HIP IMPLANT IN FEMUR BONE

Initial CAD geometry source: https://grabcad.com

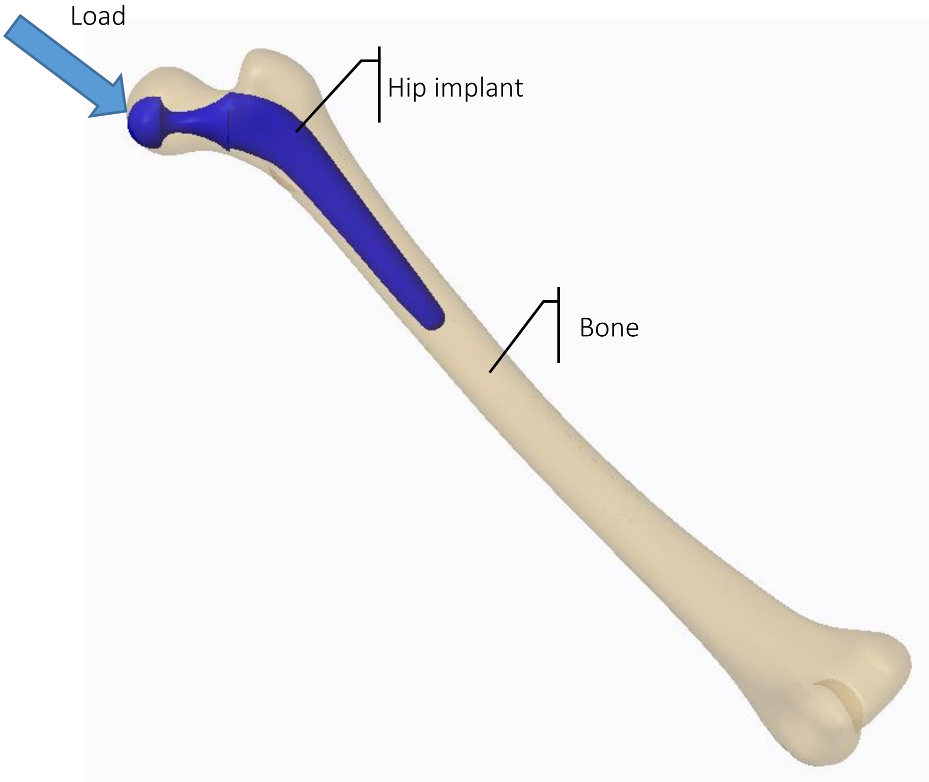
Problem description

Hip implants are highly loaded parts and they must be lightweight structures with the longest possible service lifetime. To meet these requirements, a fully 3D optimized implant made of sintered shell/lattice structure might be a very good solution. A shell/lattice structure guaranties lightweight and full 3D topology optimization of the structure (modeled exclusively with 3D solid finite elements) guaranties low stresses and removed stress concentrations, which prolongs dramatically the service life.

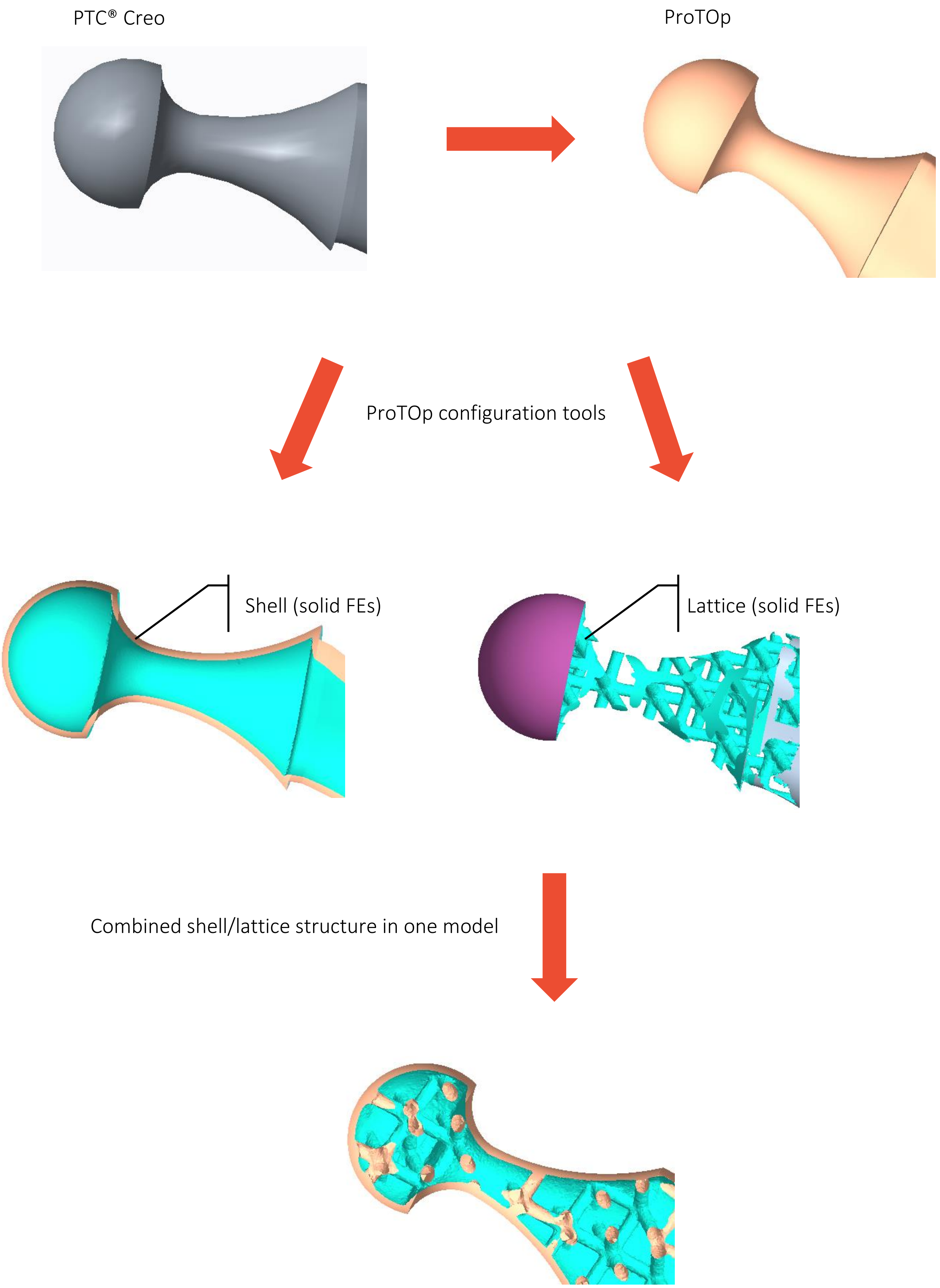
This example shows a simultaneous topology optimization of shell thickness and inner lattice structure of the implant while its outside geometry remains unchanged. The result obtained with CAESS ProTOp exhibits low weight with remarkable stiffness and low stress levels without concentrations. The optimized geometry can be directly used for Additive Manufacturing technologies.

