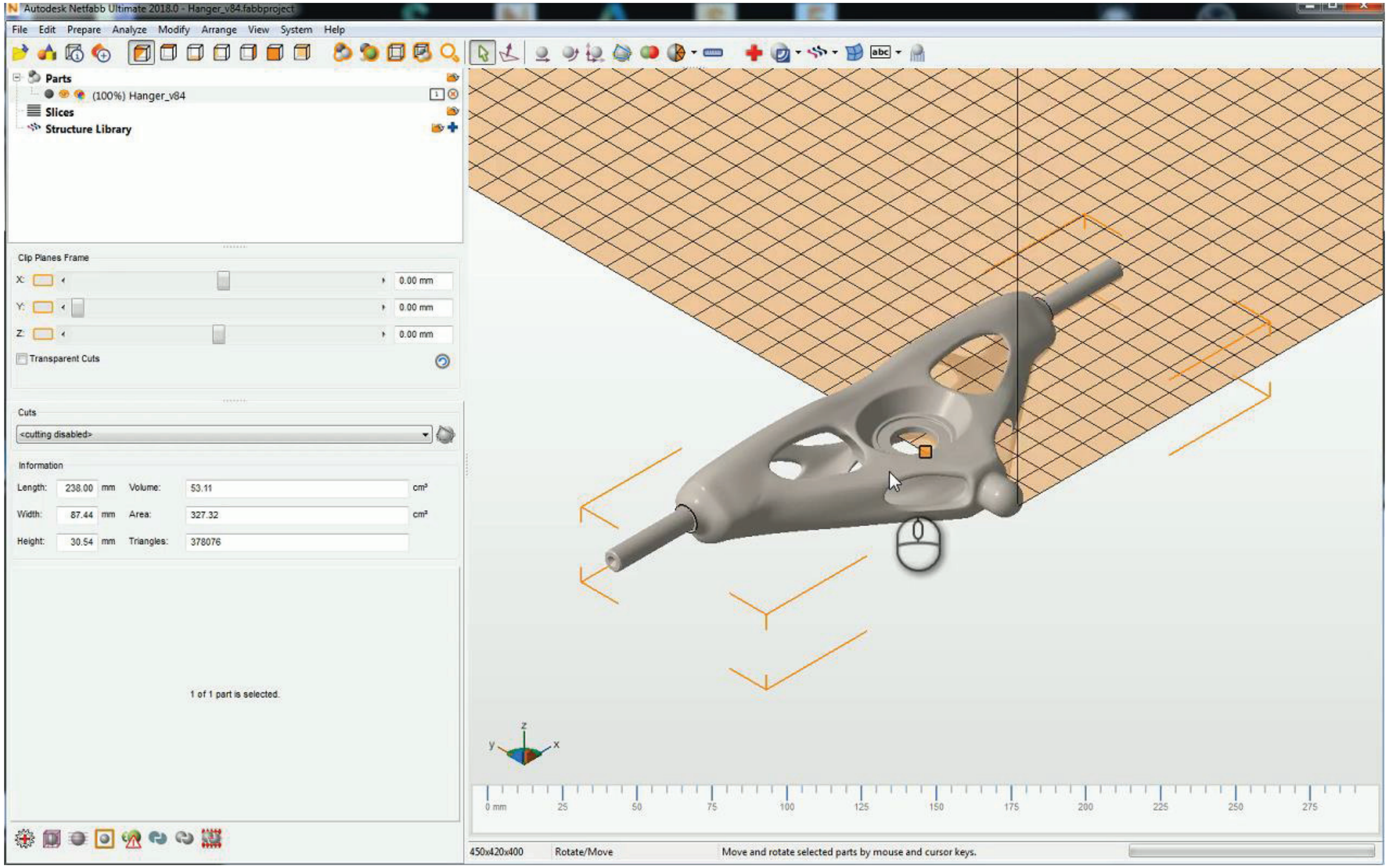
➢ Volume = Weight reduction about 65-70% compared to solid

5. ANALYZE

(Level X)

