TOPOLOGY OPTIMIZATION process description using Unigraphics NX

Topic: Creating a new topology optimization simulation

Name: Steffen Johnsen

Date: 28.05.2013

Approved by: Terje Rølvåg

NX Topology optimization is a powerful tool for enhancing creativity and finding optimal distributions of material given a design space, loads and boundary conditions.

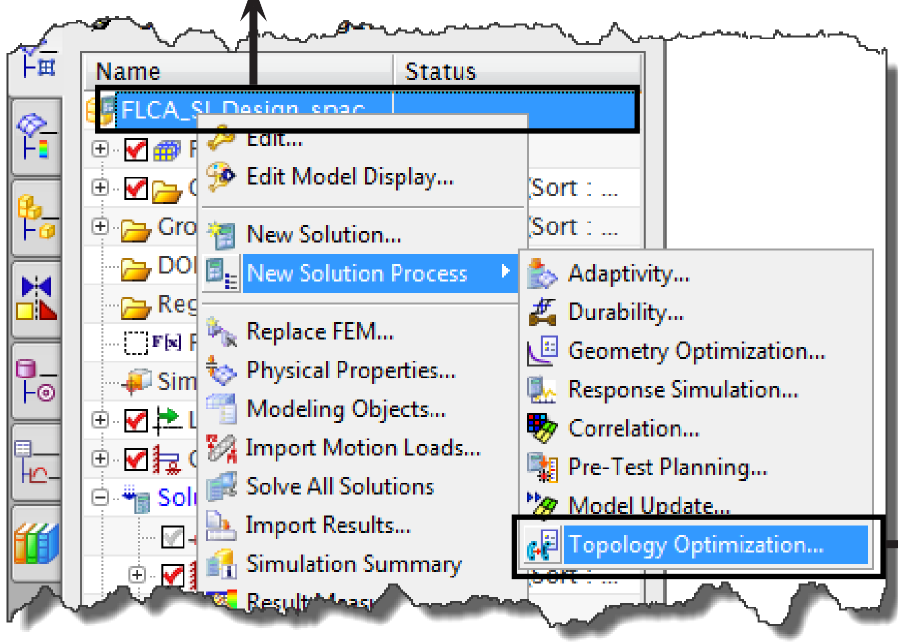
NX Topology optimization is a part of the NX Advanced simulation environment, and can be added as a New Solution Process after defining the initial FE- simulation file. The tool is easily configured using the Topology Optimization step- by- step wizard.

The optimization tool is capable of handling a Single Objective Analysis, that is an analysis aiming to optimize one variable, while treating other variables (later refered to as design responses) as constraints.

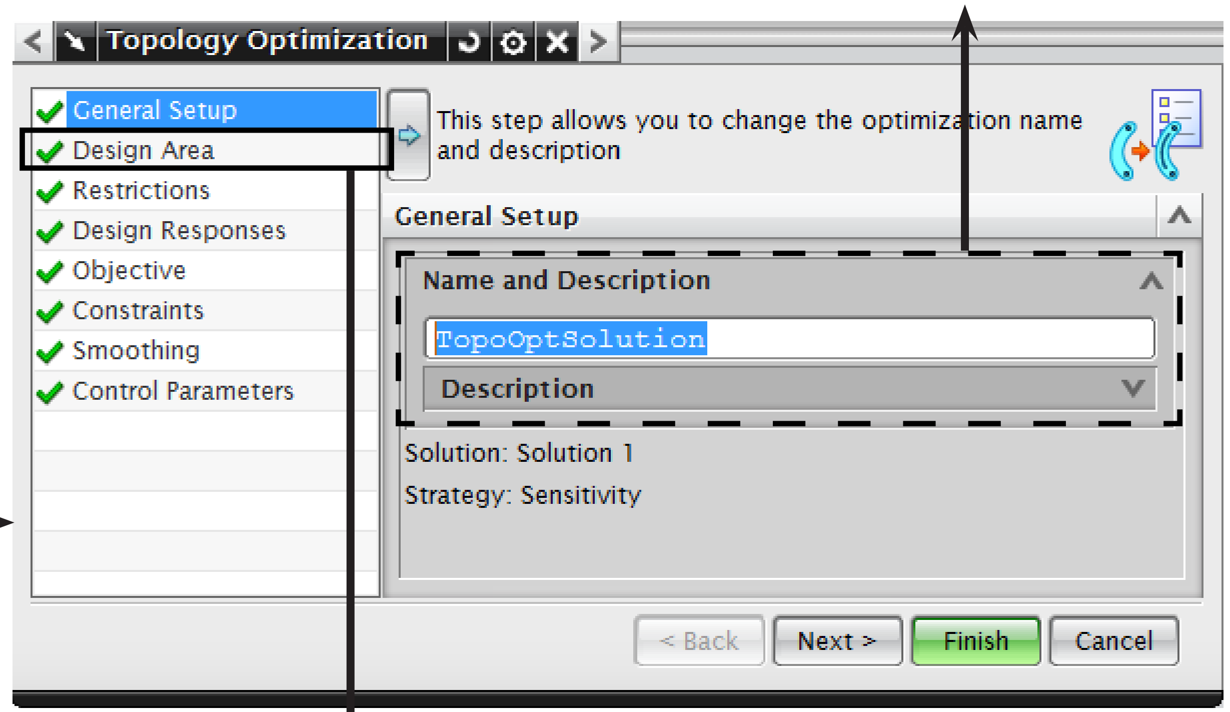
The NX topology optimization is also capable of handling multiple loads, contact forces, assemblies, etc.

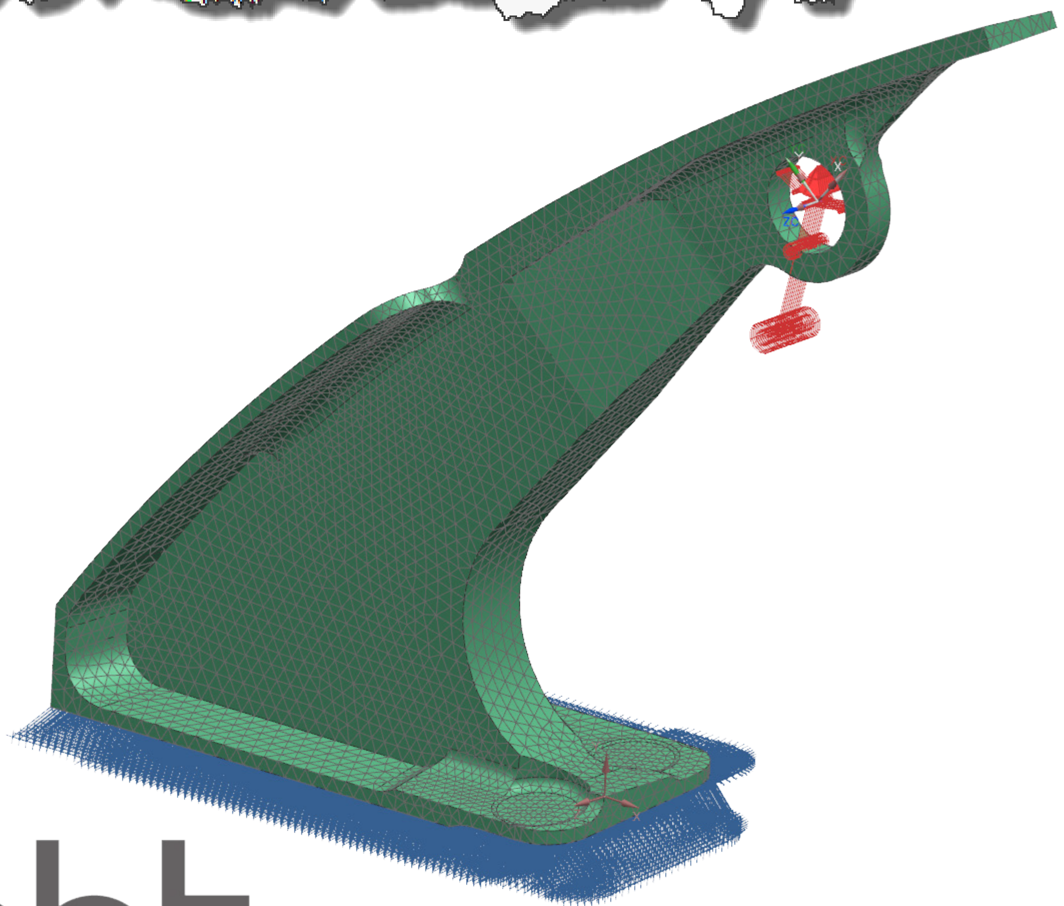
The tool is designed to handle static, structural simulations of both 2D and 3D continuum structures.