The basic requirements are as follows:

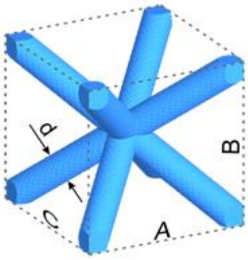
- The optimized geometry of the hip implant must be a stiff structure with low weight, without stress concentrations, and it must fit within the original bone.
- Material:
    - Implant material: Ti Alloy, Young modulus 117211 Mpa.
    - Bone: Young modulus 5000 Mpa.
- Load Conditions: Static linear load of 1000 N.



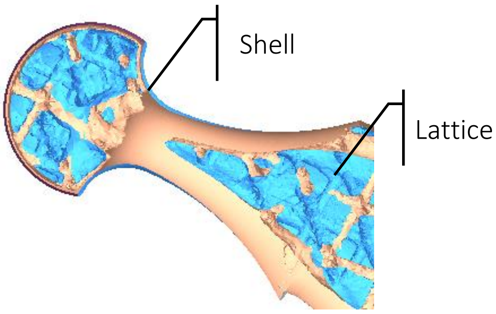
The initial CAD geometries were imported into PTC® Creo as solid parts. For the optimization purposes ProTOp's configuration tools were engaged in order to get a shell-like outer structure and lattice inner structure from the simple solid part.



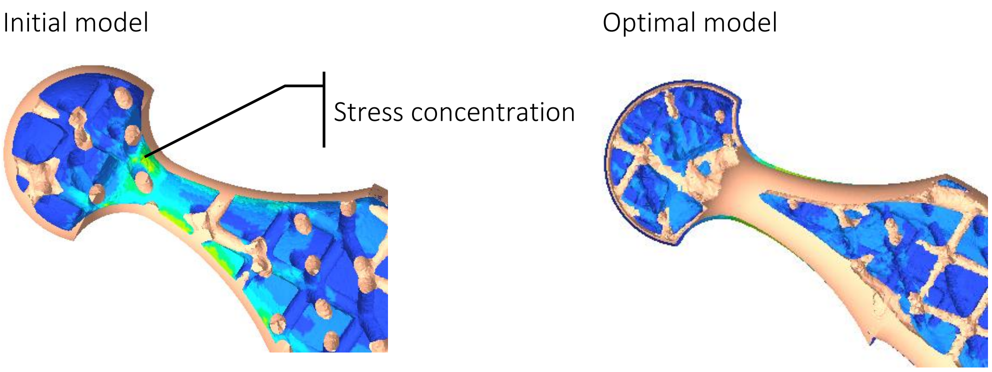
With ProTOp configuration tools various unit cells for the lattice structure can be selected. In this case study, a cell being well suitable for SLS (Selective Laser Sintering, 45° TC) was chosen.



Running topology optimization with ProTOp means simultaneous adjustment of non-uniform shell thickness and inner lattice structure – within the specified limits. Both, the shell thickness and lattice structure may spatially vary according to inner loading in the implant.

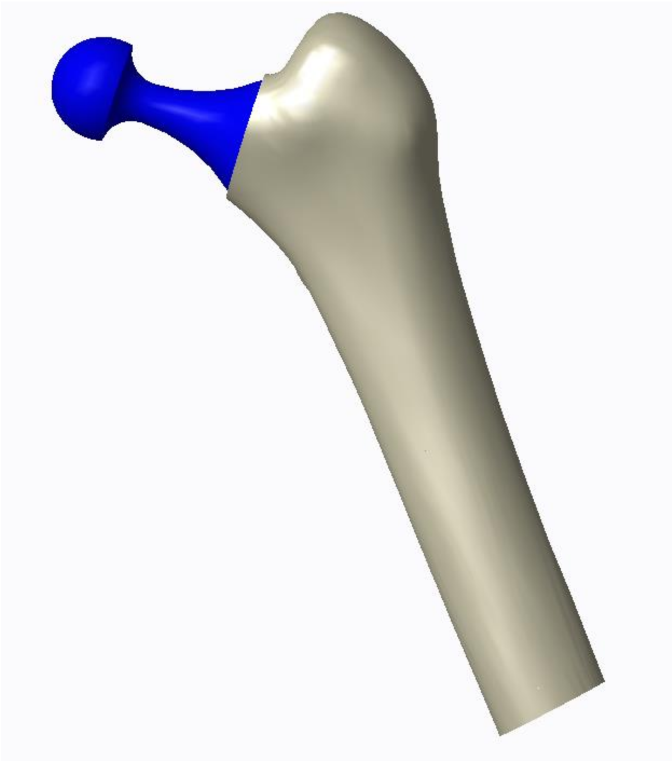


In both, solid and shell/lattice structures without topology optimization, the stresses exhibit large variations and high concentrations. This can be changed significantly by material redistribution achieved by optimization with ProTOp. This process leads to greatly reduced stress levels and removed stress concentrations.