ANALYZE – Checking for the best build direction for the build process via LBM

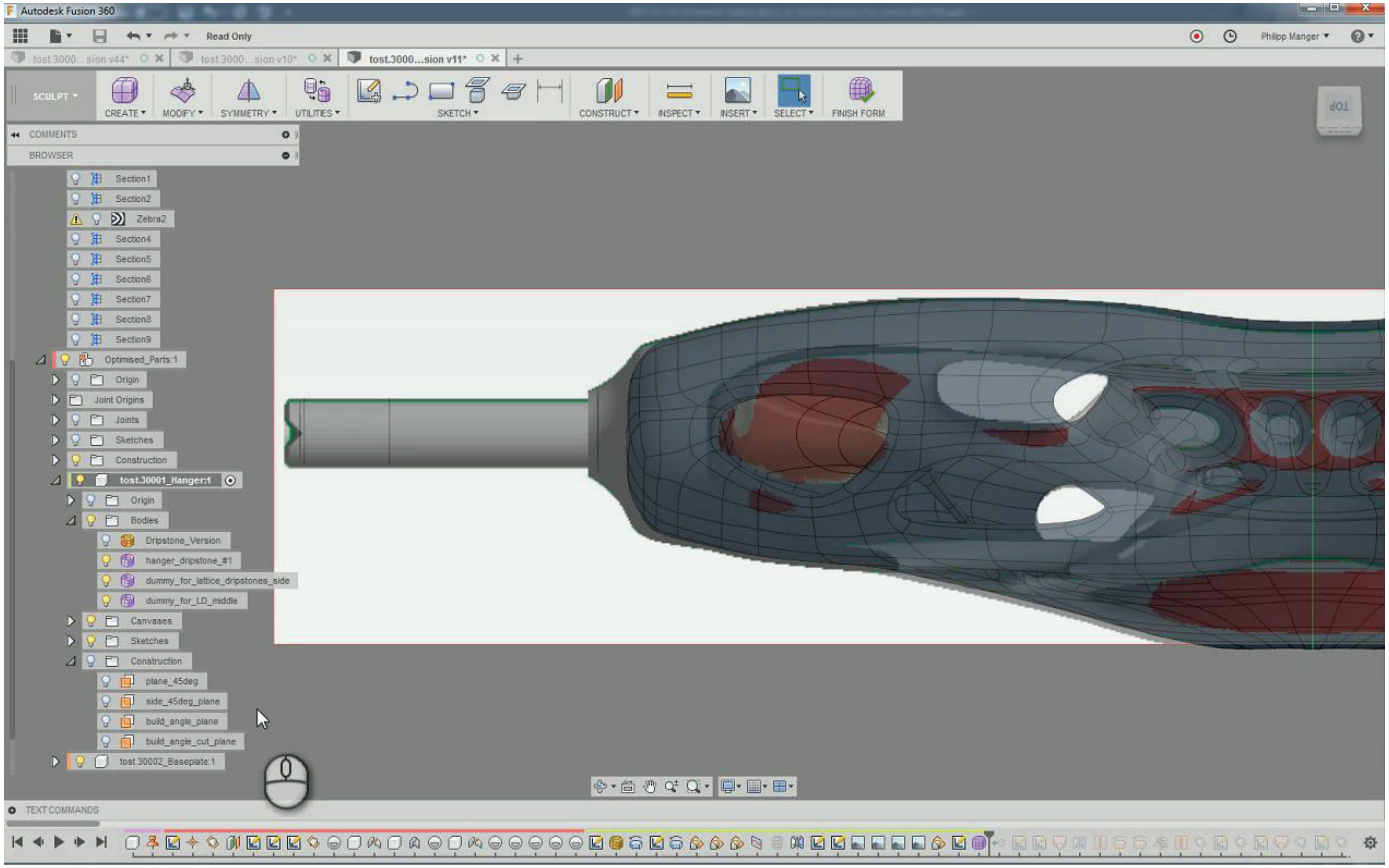
LEVEL X



6. DESIGN
(Level X)

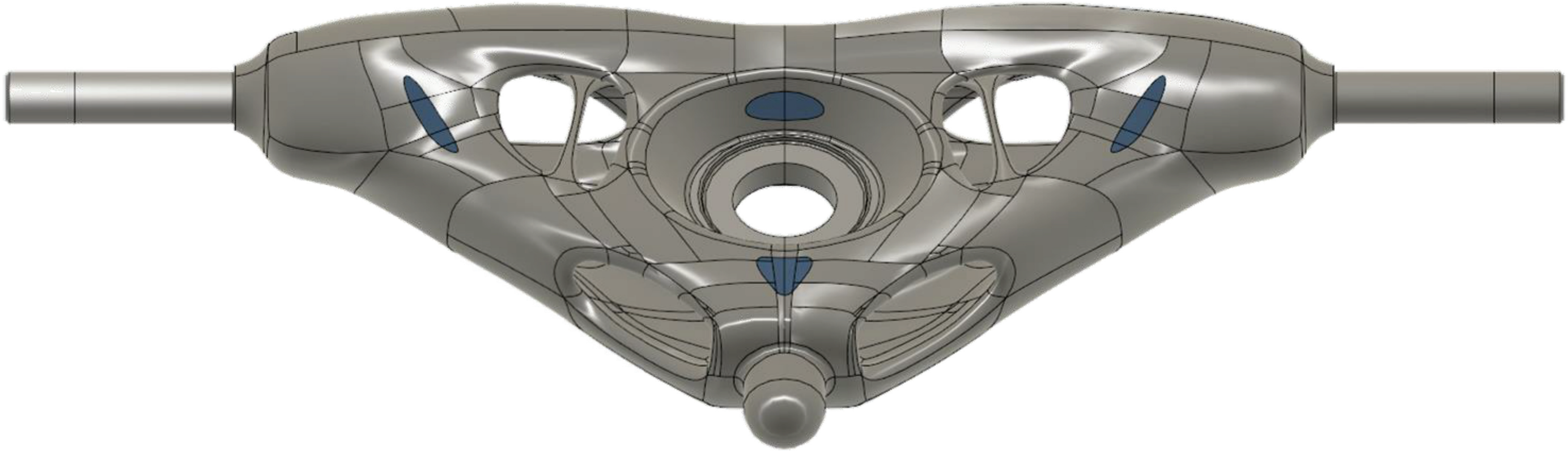
DESIGN – Reducing the necessary build support / Creating “dripstones” and “lattice dripstones”

LEVEL X



DESIGN – Preparing part for optimization via lattice structures / Creating inside / Adding shell openings

LEVEL X

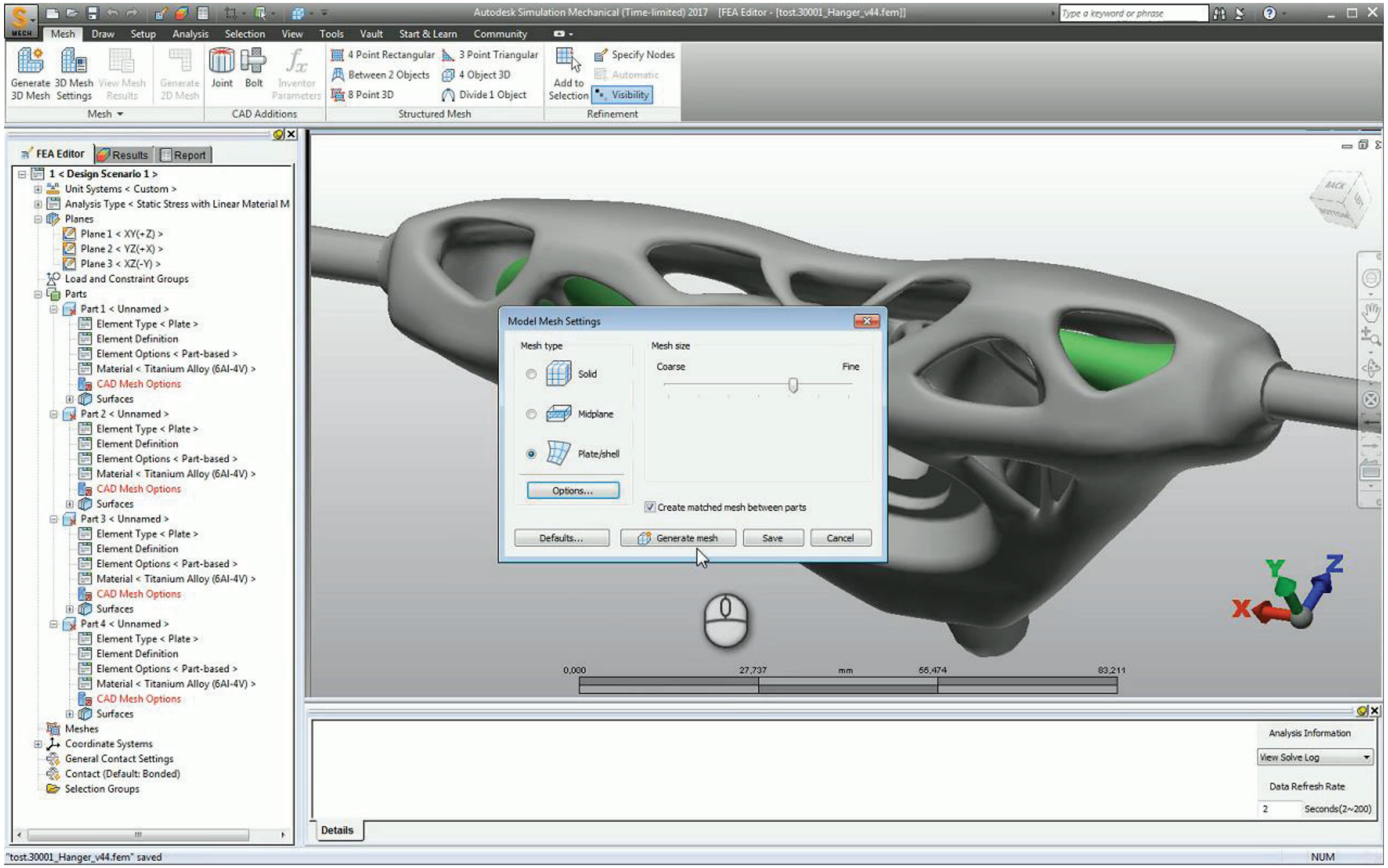


7. PREPARE

(Level 2)

PREPARE – Meshing the part for a FEA suitable mesh using Autodesk Simulation Mechanical