Right- click

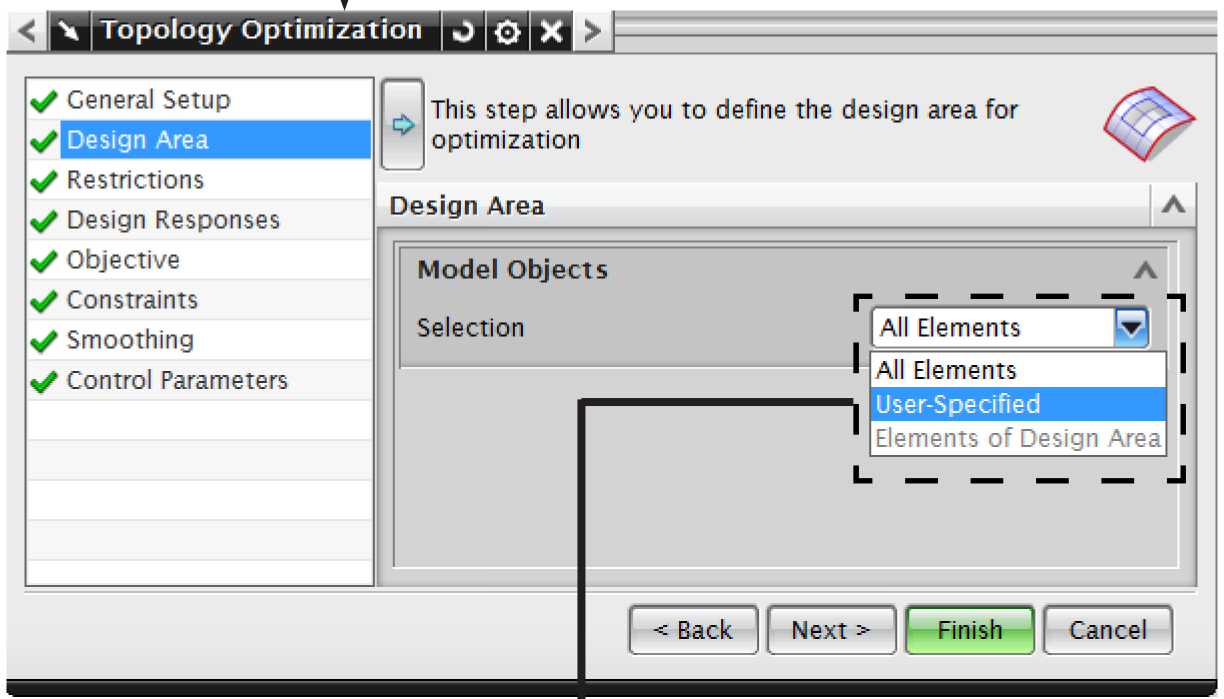


Name the optimization





Simulation model



Define modeling objects that should take part in the optimization. "All elements " is the standard selection for single- body FE- files. Specifying bodies is only applicable when simulating assemblies.

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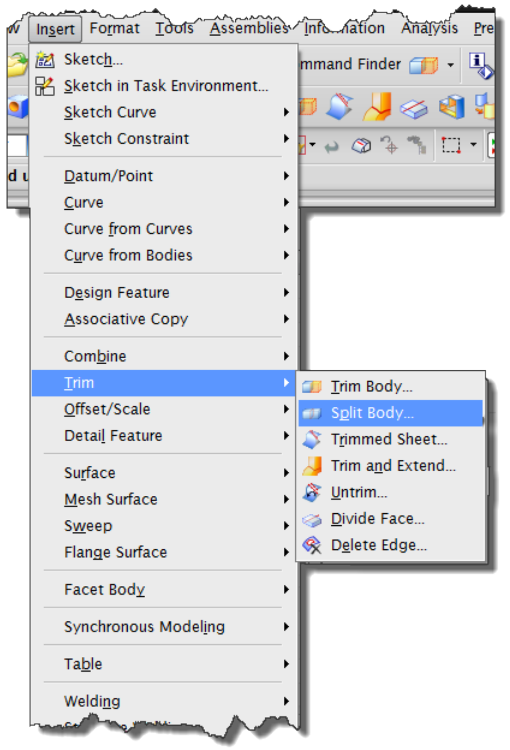
TOPOLOGY OPTIMIZATION process description using Unigraphics NX

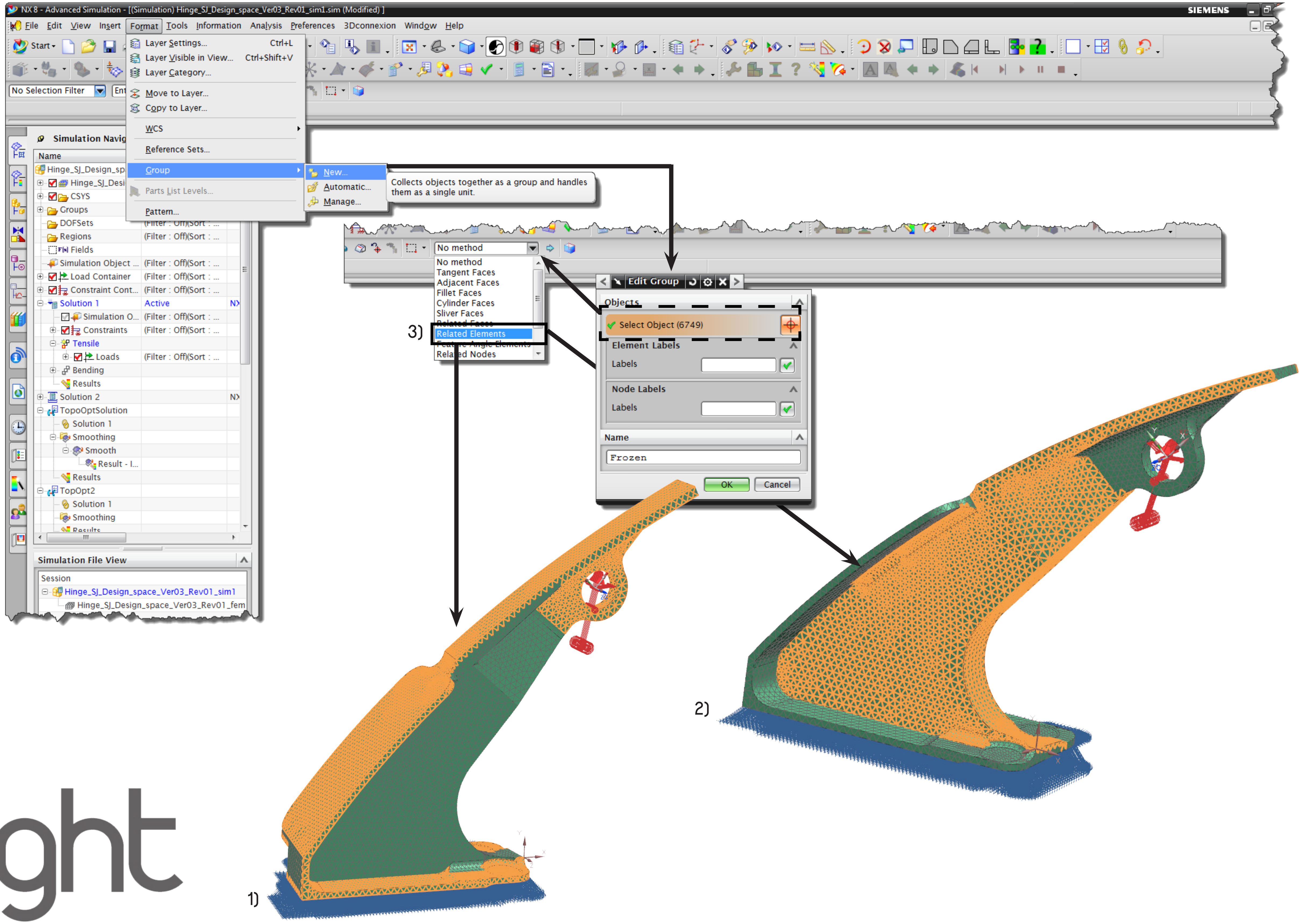
Topic: Defining element groups | Name: Steffen Johnsen | Date: 28.05.2013 | Approved by: Terje Rølvåg

Defining element groups simplifies the geometric constraints definition. In the following example, groups for 1) Frozen areas and 2) Manufacturing areas are defined.

Best practice have been found to define areas by using the 3) Related Elements selection method.

Be aware that only surface elements are selected with this method, and depending on Cast condition settings (see A3 sheet on Geometric constraints), internal voids and undercuts may appear. Using the Split Body command for creating separate bodies enable choosing regions of elements if more suitable (Modeling environment).





TOPOLOGY OPTIMIZATION process description using Unigraphics NX

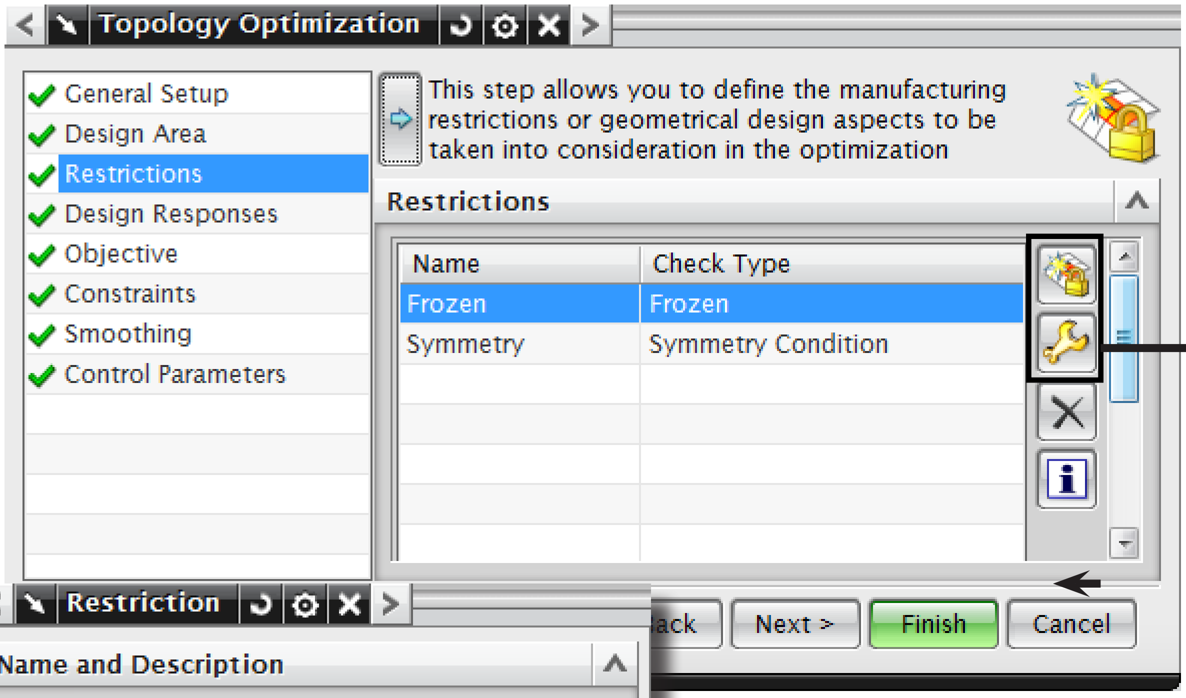
Topic: Defining geometric constraints (restrictions) | Name: Steffen Johnsen | Date: 28.05.2013 | Approved by: Terje Rølvåg

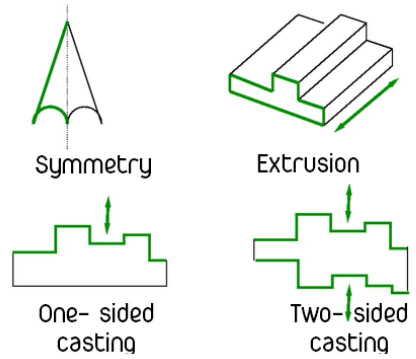
As a rule of thumb, a general analysis should be performed before geometric constraints are introduced, as they will increase computational time as well as limit the available design space, giving a less optimal solution.