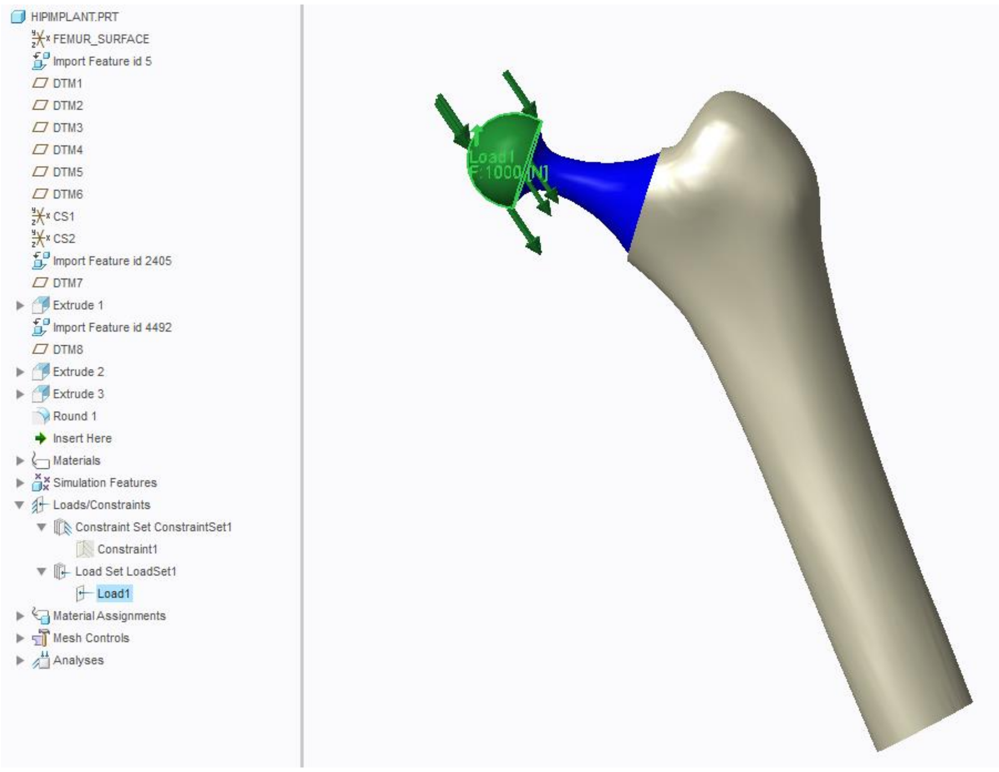


CAD and FEA model

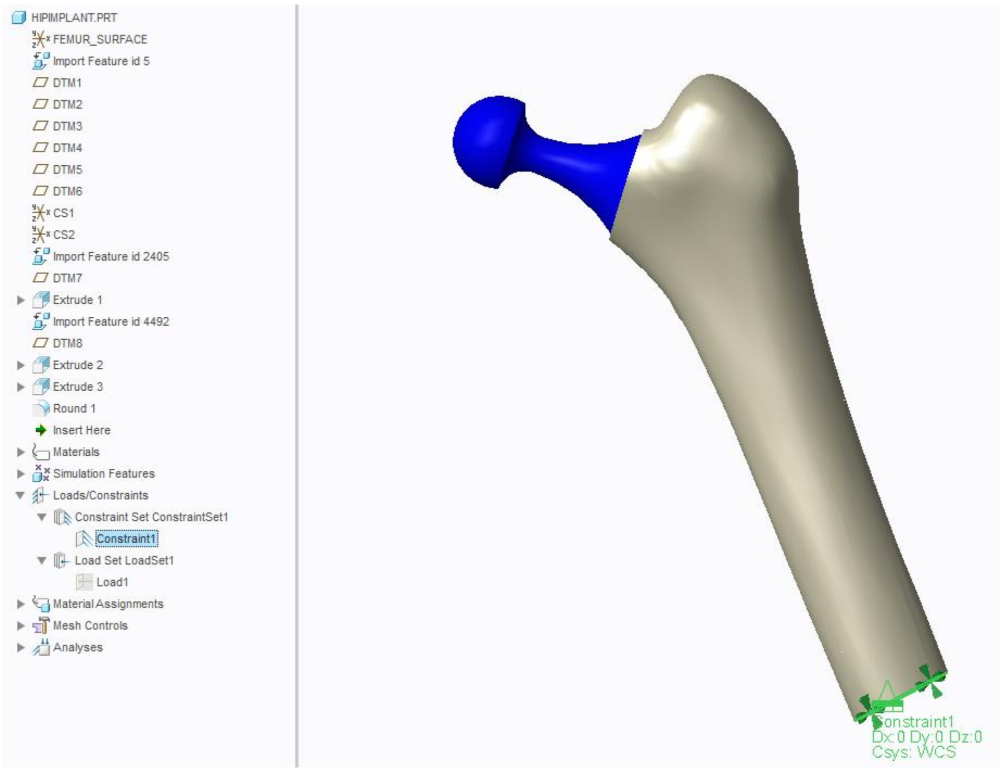
The hip implant in femur bone - initial model in PTC® Creo.



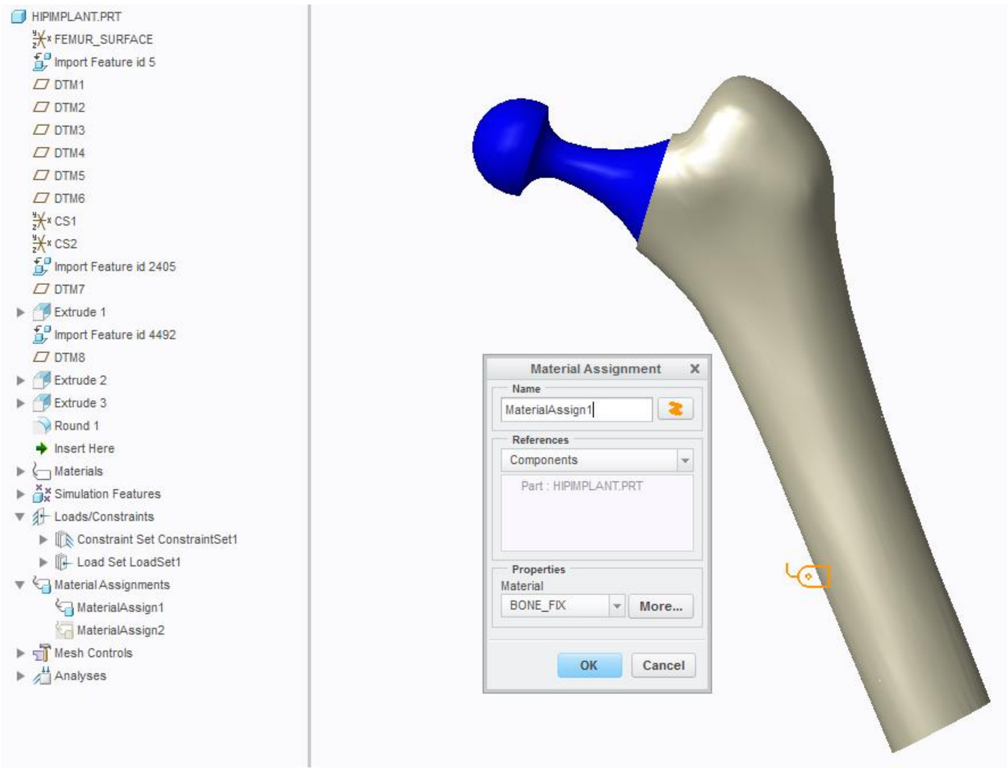
Loading.