LEVEL 2

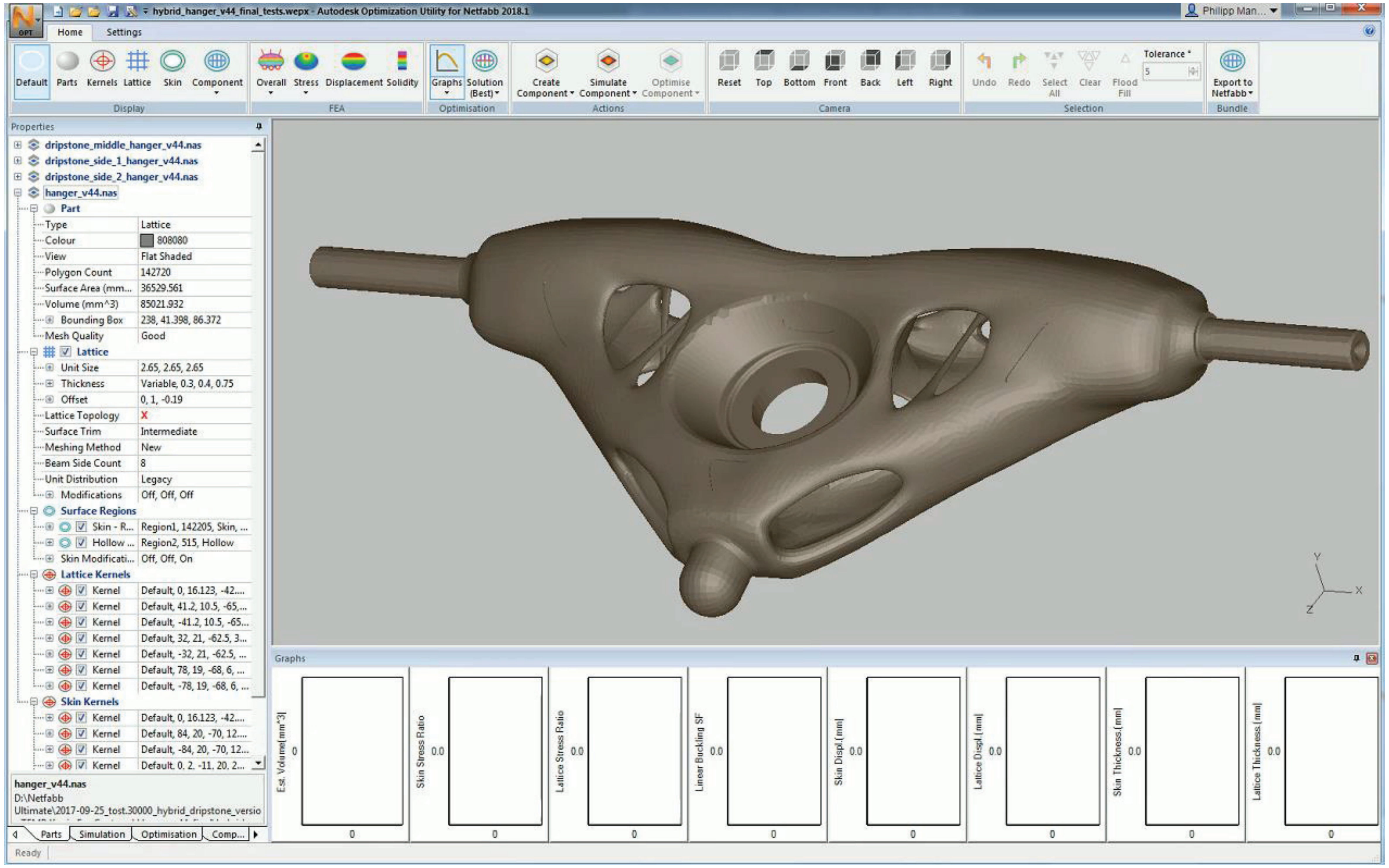


8. DESIGN

(Level 2)

DESIGN - Setting the options for the lattice generation / defining skin surfaces / Modifying lattice

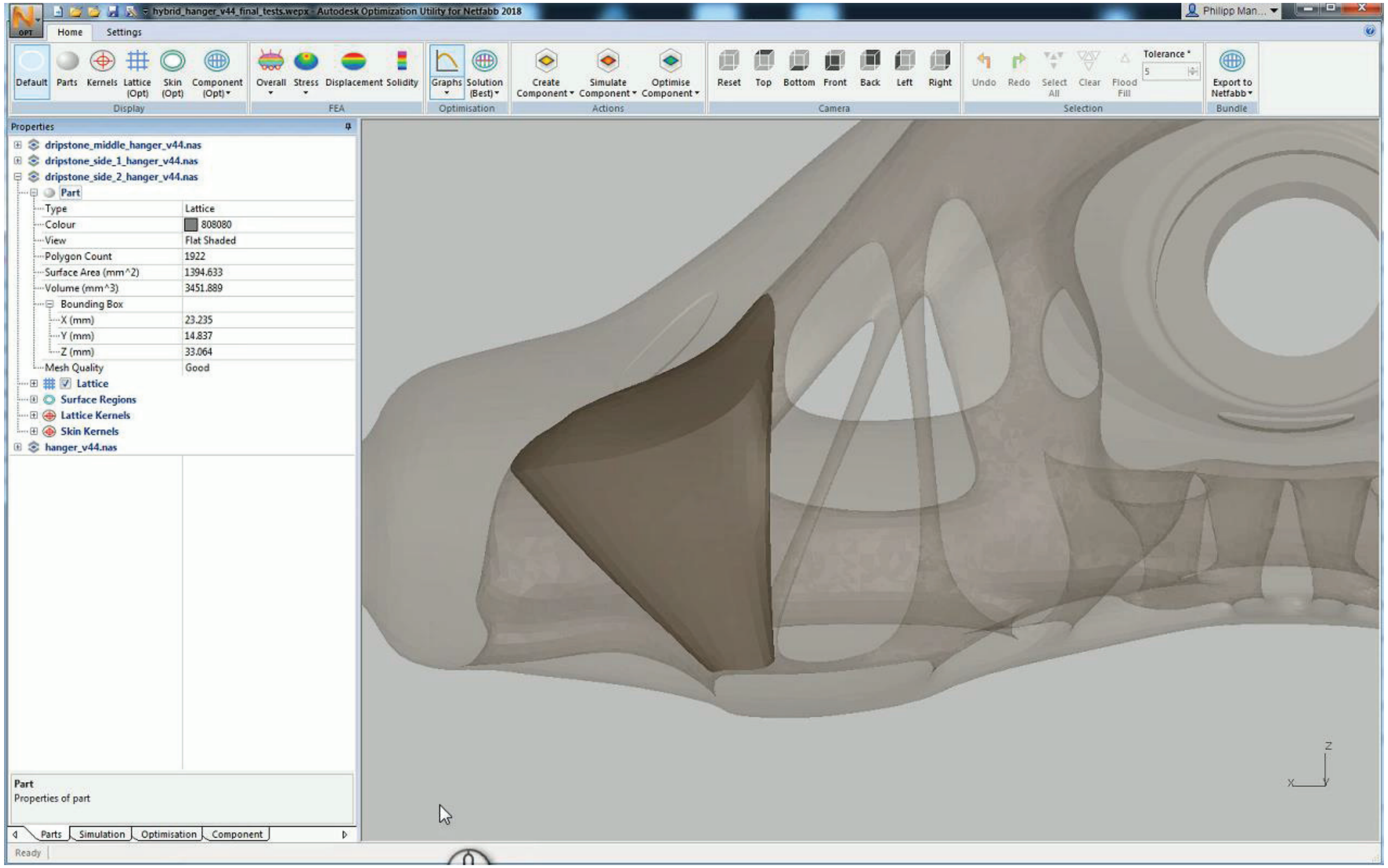
LEVEL 2



- Volume reduction about 60% to solid organic form

DESIGN – Generating lattice dripstones for lightweight build support minimization on NO-tool access areas