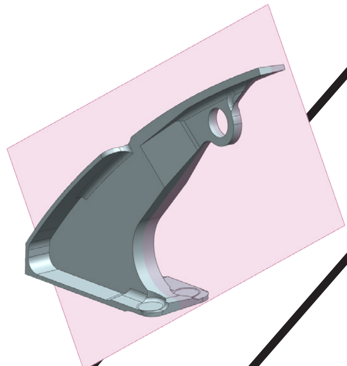
Cast condition is probably one of the most important geometric constraints, as it ensures that production methods like casting, stamping, forging and machining can be used. If the design space BC's introduce some kind of torsion or angular momentum in the part, internal voids and holes will be made, as material is preferred at the outer premises of the design space. This is done to increase the second moment of inertia. Cast condition specification is omitted, because significant simulation errors occurred. No apparent fault were found, however the problem may still be a result of faulty setup.

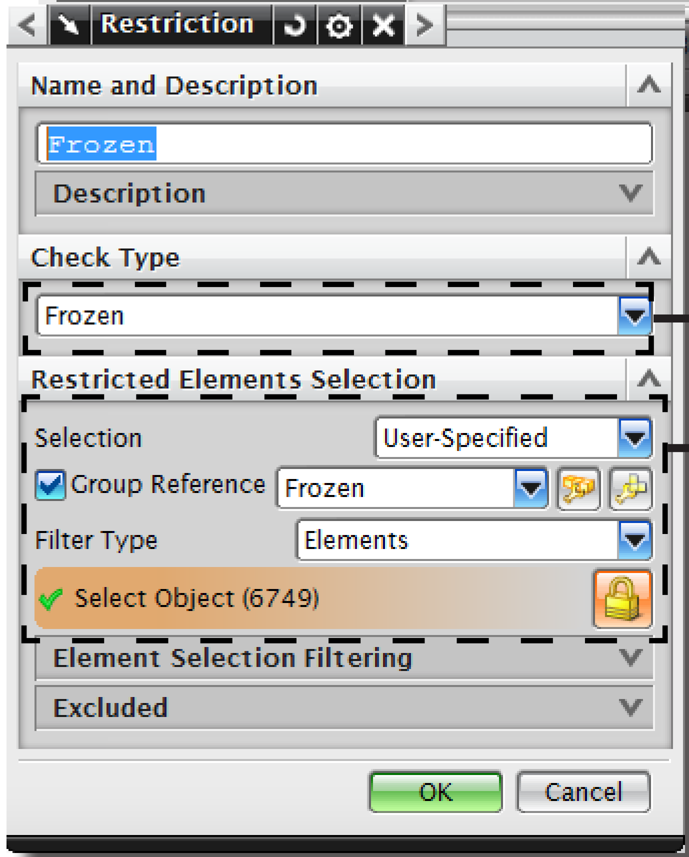
Symmetry constraints can be specified as planar or cyclic. Using the symmetry constraint, solutions will look more aesthetic, and they will be easier to produce.

Frozen faces will not be affected, and will remain the same after the analysis has ended. This is particularly useful to maintain areas of geometric significance, as the algorithm is forced to shave off weight from other areas of the design space.





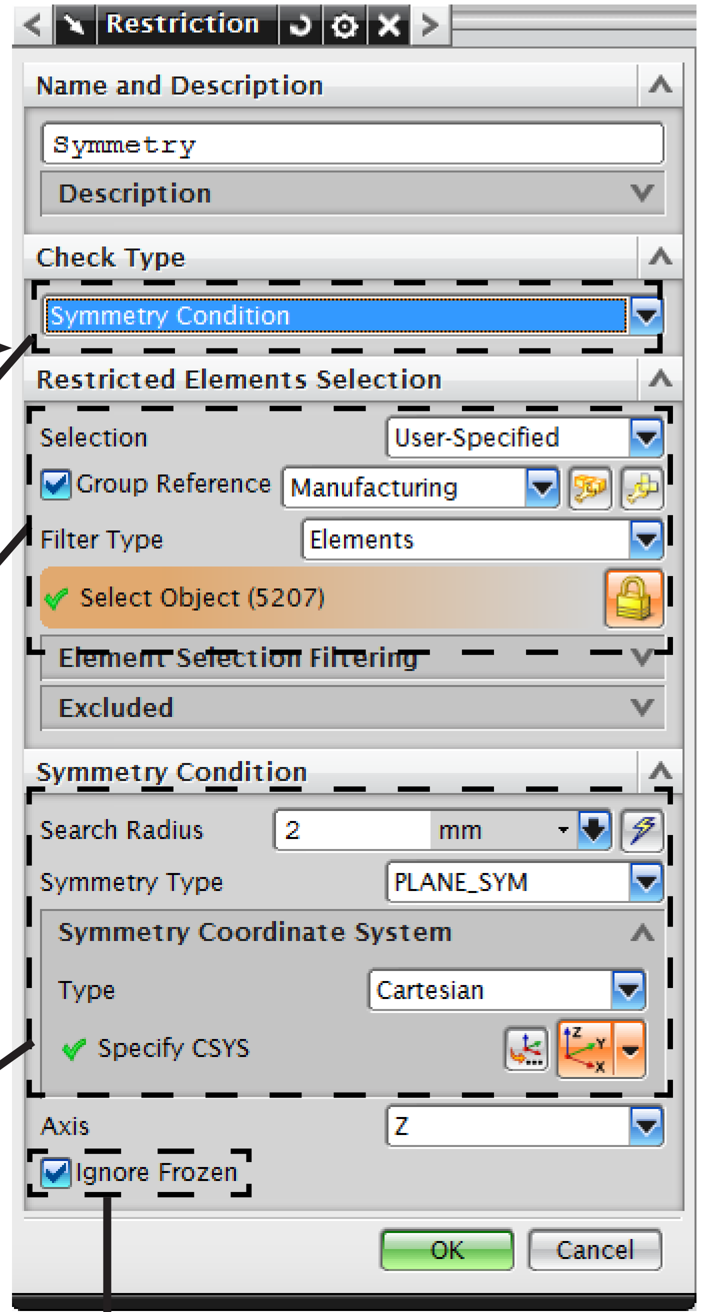




Check Type defines the type of geometric constraint you wish to introduce to the model

Set Selection to User- Specified, tick the Group Reference box and choose the previously defined element group to be restricted.

The NX manual specifies that the search radius must be larger than 80% of the element size. Symmetry type can be set to either Planar or Cyclic. For Planar symmetry, a coordinate system and normal axis must be specified.



Check Ignore Frozen box to prevent symmetry condition to apply to frozen areas.

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TOPOLOGY OPTIMIZATION process description using Unigraphics NX

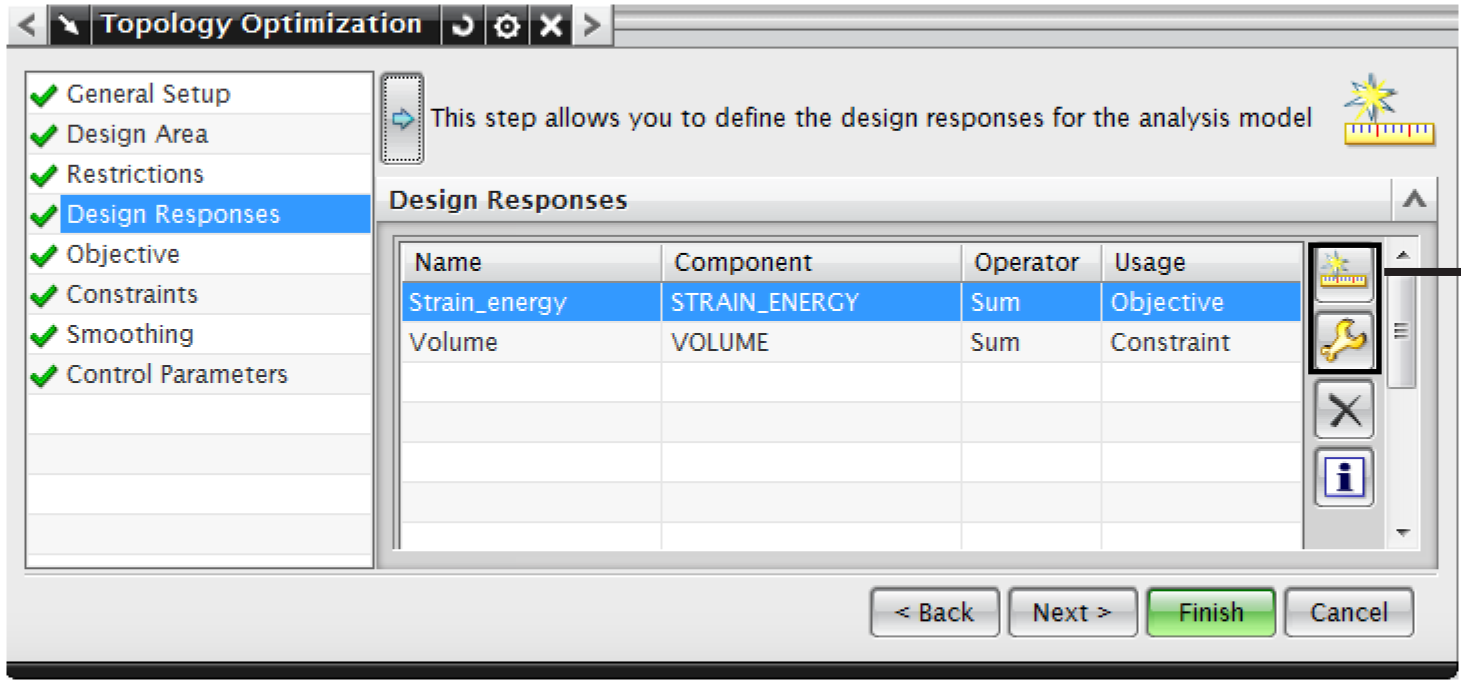
Topic: Defining design responses for the optimization | Name: Steffen Johnsen | Date: 28.05.2013 | Approved by: Terje Rølvåg