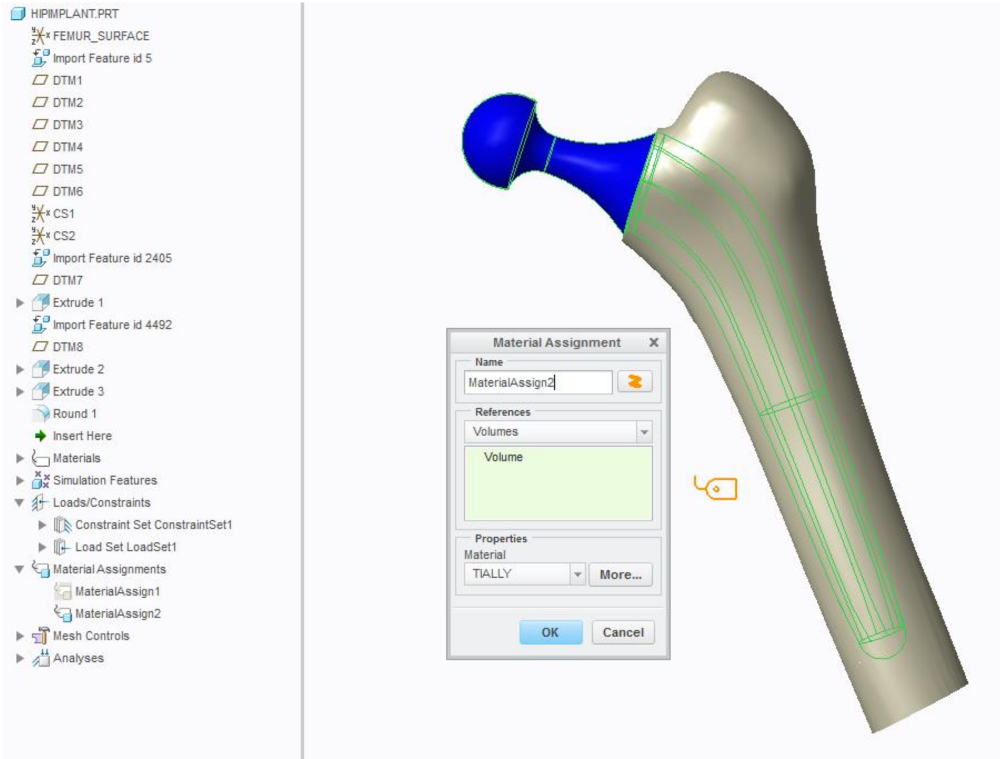
Boundary conditions.



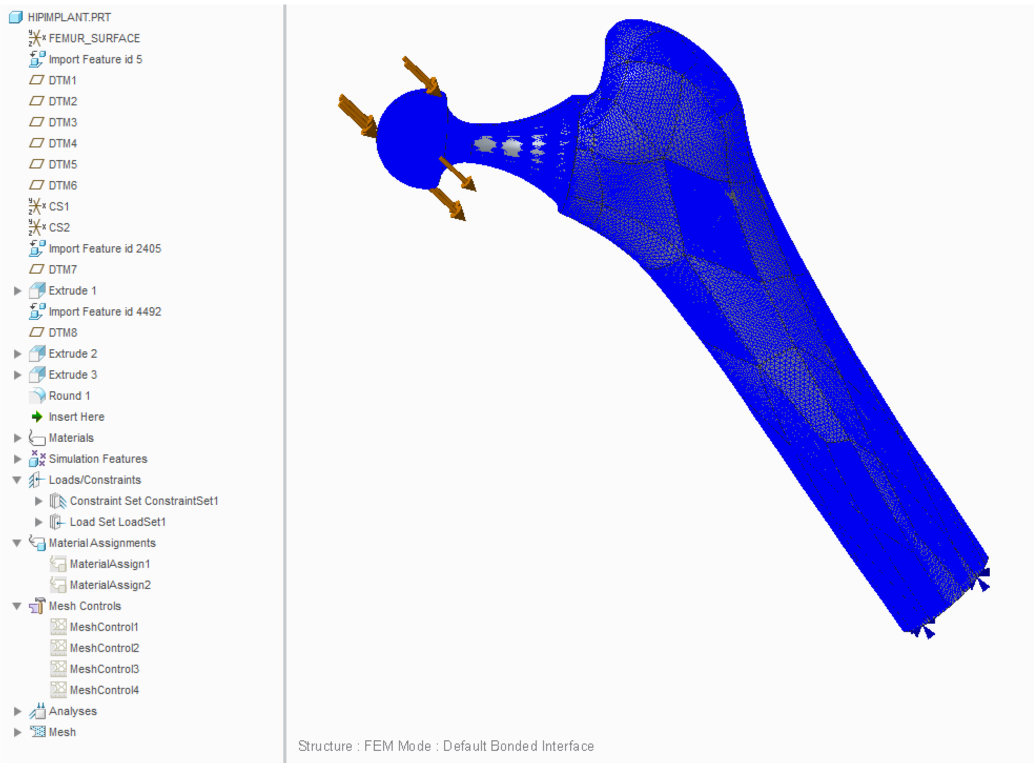
Material assignment: Bone_FIX to created volume region for the bone component.