LEVEL 2

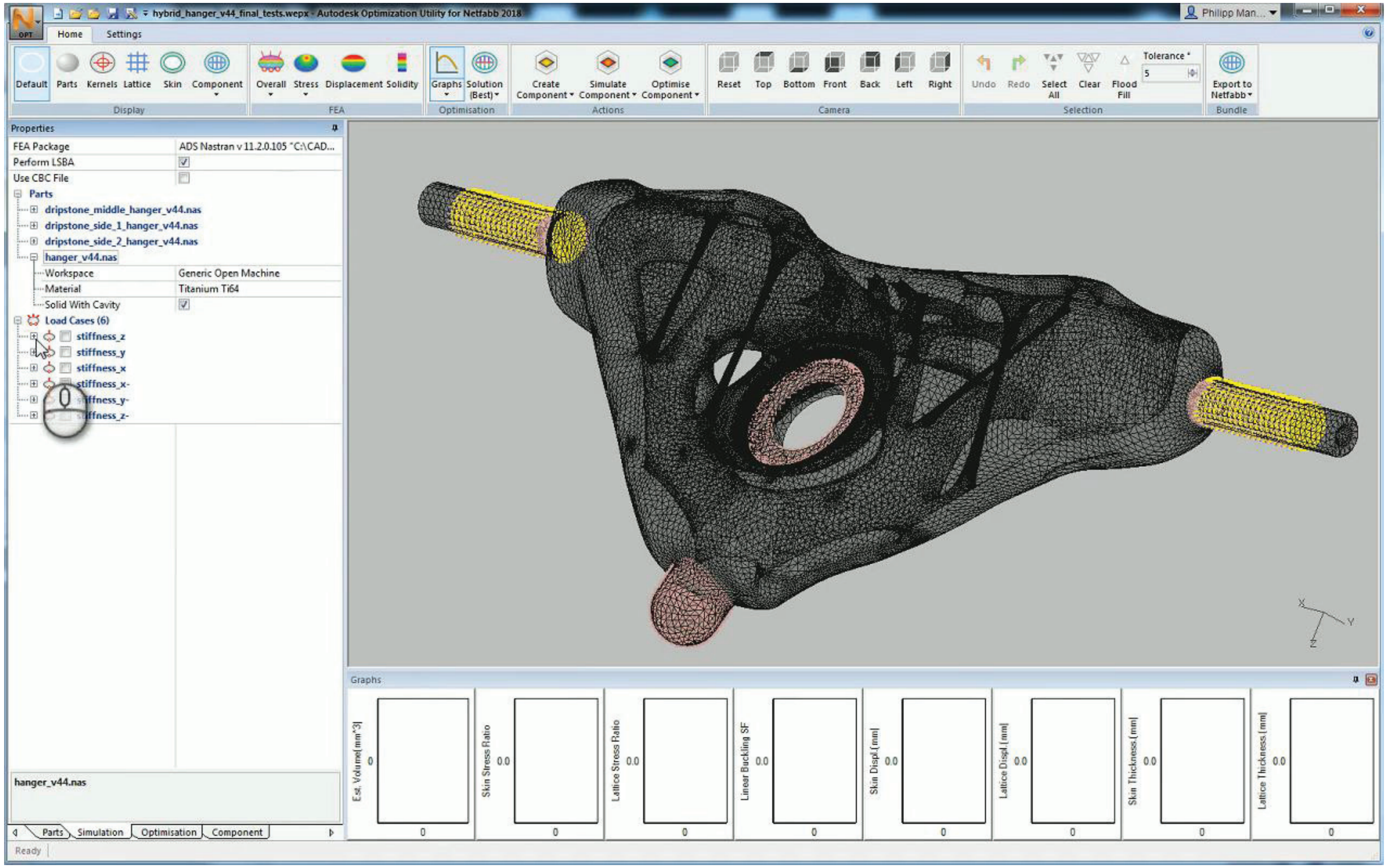


9. SIMULATE

(Level 2)

SIMULATE - Setting up the loads for the FEA of the lattice and then for optimization

LEVEL 2

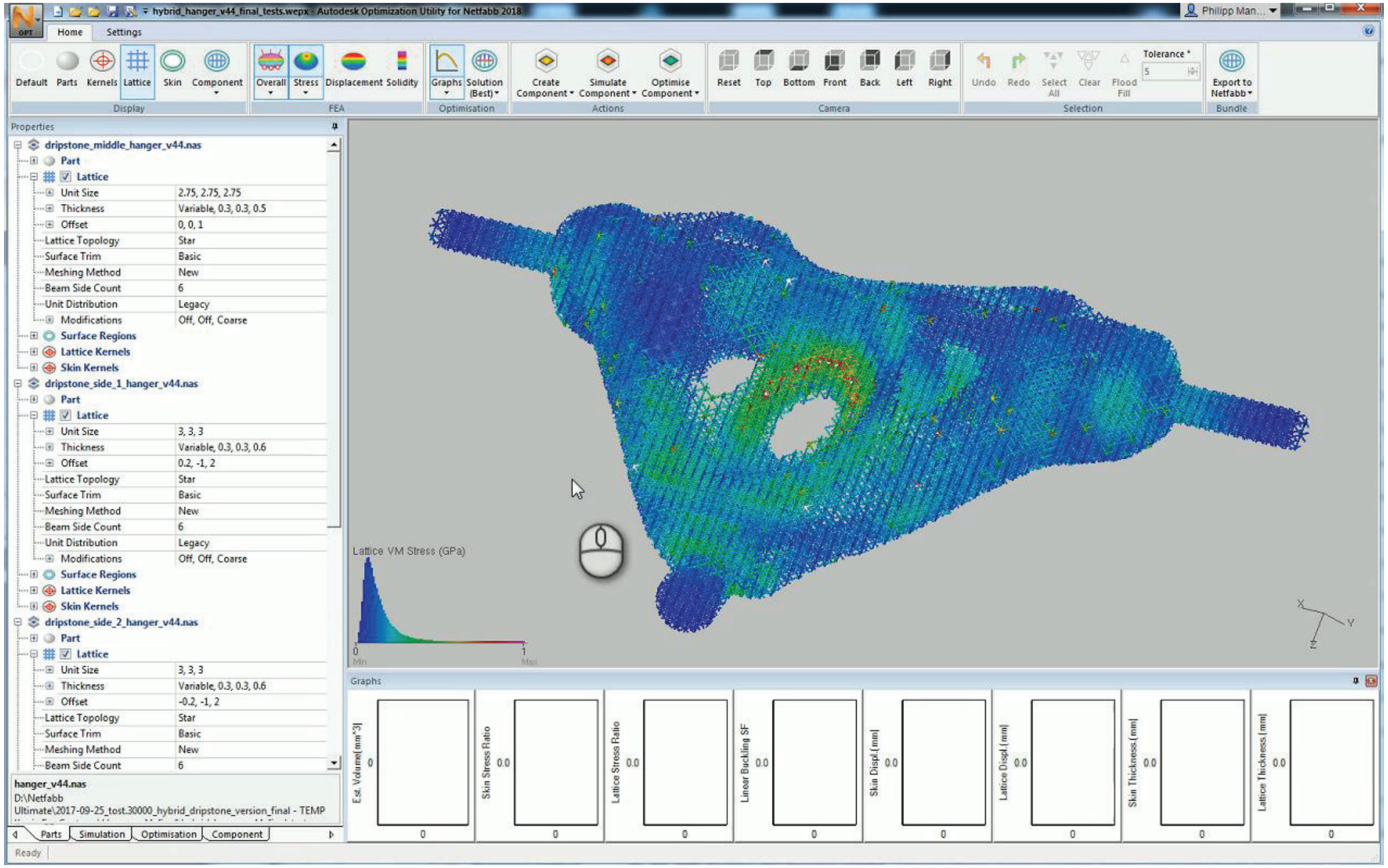


10. OPTIMIZE

(Level 2)