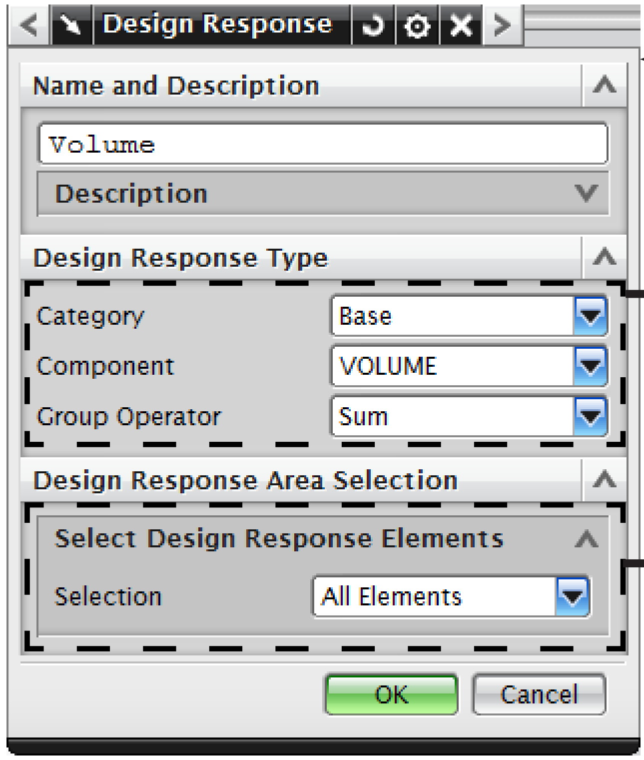
Design responses can be seen as the simulation variables. They are defined before the simulation objective and constraints are set.

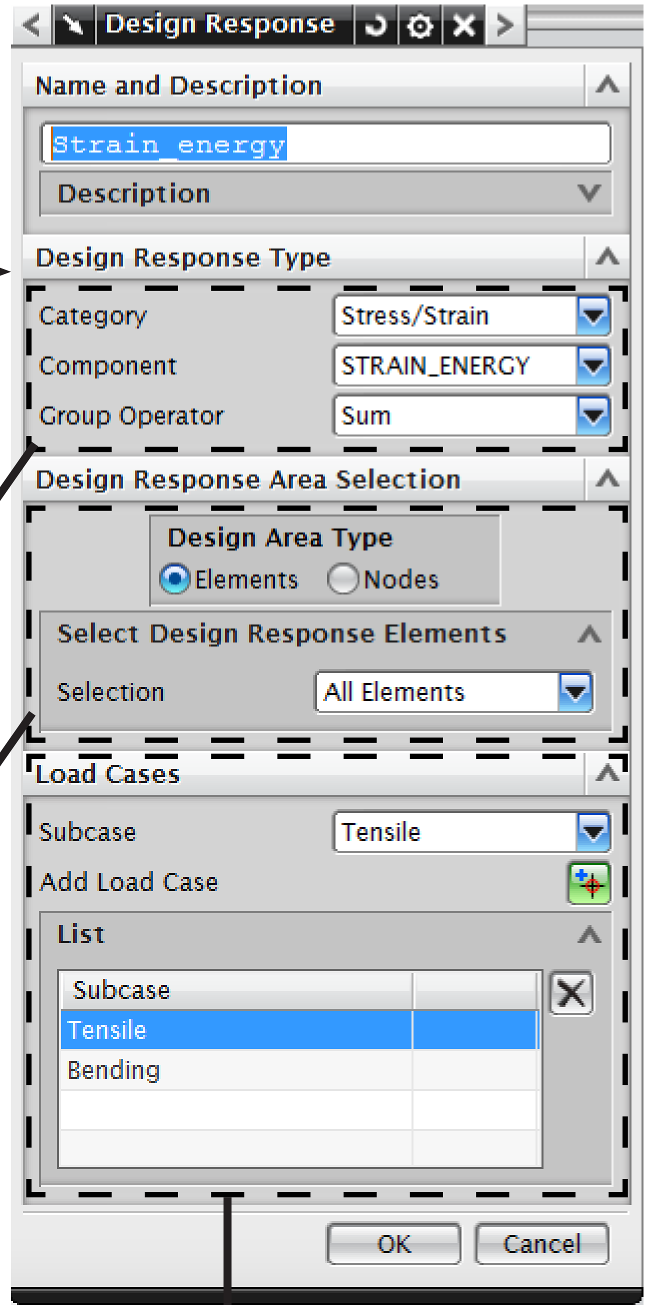
Design responses may be specified for the entire model, or for specific regions of the geometry.

For certain design responses, e.g. strain energy and displacement, Load Cases must be specified.

The Group Operator can be used to change the interpretation of the Design Response of interest, changing between Sum, Maximum, Minimum (value), etc.







Design responses that are available for the chosen optimisation algoritm.

Best practice is to select All Elements to include all previously included elements in the design space for general purpose design responses like Volume and Strain energy

Load- dependent design responses require specification of which sub-cases to be included in the analysis.

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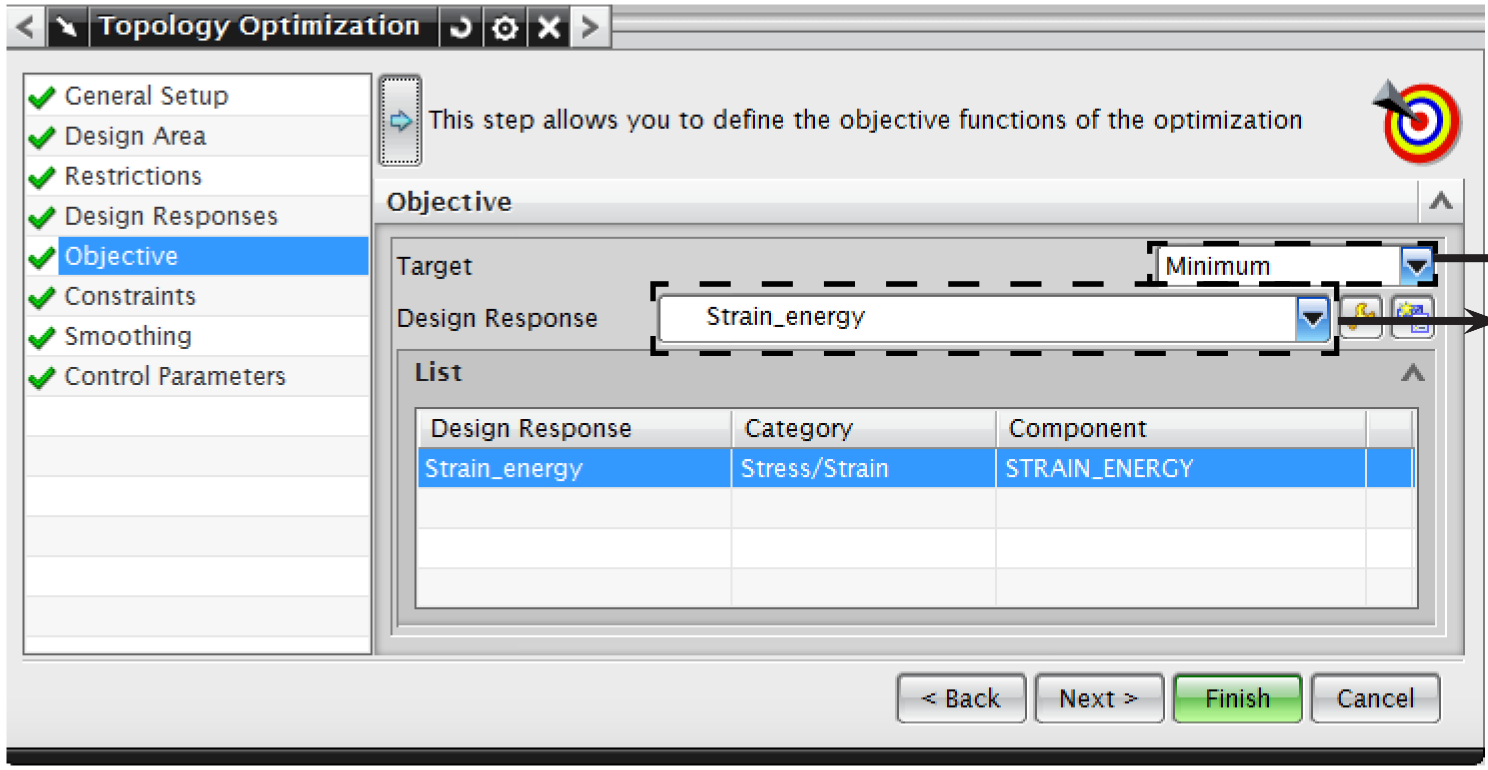
TOPOLOGY OPTIMIZATION process description using Unigraphics NX

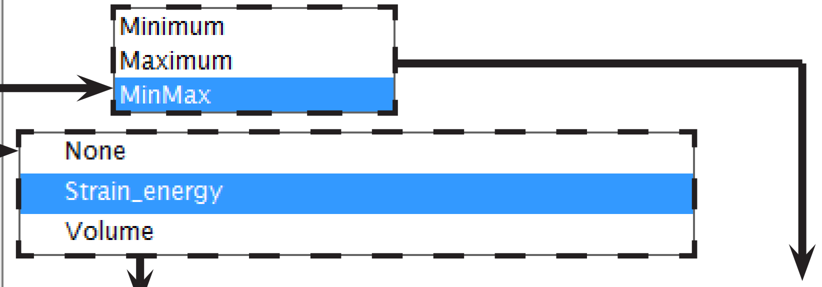
Topic: Defining the objective definition	Name: Steffen Johnsen	Date: 28.05.2013	Approved by: Terje Rølvåg

In general, there are three different proposed approaches to optimizing a structure using NX:

1) Minimize (or minimize the maximum) strain energy, constrained with an upper limit on the relative volume fraction.
2) Minimize the volume, constrained with an upper limit for displacement, moment of inertia, reaction forces, CoG or rotation (or a combination of these).
3) Maximize eigenfrequencies, constrained with a LOWER limit for volume or/and limits for other design responses that are independent of loads (as eigenvalue analysis are performed without external forces applied).