Material assignment: Tially to created volume region for the implant component.



FEA model in PTC® Creo.



Optimization by CAESS ProTOp

Optimization targets:

- Volume reduction to 45% of the full-solid implant optimization domain.
- Lowest possible stress levels.
- No stress concentrations within the optimized domain.

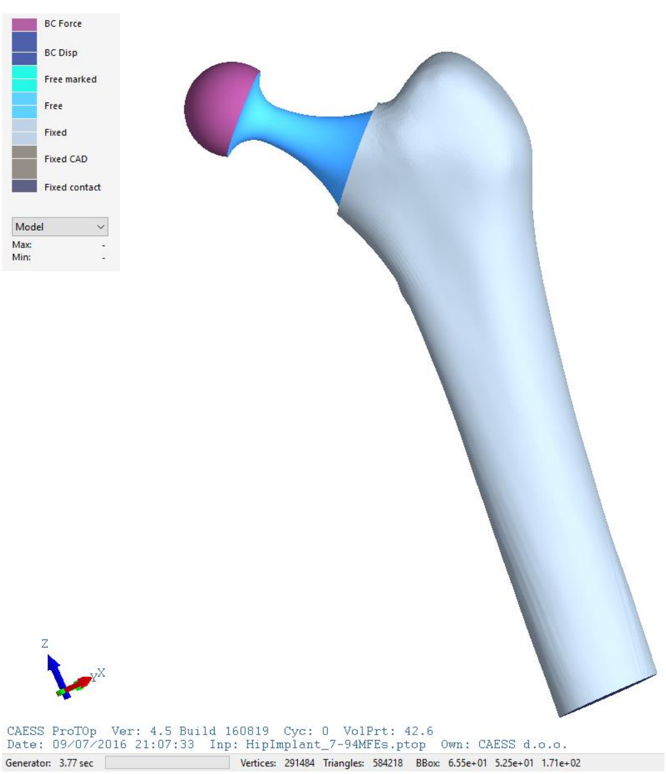
Finite elements: special topology-optimization-enriched linear tetrahedrons.

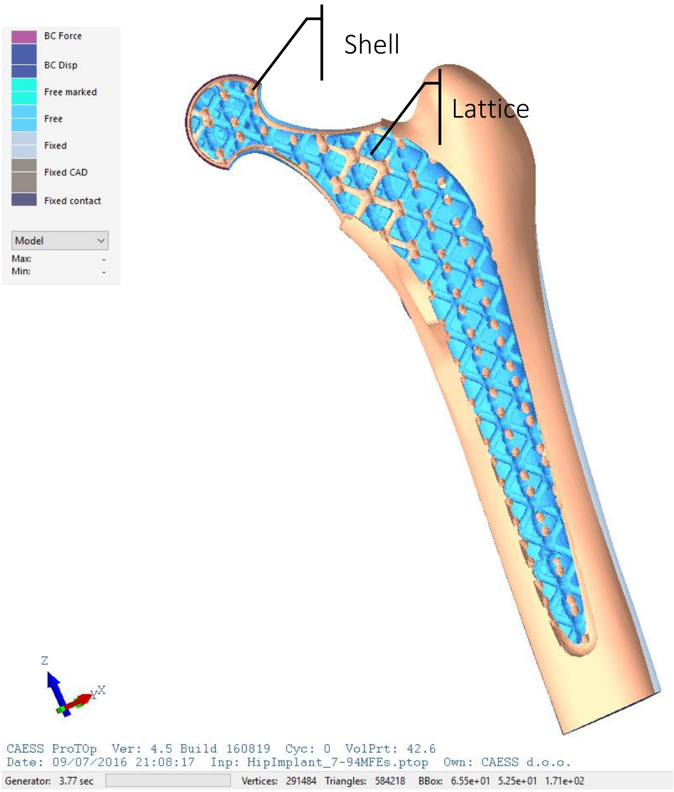
Configuration: using shell/lattice structure (implant).

Numerical data of the model			
Elements: 7.9 million	DOF: 4.0 million	Total CPU time: 09:29:12 (PC with 4-core i7 CPU)	Max RAM: 41 GB