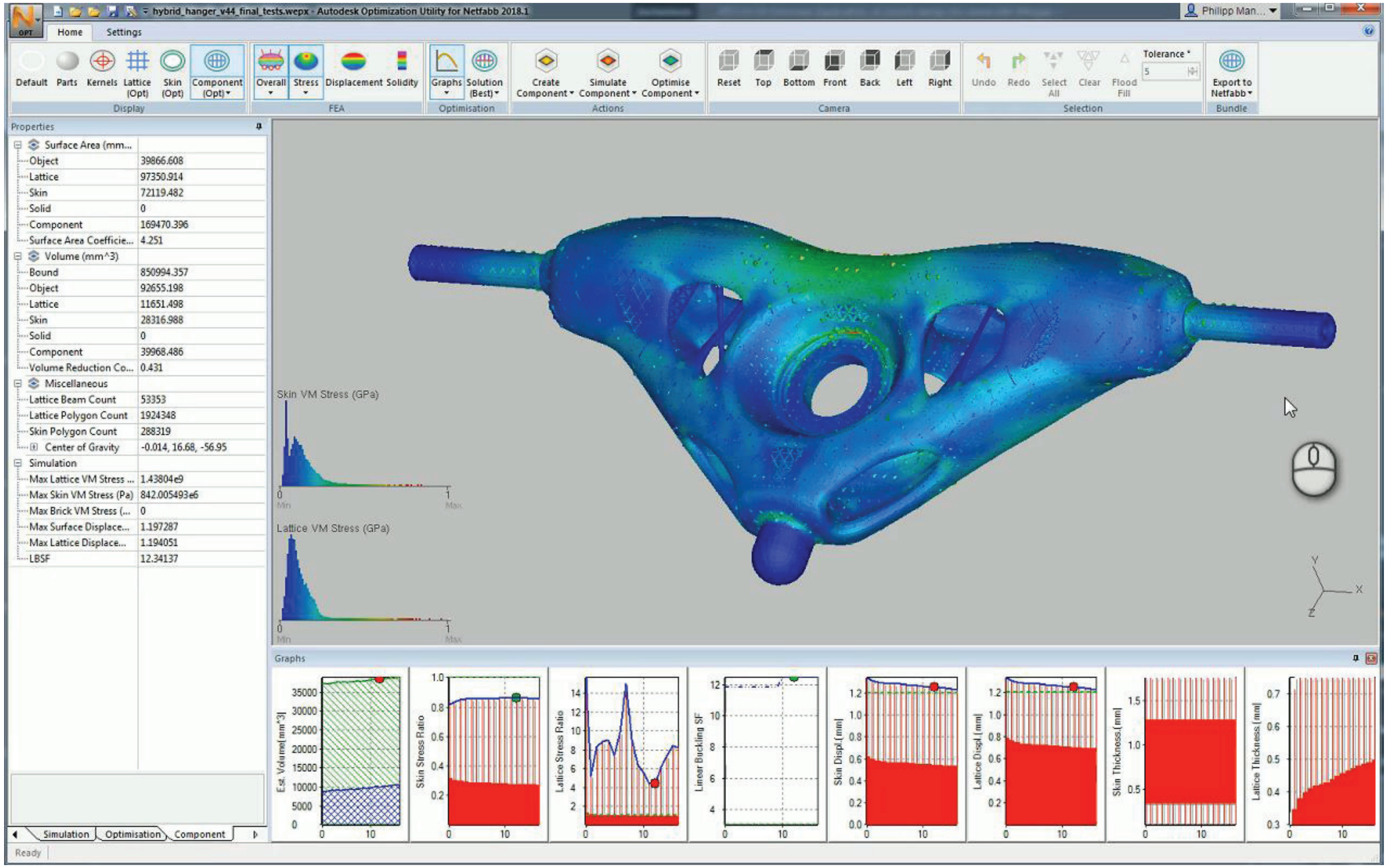
OPTIMIZE – Defining lattice optimization criteria / Starting with the iterations

LEVEL 2



OPTIMIZE – Final optimization result / Export lattice to Netfabb Ultimate for further process

LEVEL 2



Before:

1,34 mm

max. displ.

1431 MPa

max. stress

After:

\+ 3% volume

1,20 mm

max. displ.