Best practice when defining the objectives and constraints:
- Choose the design response that has the highest uncertainty. If the target volume is specified, choose an approach that has volume as a constraint.
- If you have more than one load case, the MinMax formulation will provide a solution that has better overall robustness.





Choosing the design response to set as the objective.

The objective target can be set to MINIMIZE, MAXIMIZE or MINIMIZE THE MAXIMUM (MinMax). E.g you will most likely minimize a volume objective, maximize an eigenvalue objective or minimize the maximum strain energy. For NX, minimizing the maximum will create robust designs when applying loads to separate subcase (equivalent to steps in Abaqus), making the final solution equally good for alle load cases.

TOPOLOGY OPTIMIZATION process description using Unigraphics NX

Topic: (Performance) constraints

Name: Steffen Johnsen

Date: 28.05.2013

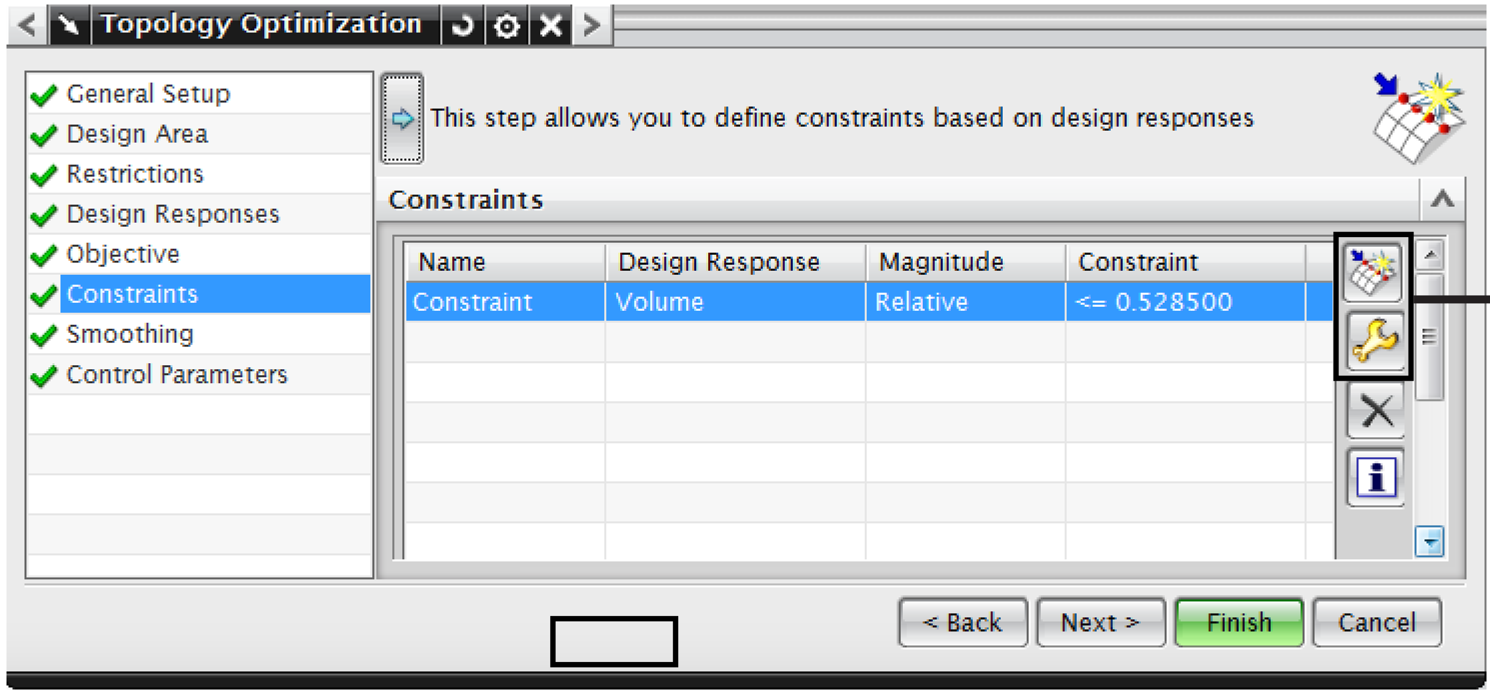
Approved by: Terje Rølvåg

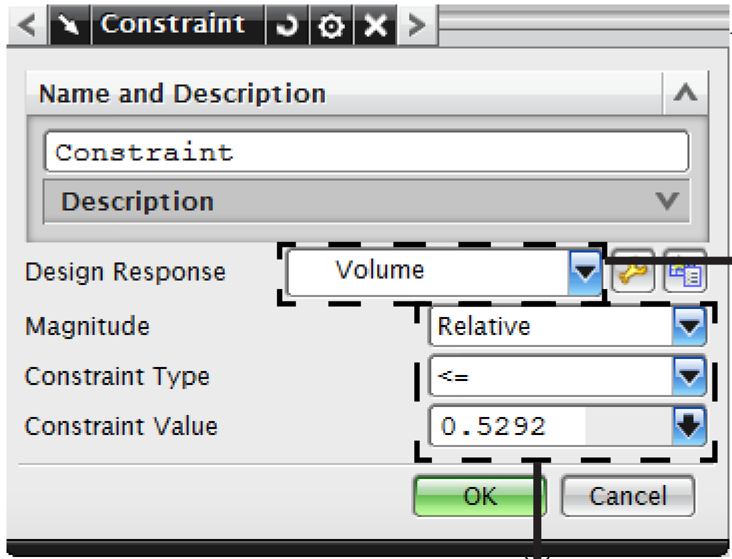
Performance constraints must be specified, otherwise the objective will go toward the objective without any limitations.

Performance constraints must be specified on all remaining design responses after defining the objective.

Values may be specified as Relative or Absolute, but are treated as scalar values.

Too strict constraints may result in invalid solutions or solution convergence.



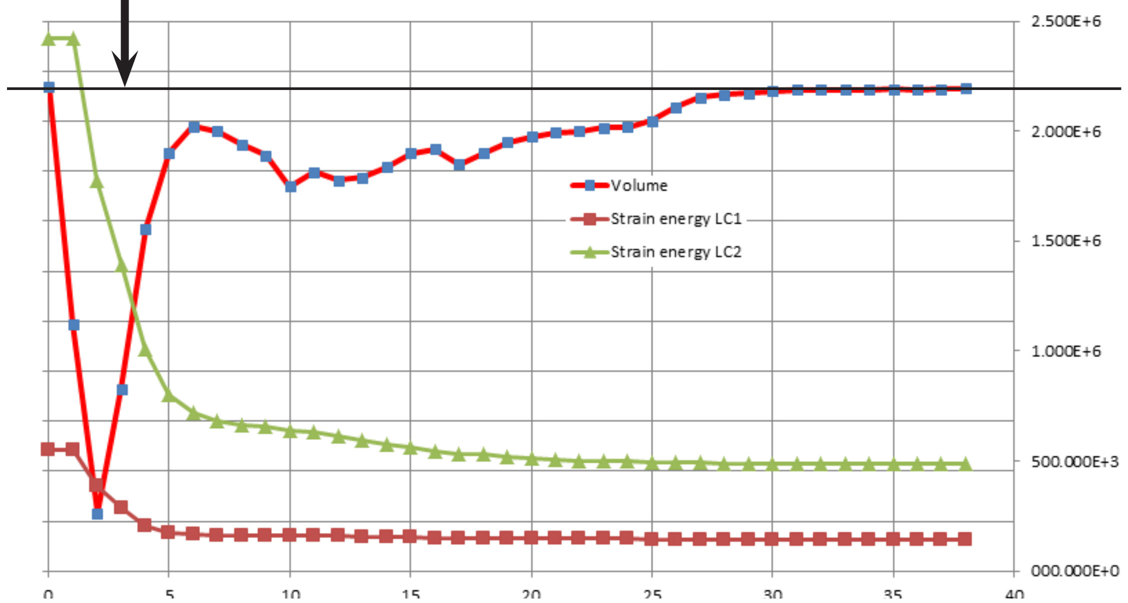


Remaining design responses must be set as constraints

Depending on the choice of constraint, the magnitude can be set to "Absolute" or "Relative". When minimizing volume (or equivalent), the "Constraint type" must be set to <= , but when minimixing eigenfrequencies, a >= constraint is necessary. The "Constraint value" is given as a fraction of the volume of the design space if a Relative Magnitude is specified.

