MINIMIZATION OF PART WARPAGE IN INJECTION MOLDING THROUGH IDEAL WALL THICKNESS DISTRIBUTION

Seminar:
Auslegung und Simulation von temperaturbeanspruchten Kunststoffbauteilen

INSTITUT FÜR WERKSTOFFTECHNIK UND KUNSTSTOFFVERARBEITUNG

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HSR HOCHSCHULE FÜR TECHNIK RAPPERSWIL
FHO Fachhochschule Ostschweiz

VDI Verein Deutscher Ingenieure
Bodensee-Bezirksverein e.V. Friedrichshafen

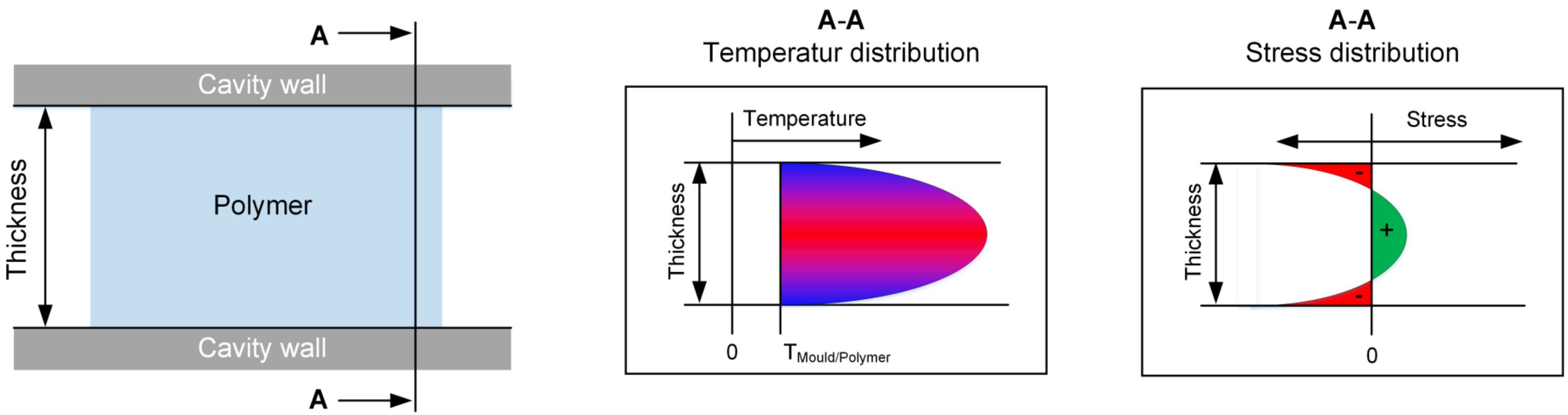
Outline

- **Introduction**
- **Automatic optimization procedure for warpage minimization**
- **Realization of the procedure**
- **Verification of the procedure on an industrial part**
- **Conclusions and outlook**

The causes of part warpage in injection molding

- Due to its processing conditions injection molded parts undergoes high thermal and mechanical stresses

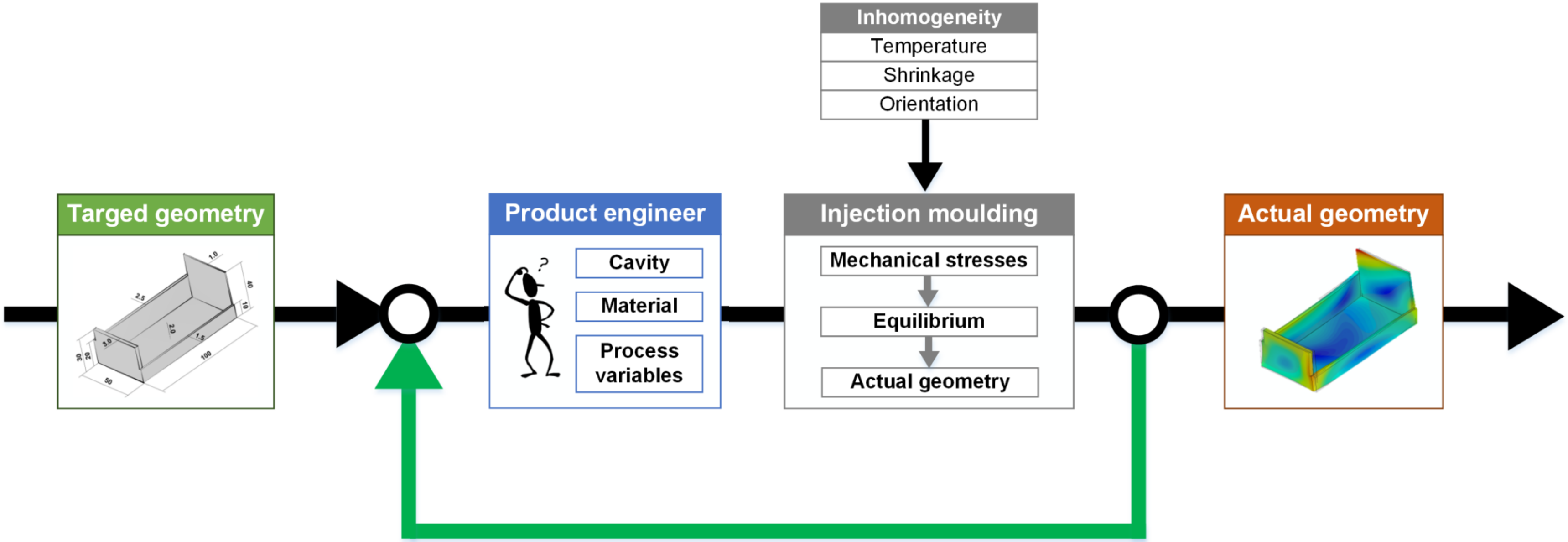
- As a result of the short processing times, the induced mechanical stresses do not completely relax inside the mold