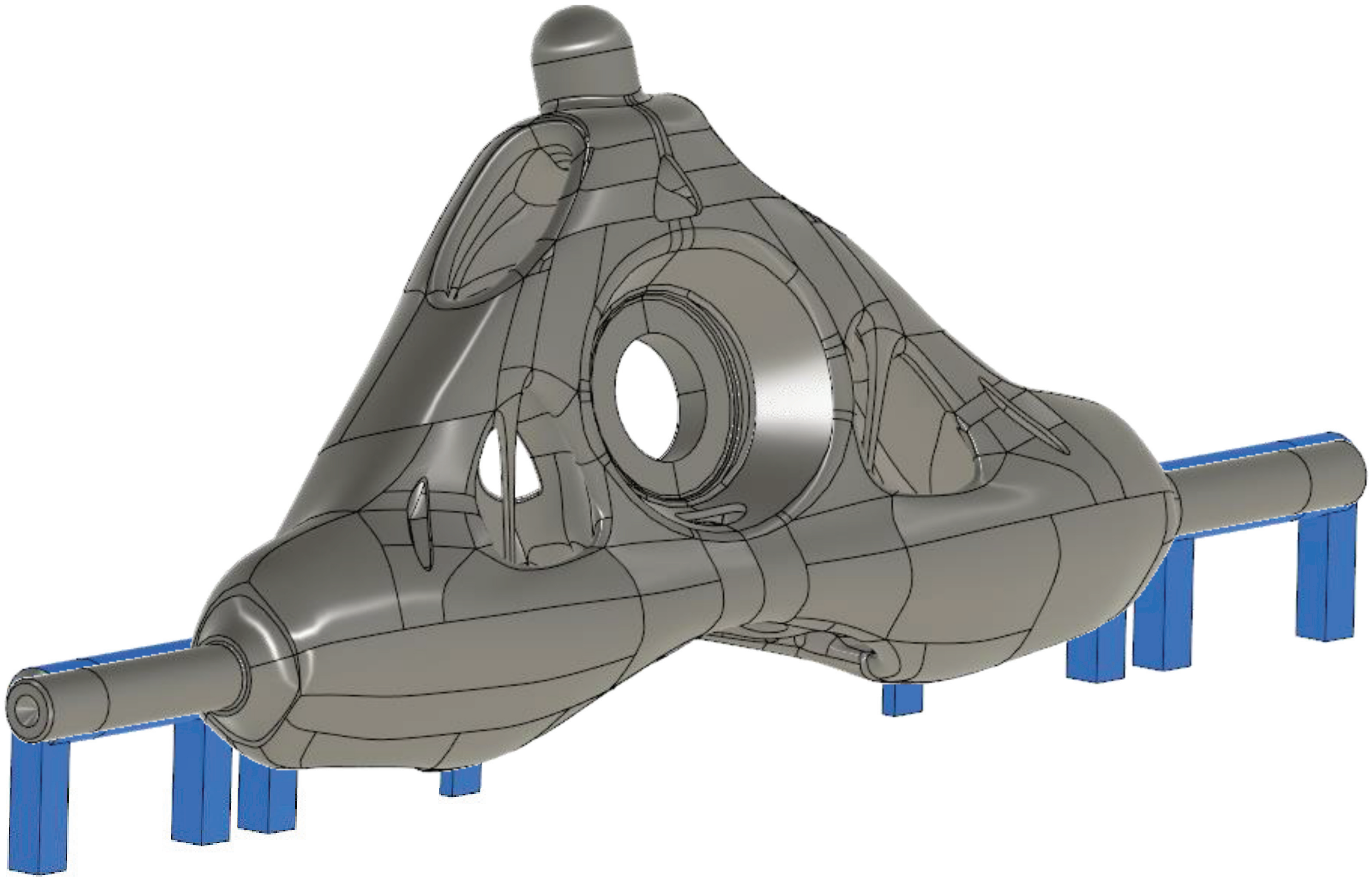
976 MPa

max. stress

11. PREPARE
(Level X)

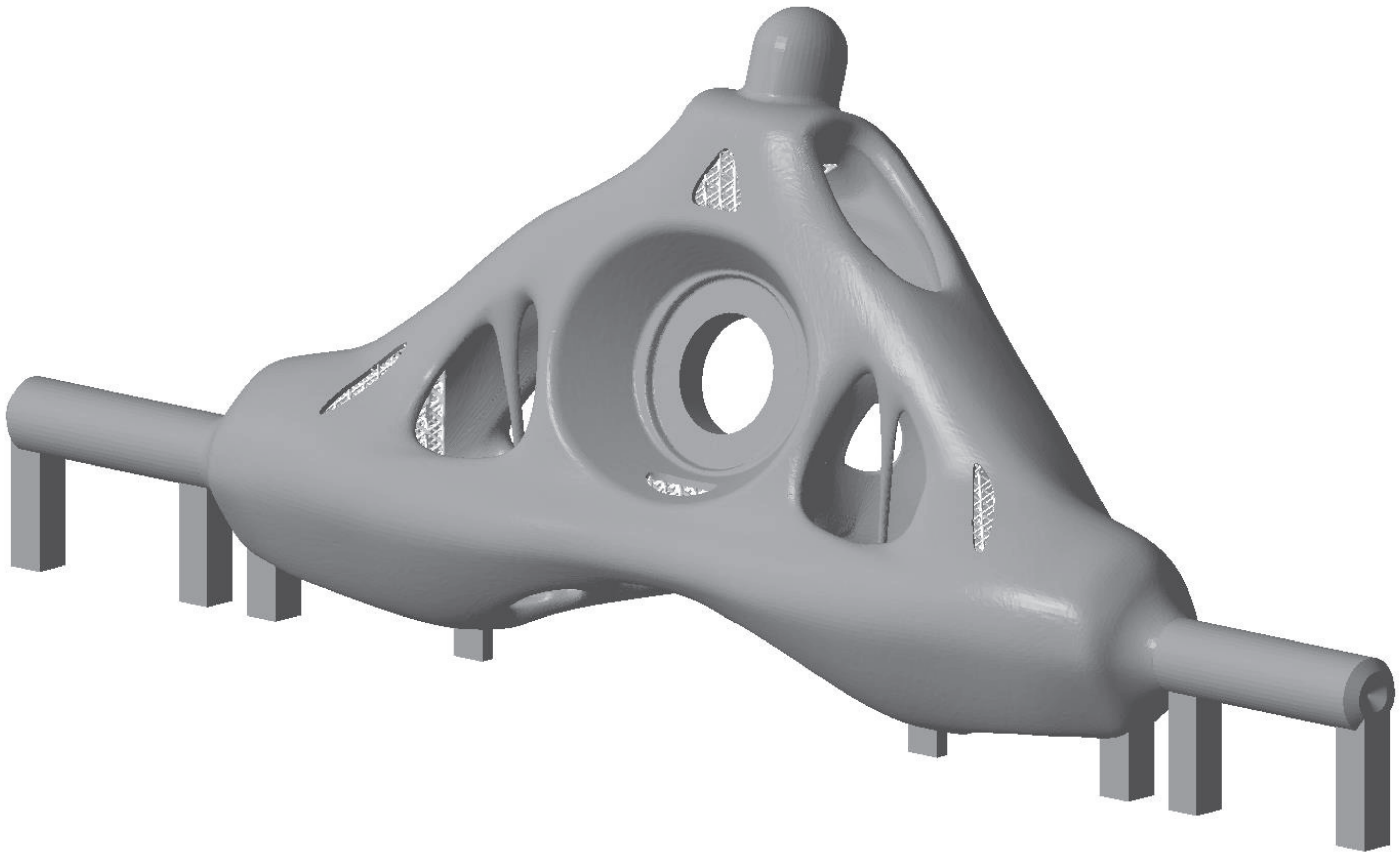
PREPARE – Shell preparation for the build process in Fusion 360 / adding tooling clearance