Volume constraint line

OPTIMIZATION RESULTS *DOOR CONNECTION JOINT*; MINIMIZING STRAIN ENERGY, CONSTRAINED BY VOLUME FRACTION



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TOPOLOGY OPTIMIZATION process description using Unigraphics NX

Topic: Settings for extracting geometry (smoothing), control parameters and solving

Name: Steffen Johnsen

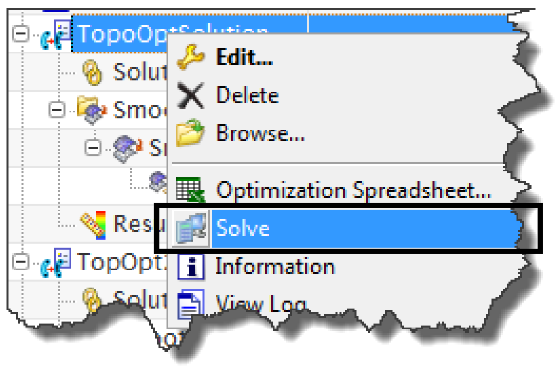
Date: 28.05.2013

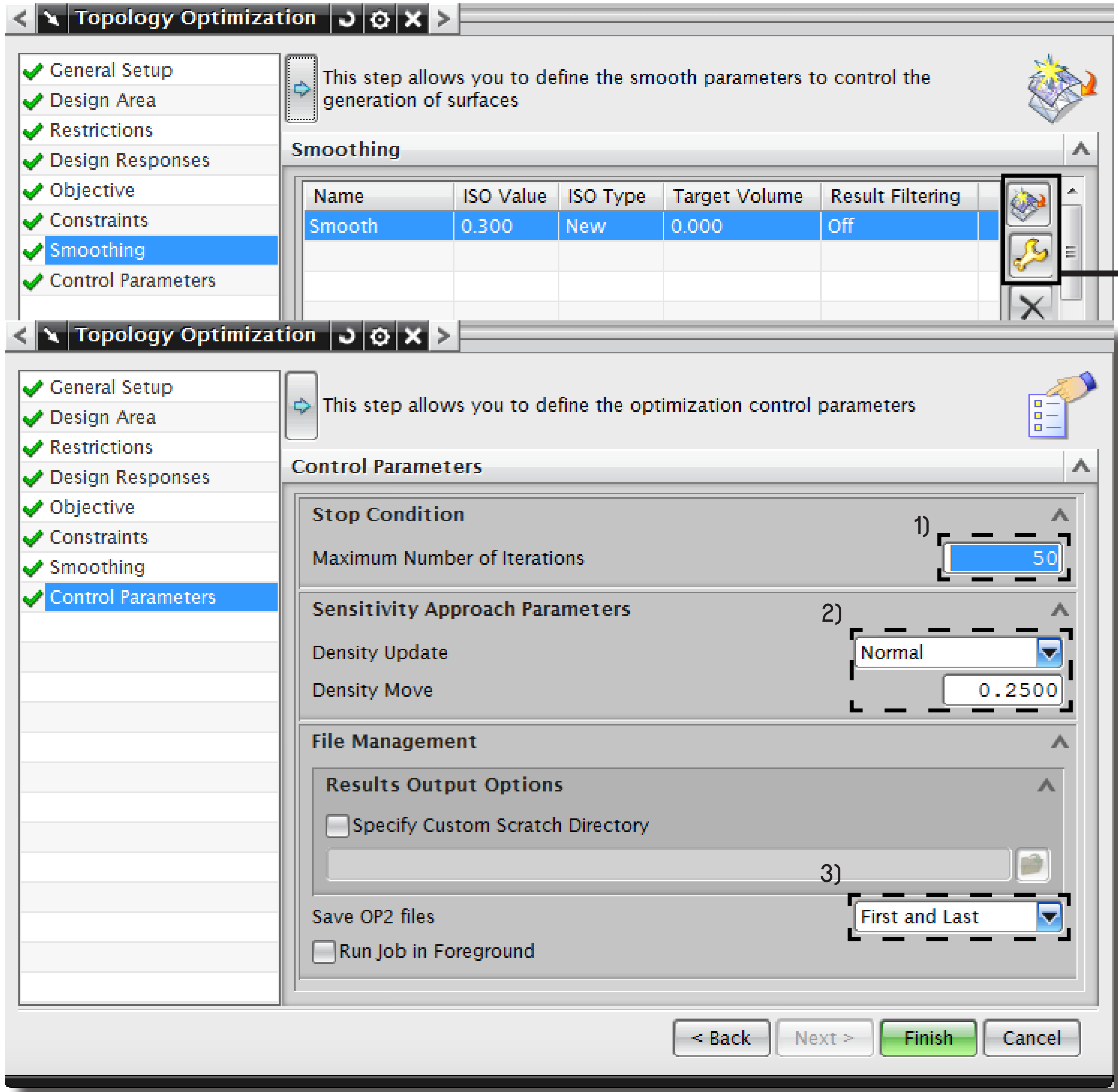
Approved by: Terje Rølvåg

Extracting geometries may be specified using the Smoothing process. Desired utput control variables may be specified. In general, standard values are reasonable and give good results. Advanced setup is therefore omitted.

Control parameters for the simulation run are:
1) The Maximum Number of Iterations will stop the simulation before if the solution diverges. The number should be so high that the simulation stops by itself when convergence is achieved.
2) Sensitivity Approach Parameters may be adjusted to reach convergence if initial simulations fail. Setting Density Update to Conservative and lowering the Density Move value will reduce the extent and magnitude of element density updates, aiding the search for a valid solution.
3) Choose between saving the First and Last .OP2 result files, None or All. The First is recommended.

Click Finish and Solve (right- click process tab and click Solve) to obtain results.

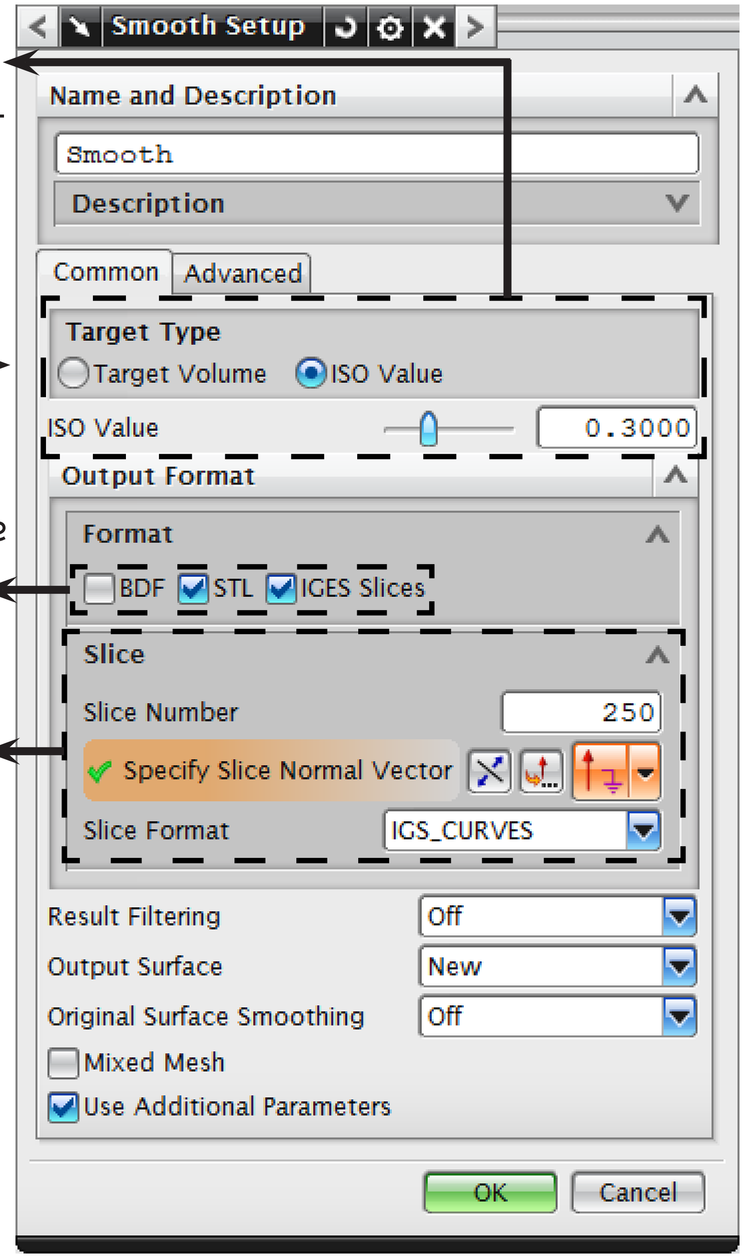




ISO- value will control how strong the smoothing is. 0.3 is recommended as a starting value