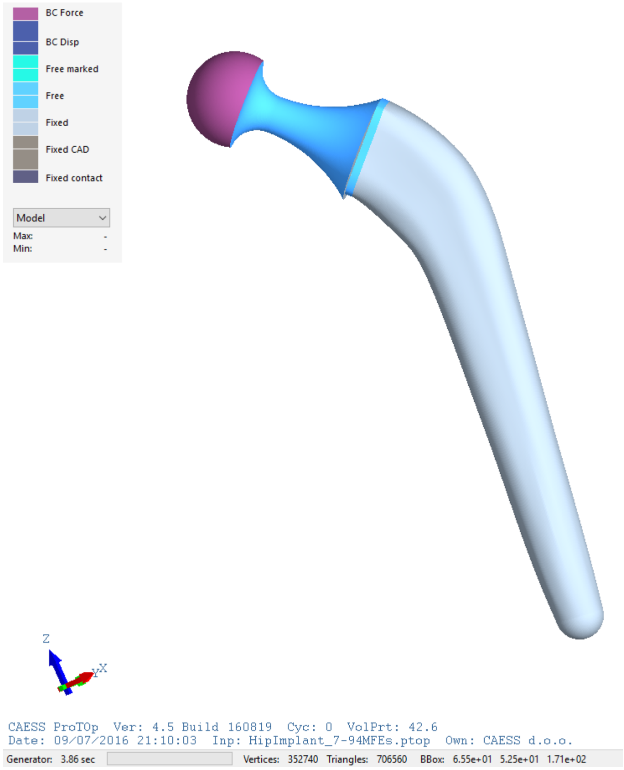
Initial model

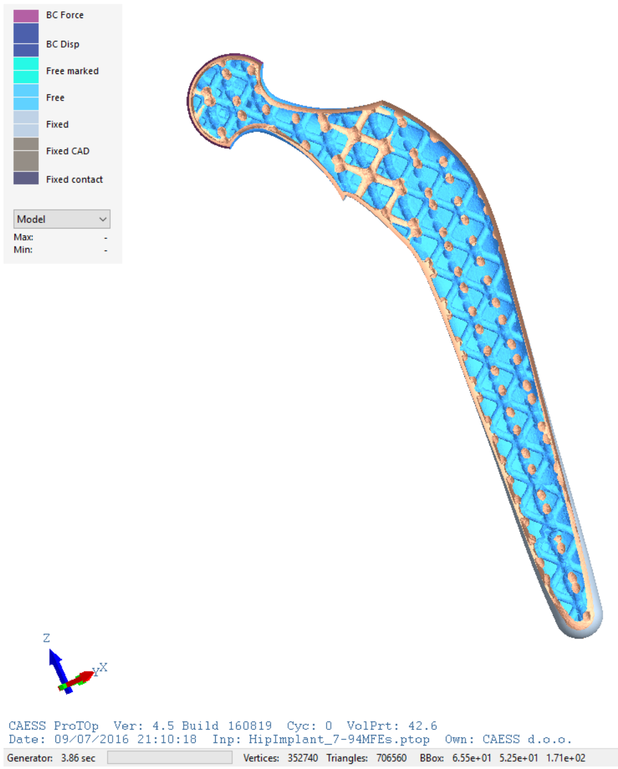
Model in ProTOp.



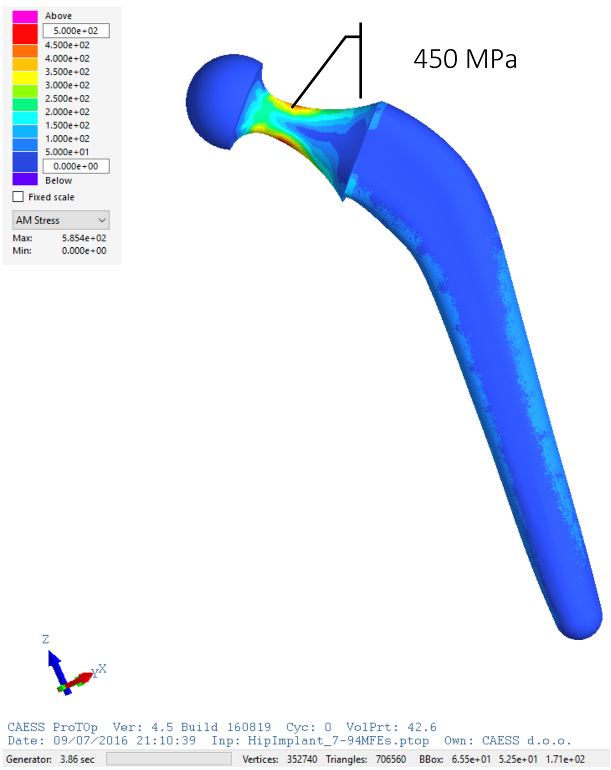


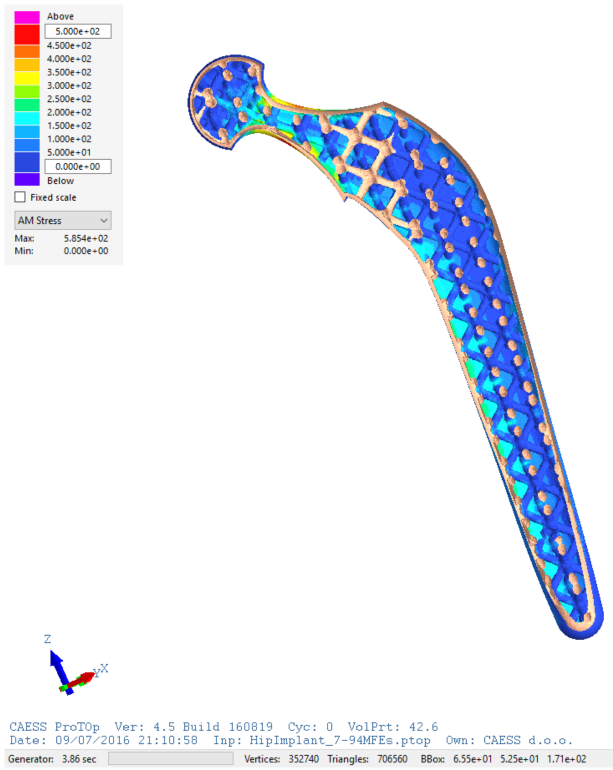
Model of the hip implant in ProTOp.