LEVEL X



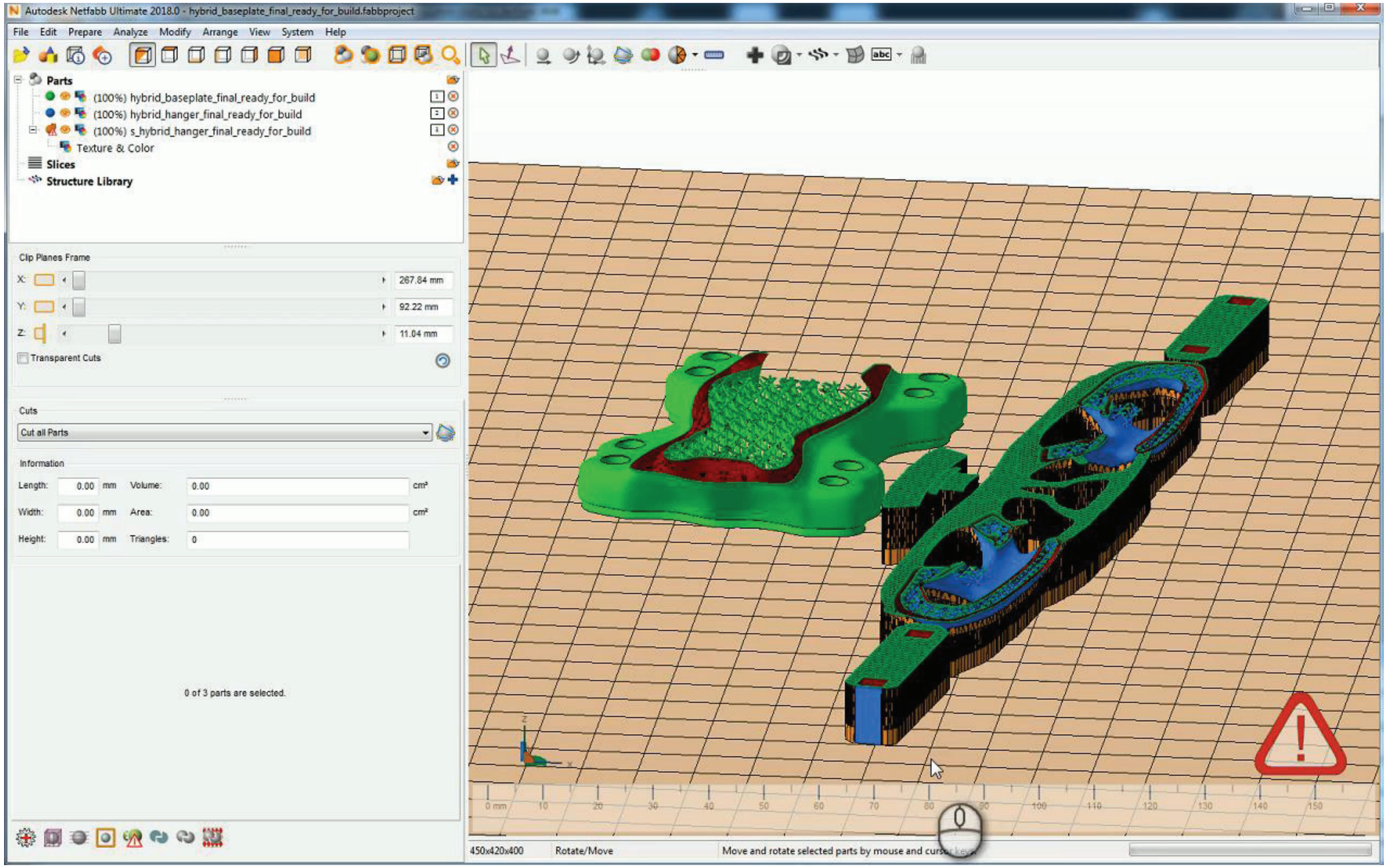
PREPARE – Final combining the shell, optimized lattice and lattice dripstones for the build process

LEVEL X



PREPARE – Final preparation for the build process / Support generating

LEVEL X

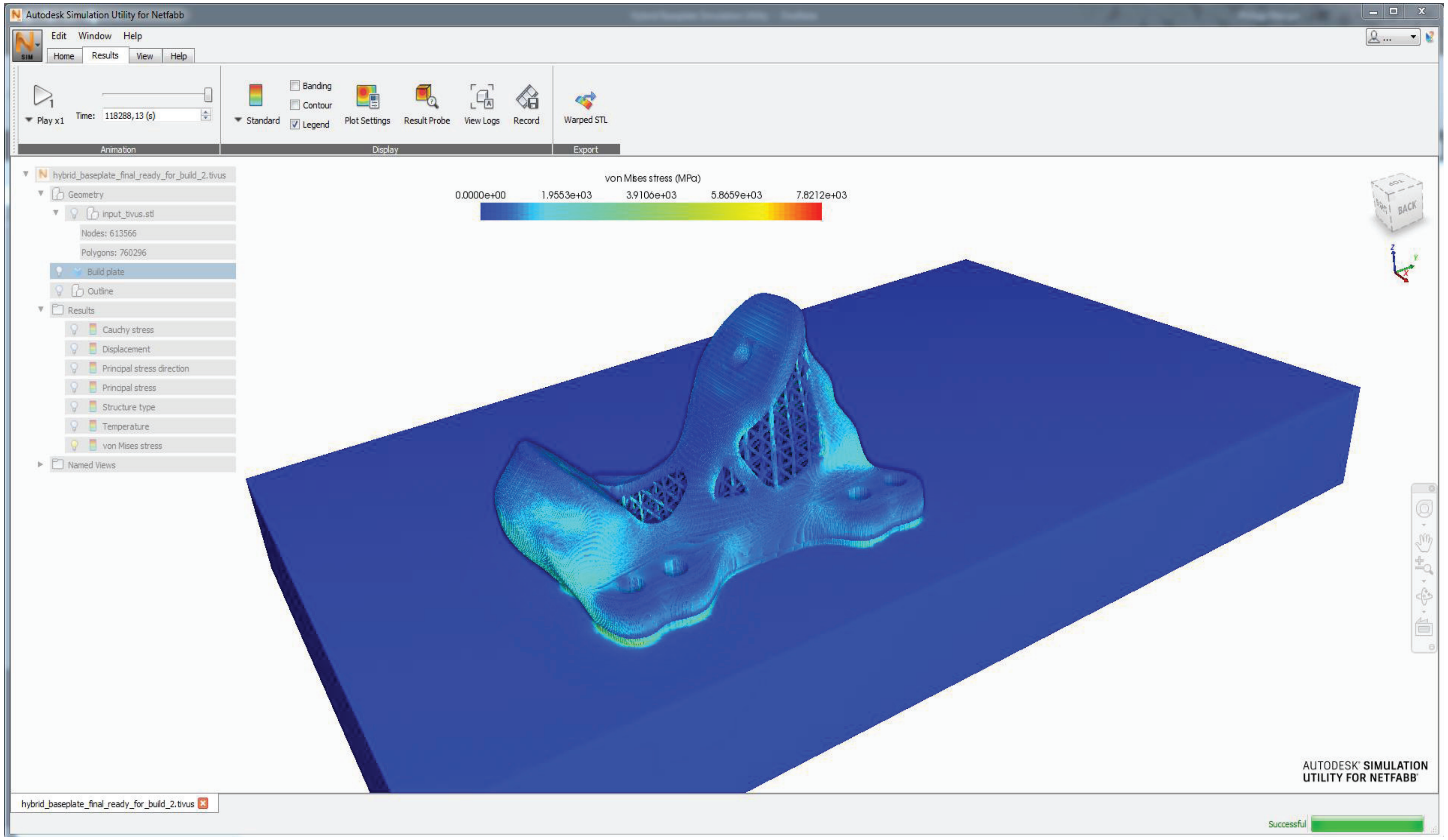


12. SIMULATE

(Level X)