Select the desired output file type

IGES slice parameter settings



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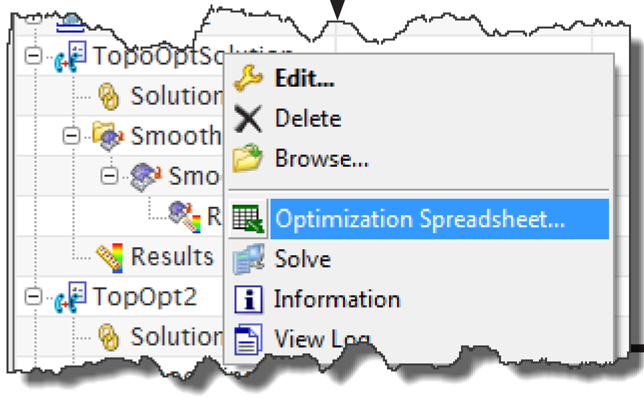
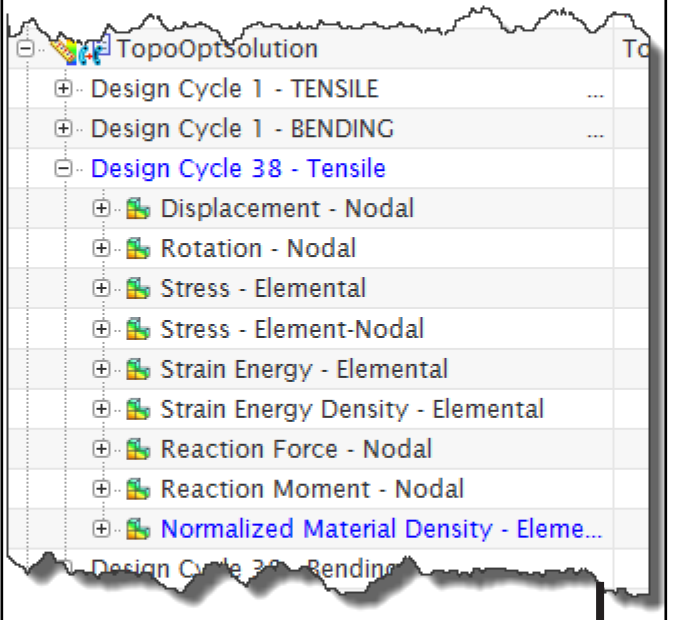
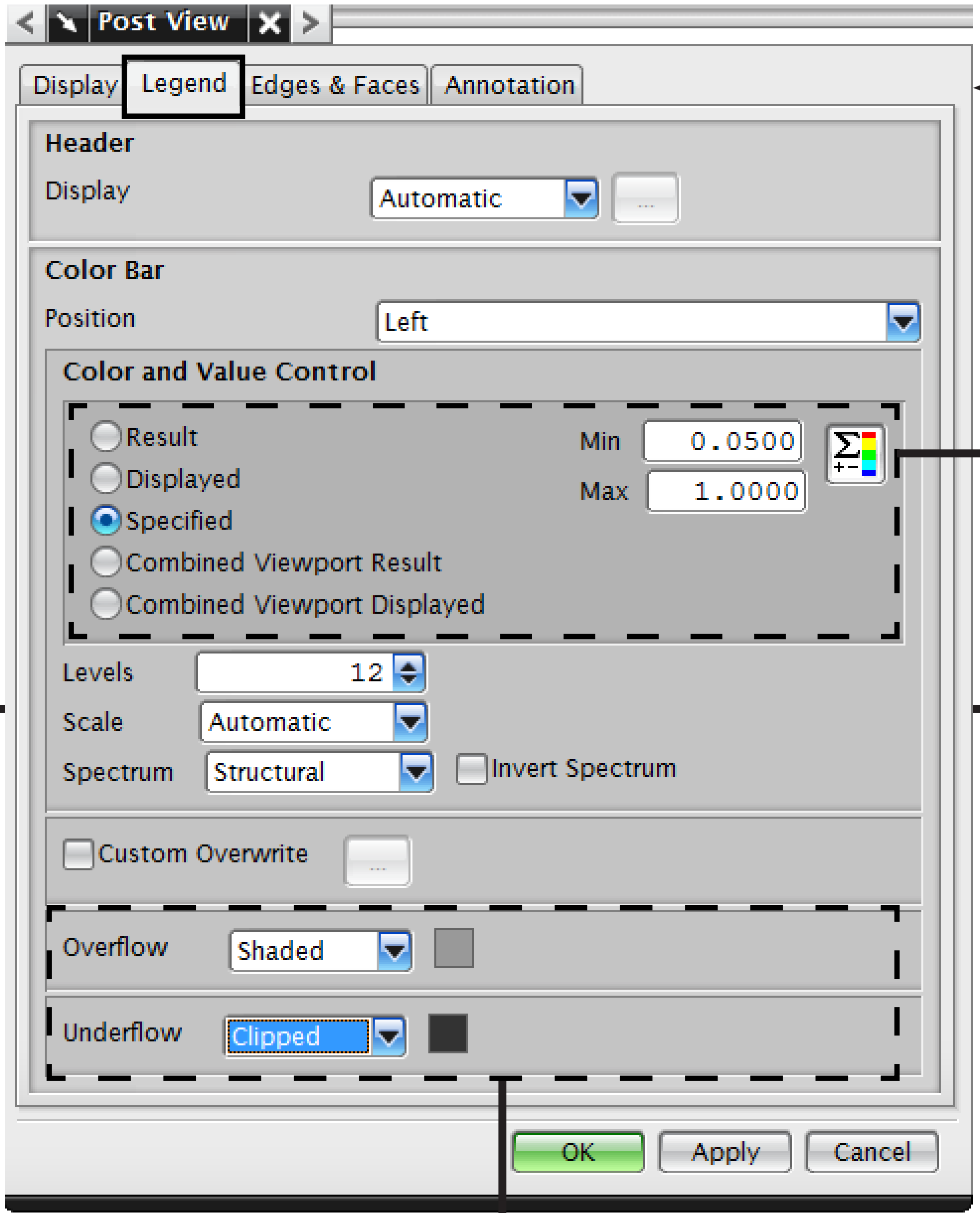
TOPOLOGY OPTIMIZATION process description using Unigraphics NX

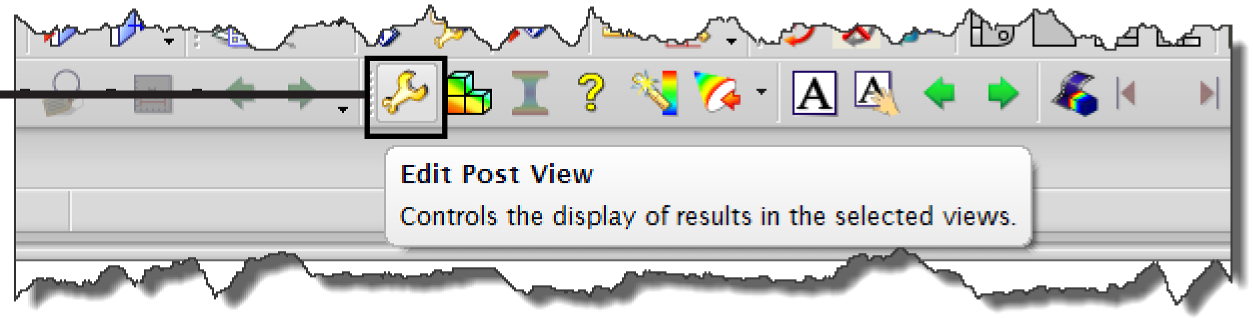
Topic: Post- processing of optimization results; showing the optimized geometry and graphs | Name: Steffen Johnsen | Date: 25.05.2013 | Approved by: Terje Rølvåg

Post- processing of results is important to verify that the simulation has converged, and that the design constraints are within limits. Graphs can be generated by the software by right- clicking the process tab and selecting Optimization Spreadsheet.

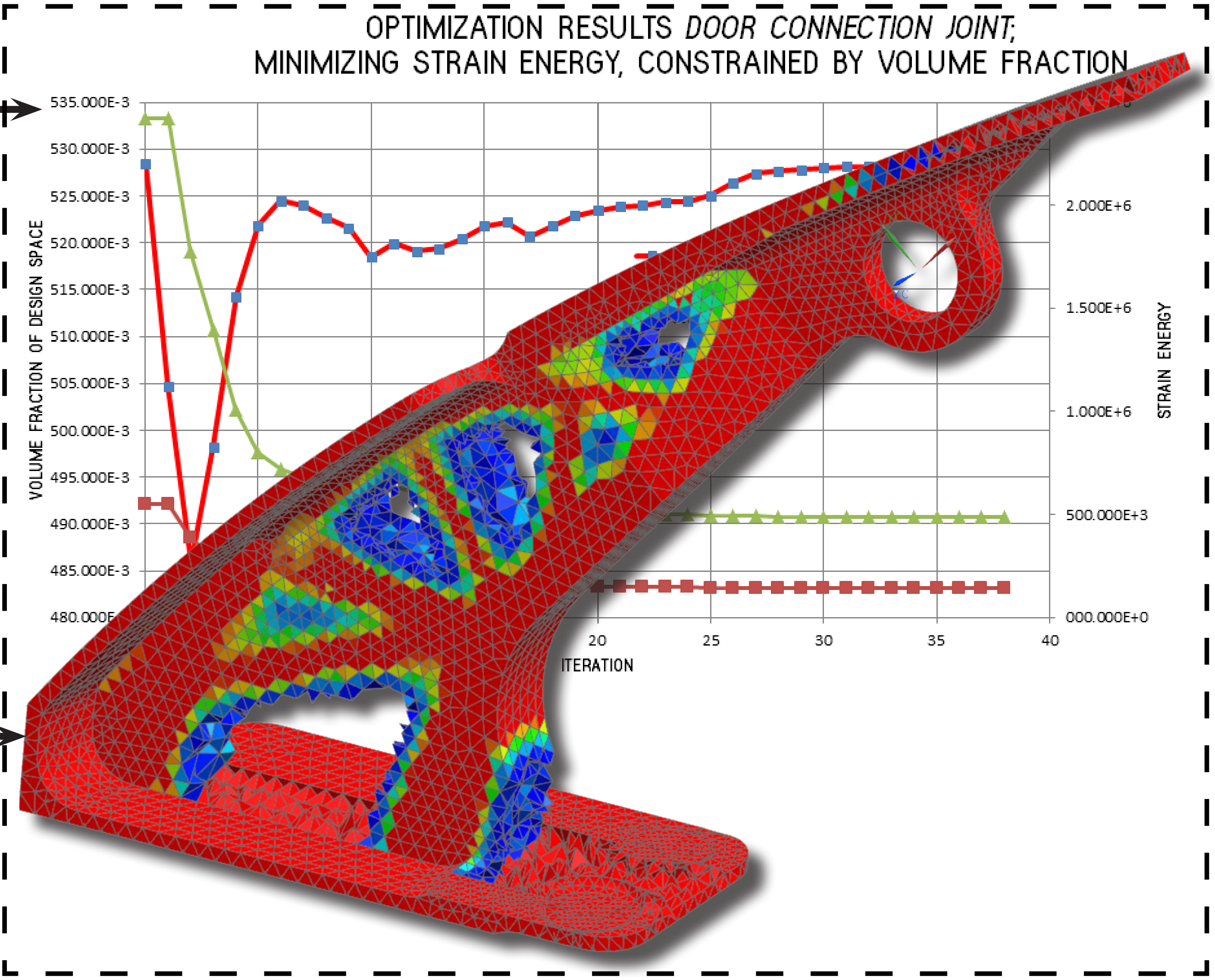








Tick the Specified radio button and set the Min value to 0.05. All elements below 5% of unit normalized density will be removed. This is a conservative value, but often gives adequate removal of material, since intermediate values are not favored by the optimization algorithm.