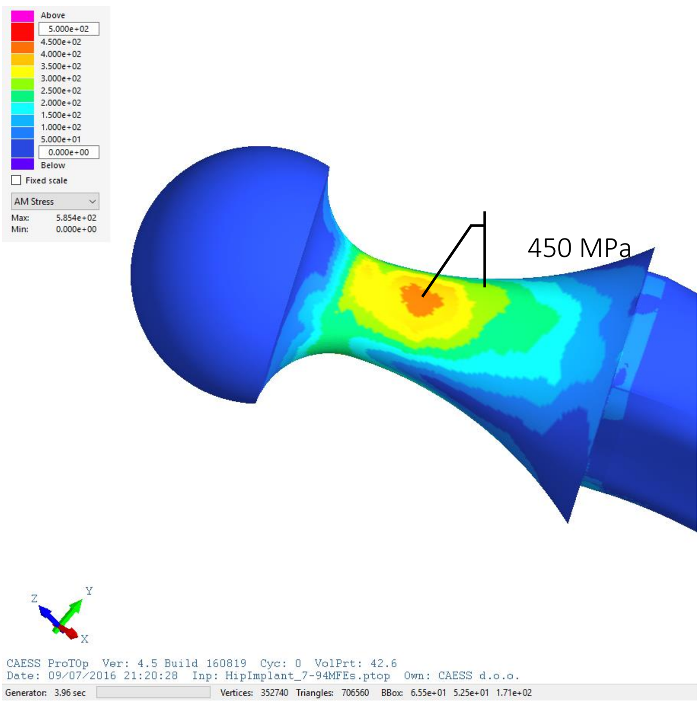


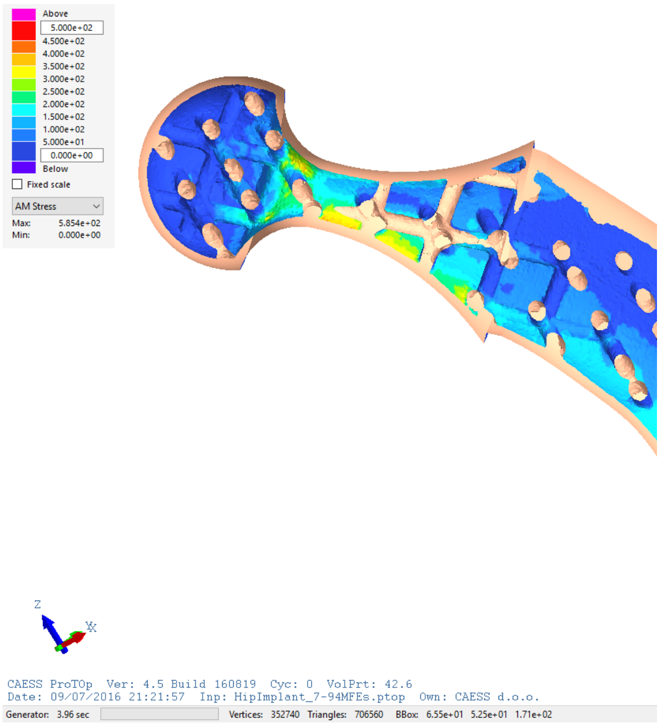


Stress concentrations of the initial model.