SIMULATE - Simulation of the build process using Netfabb Simulation Utility

LEVEL X



13. BUILD

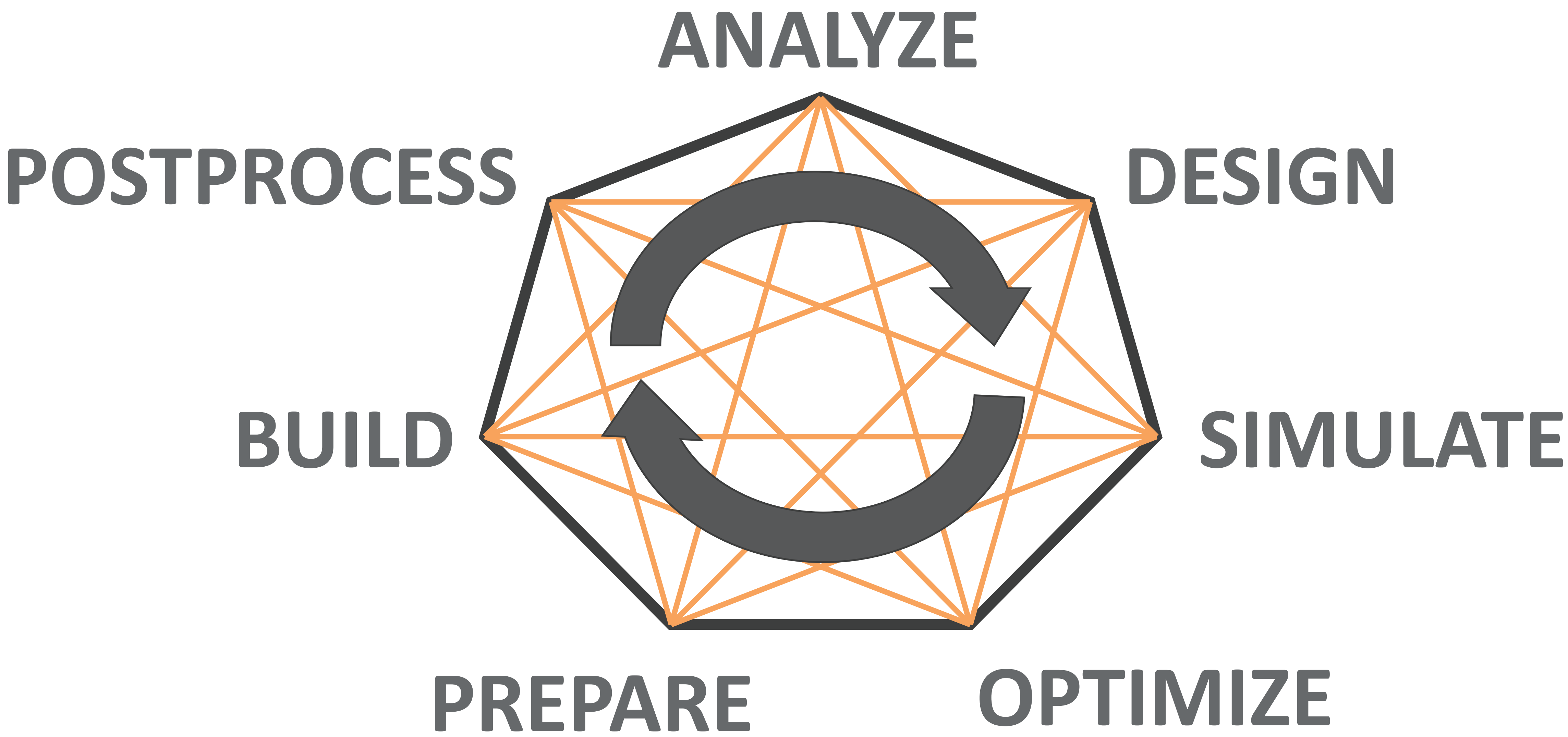
14. POSTPROCESS

POSTPROCESS - Heat treatment of the parts / removing from build plate and support structure

1. heat treatment under vacuum atmosphere
   - reduce the residual stress in the parts
   - increase the elongation at break (~ 14% instead of ~ 6% as build)
2. removal from the build plate with wire EDM
3. manual removal of remaining support
4. CNC Turning of the hanger axel ends

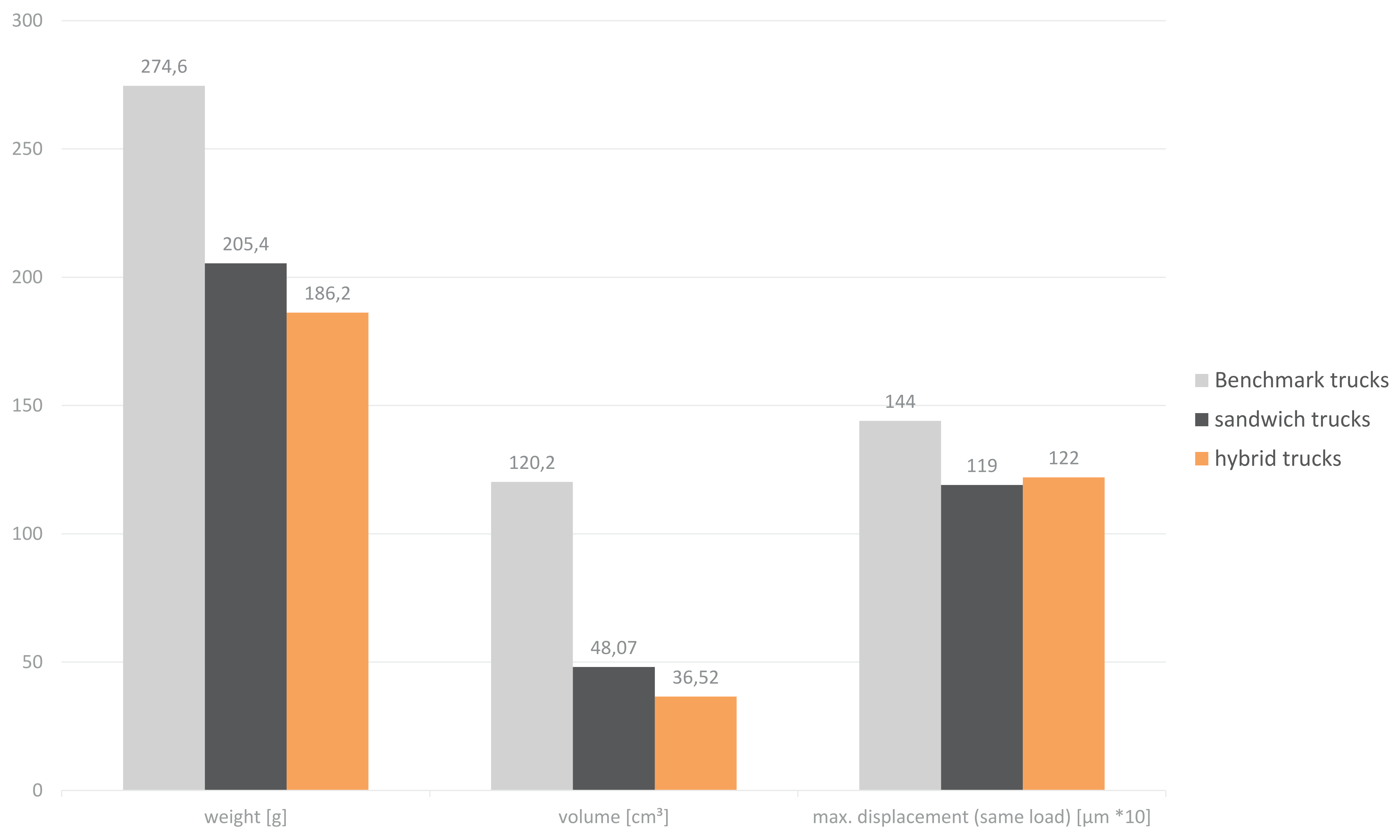
Results – Workflow / Comparison to benchmark / Testing

Seven points of AM product development
- The workflow for successful hybrid design



➢ **Involve all points from start on!**

Comparing weight, volume and max. displacement on the hanger to benchmark truck



You can see both version of the trucks at the following booths:

- **Fraunhofer Additive Manufacturing Alliance (3.0-F50)**
- **Autodesk (3.0-F70)**
- **GE - Concept Laser (3.0-E30)**
- **AGENT-3D (3.0-A65)**