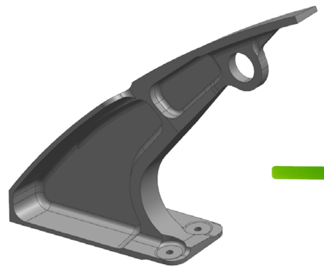


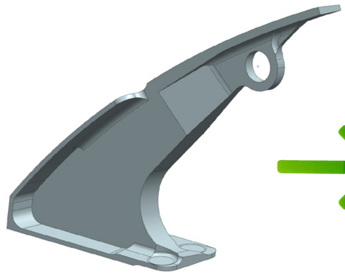
Set Overflow to Shaded and Underflow to Clipped. This will remove elements with normalized densities below the Specified Min value.

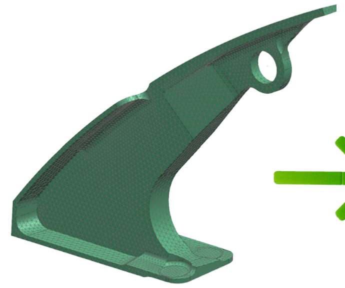
TOPOLOGY OPTIMIZATION process description using Unigraphics NX

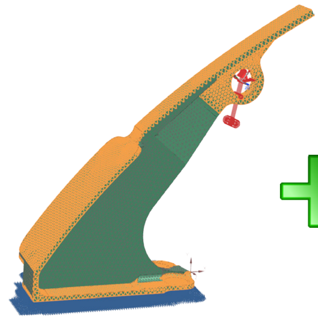
Topic: Topology optimization; minimize strain energy with upper volume limit, summary	Name: Steffen Johnsen	Date: 28.05.2013	Approved by: Terje Rølvåg

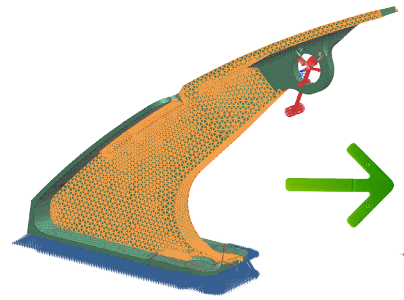
1. Setup a normal static analysis containing all boundary conditions.
2. Evoke the Topology Optimization subprocess wizard, create a new Optimization process, and define a name for the optimization.
3. Define the Design Area
4. Define restrictions (Geometric constraints) to suit the desired output.
5. Define all Design responses (all properties that will be influenced in the analysis; volume, eigenfrequencies, strain energy, displacement, etc.)
6. Choose which Design response to use as an Objective and optimization Target.
7. Define scalar Performance Constraints for the remaining Design responses.
8. Define Geometric Constraints (symmetry, frozen areas, cast condition, etc.). Use as few as possible, and run the first optimization without to see what is demanded.
9. Setup the Smoothing and model extraction process.
10. Adjust Control Parameters.
11. Submit the simulation.
12. When optimization has converged: Look at results by clicking Results and find the Normalized Density. Specify result limits, Underflow and Overflow characteristics.
13. Make a copy of the .prt- file with the Design Space, import the STL file and use modeling tools and transform the part to look like the optimization result, or import the STL into an empty part and build the new part from scratch.

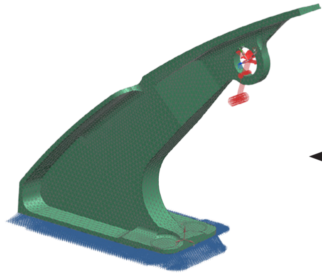

Original geometry


Design space

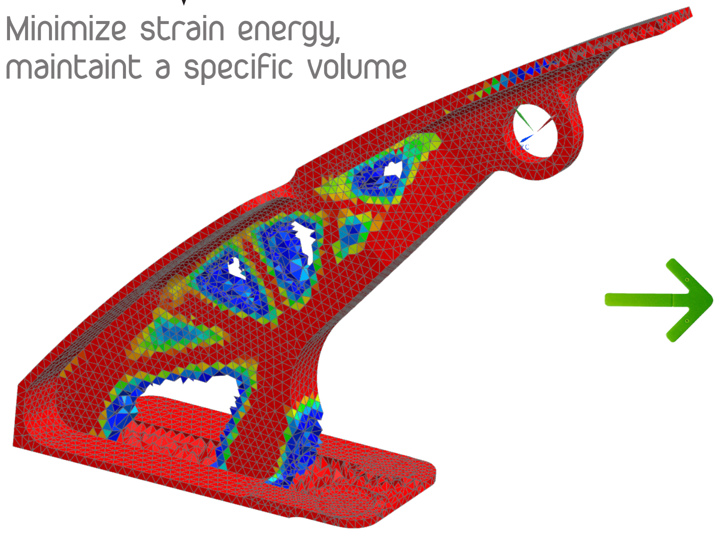

Meshed model


Model w/ geometric constraints

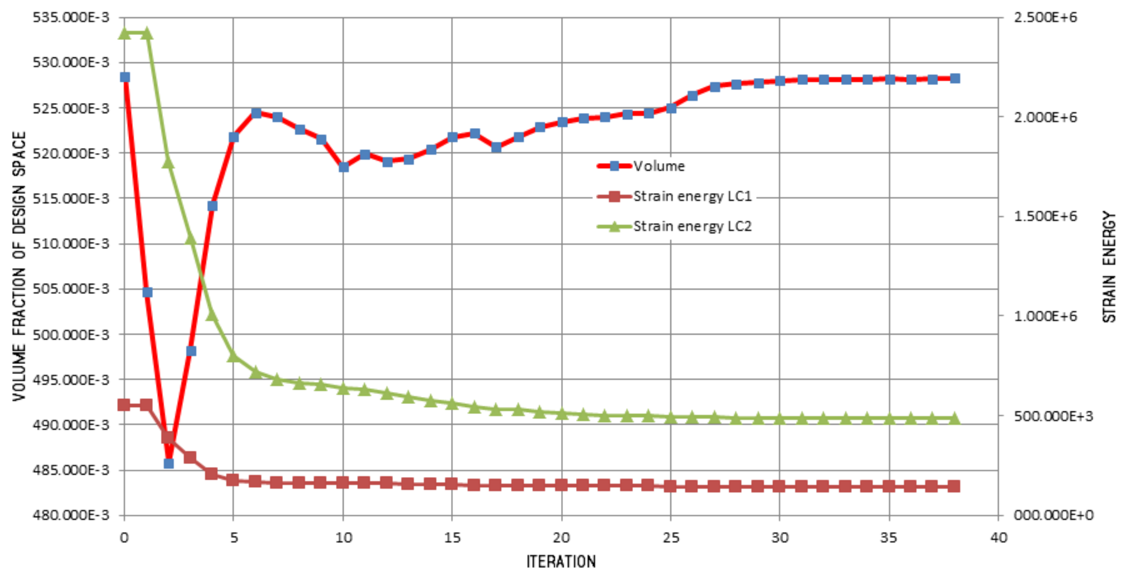



Loaded model (2.5 kN LC1 and LC2 load defined in subsequent subcases). Constrained at the bottom surface.

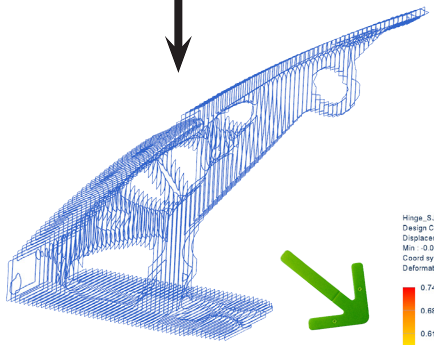
Minimize strain energy, maintaint a specific volume

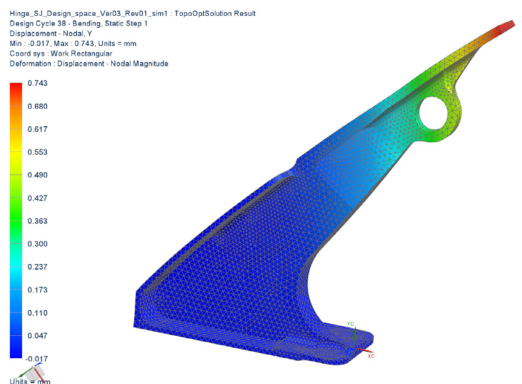

Optimization result

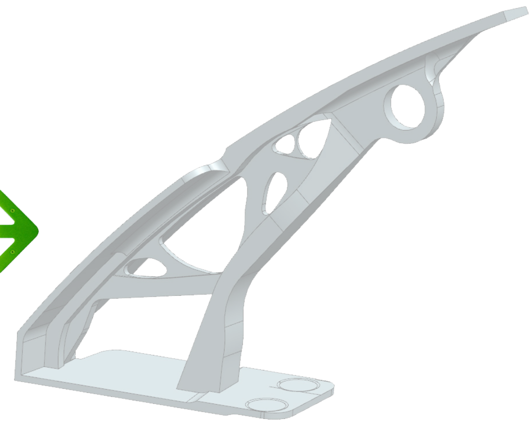
OPTIMIZATION RESULTS *DOOR CONNECTION JOINT*; MINIMIZING STRAIN ENERGY, CONSTRAINED BY VOLUME FRACTION



Optimization graph


Extracted geometry (IGES slices shown)


Results read- out


Reengineered part (illustration picture)

Objective:	Minimize strain energy (max. stiffness)
Constraints:	Save 10% volume -> Volume fraction
Geometric constraints:	Frozen areas (see figure) and symmetry (not for frozen areas).

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