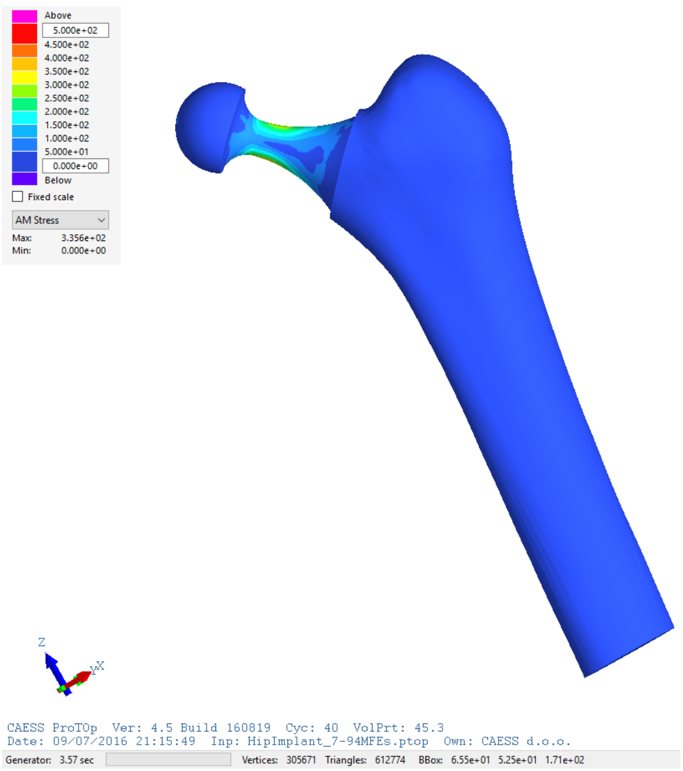


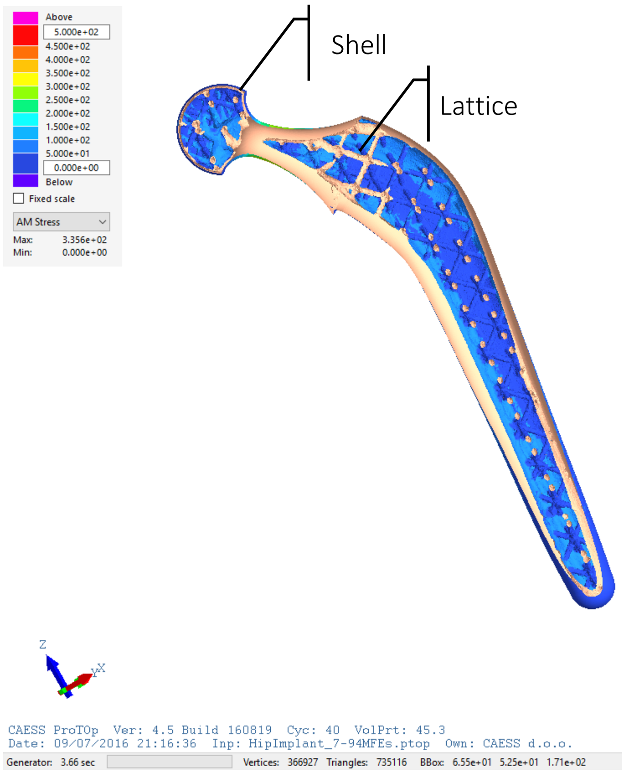


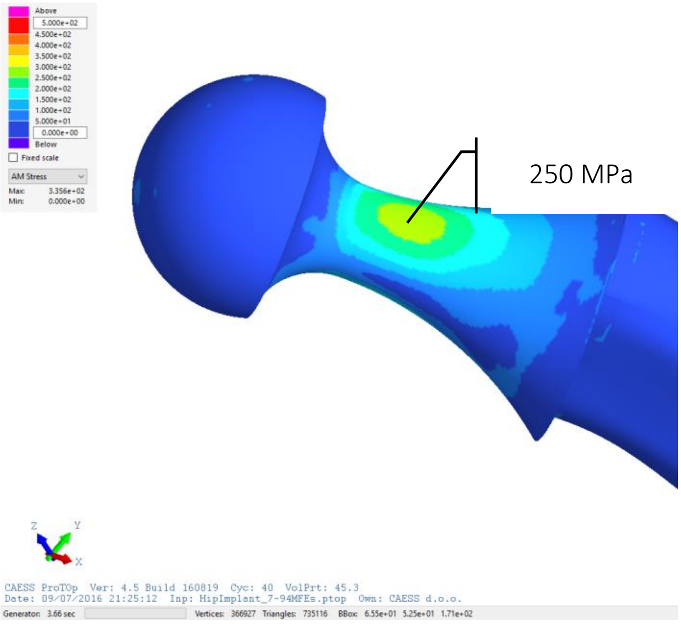


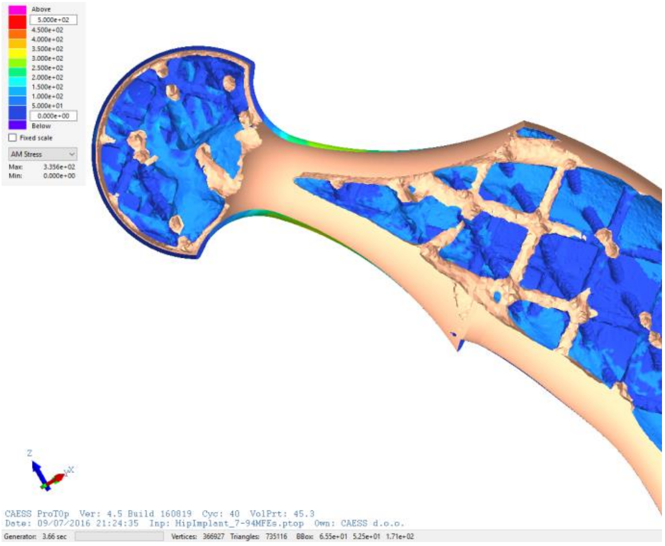
Optimal model

Stress concentration and optimal design of the optimized model. New design.







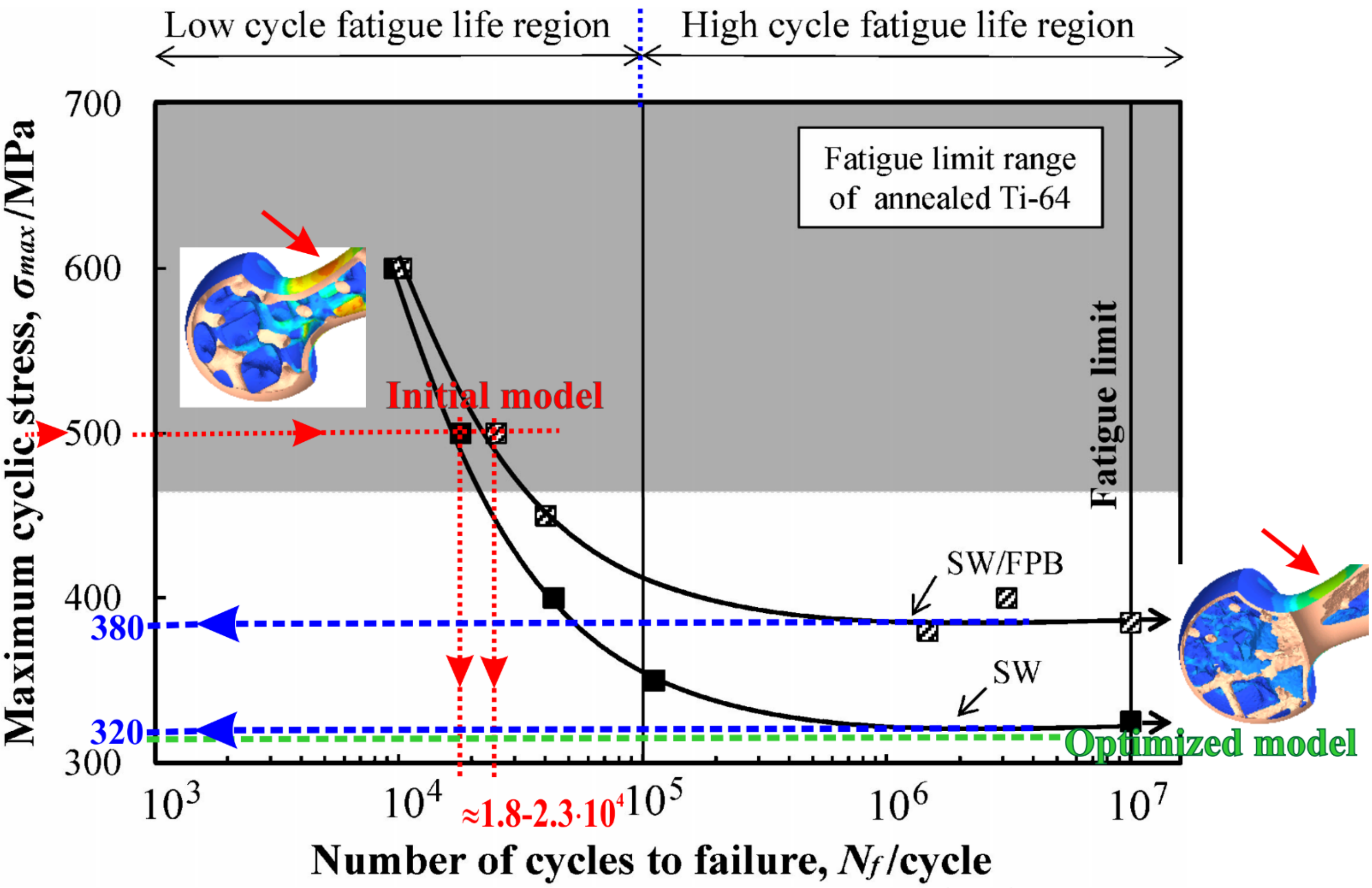


Results

Numerical data	
Starting volume of hip implant (shell/lattice)	Stresses
43% of the full-solid	max stresses 450 MPa
Optimal volume of hip implant (shell/lattice)	Stresses
45% of the full-solid	max stresses 250 MPa

Service life of the HIP IMPLANT

Topology optimization of the hip implant with ProTOp brings low stresses without stress concentrations in the structure and the result is significantly prolonged service life. As a raw estimate, one can get the number of load cycles from corresponding material diagrams, obtained by experiments. In our case the optimization increased the number of cycles-before-failure from about $2 \cdot 10^4$ up to virtually infinite (see figure below).



material data: J. Japan Inst. Metals, Vol. 78, No. 4, (2014), pp. 163-169