- As a consequence, the shape of most molded parts differs from the intended design and results in warpage

Consequences for the product development

- Complex relationships and limited resources for automatically optimization lead to a manual driven closed loop control during product development



- Many time consuming iterations and expertise of specialists are needed

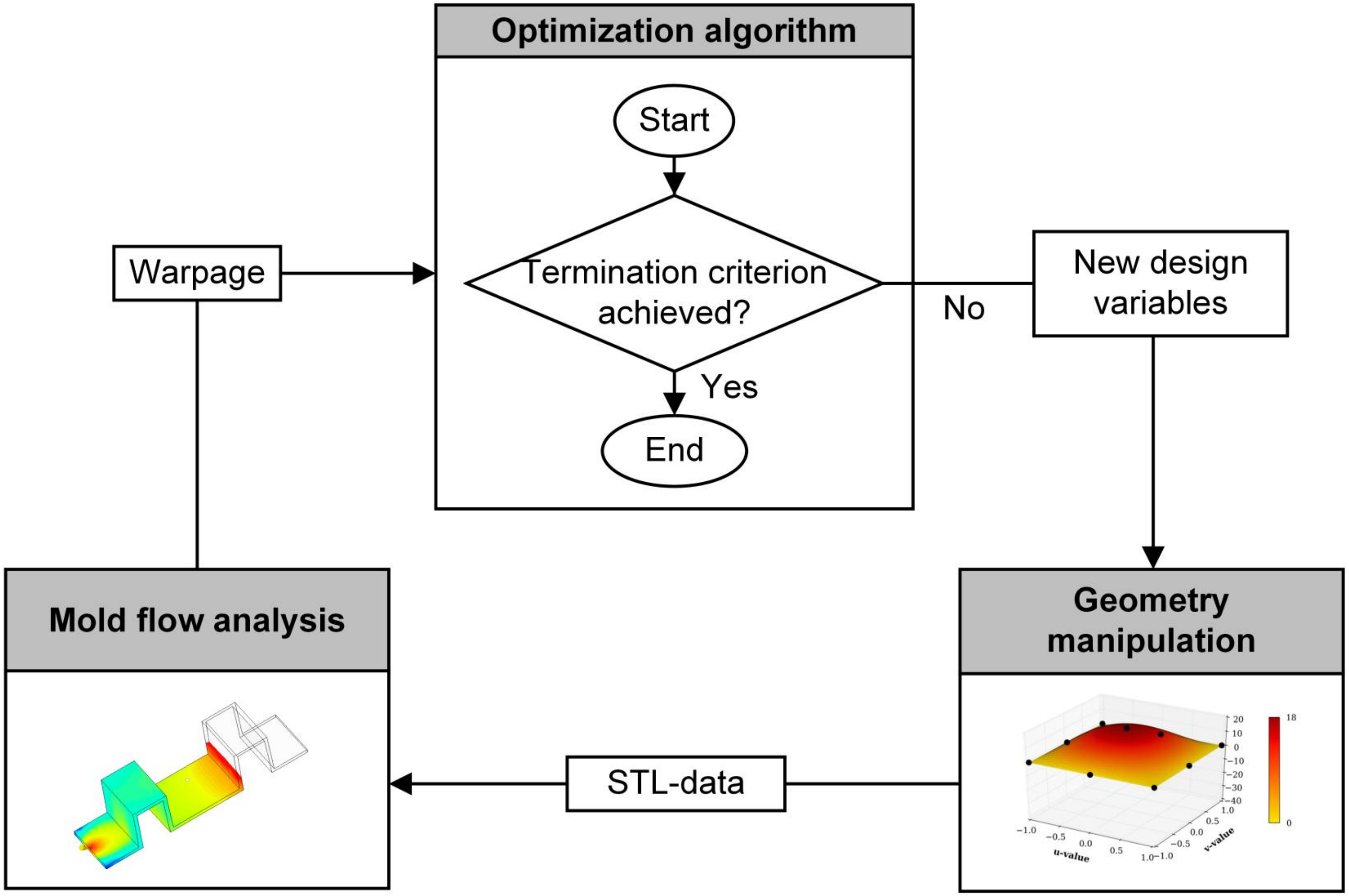
Measures to reduce part warpage

- Based on a defined polymeric material and a fixed gate position, there are three practicable methods to reduce the part warpage:

		Impact	Remarks
Root caused methods	Optimization of process variables	global	Influence on process window and assurance
Root caused methods	Optimization of wall thickness distribution	global / local	Incluence on filling-, post-filling and cooling stage
Treatment of the symptoms	Reverse Engineering (pre deformation of cavity)	global / local	High risk for post-deformation after relaxation of the stresses

[Lee, Kim 1995]

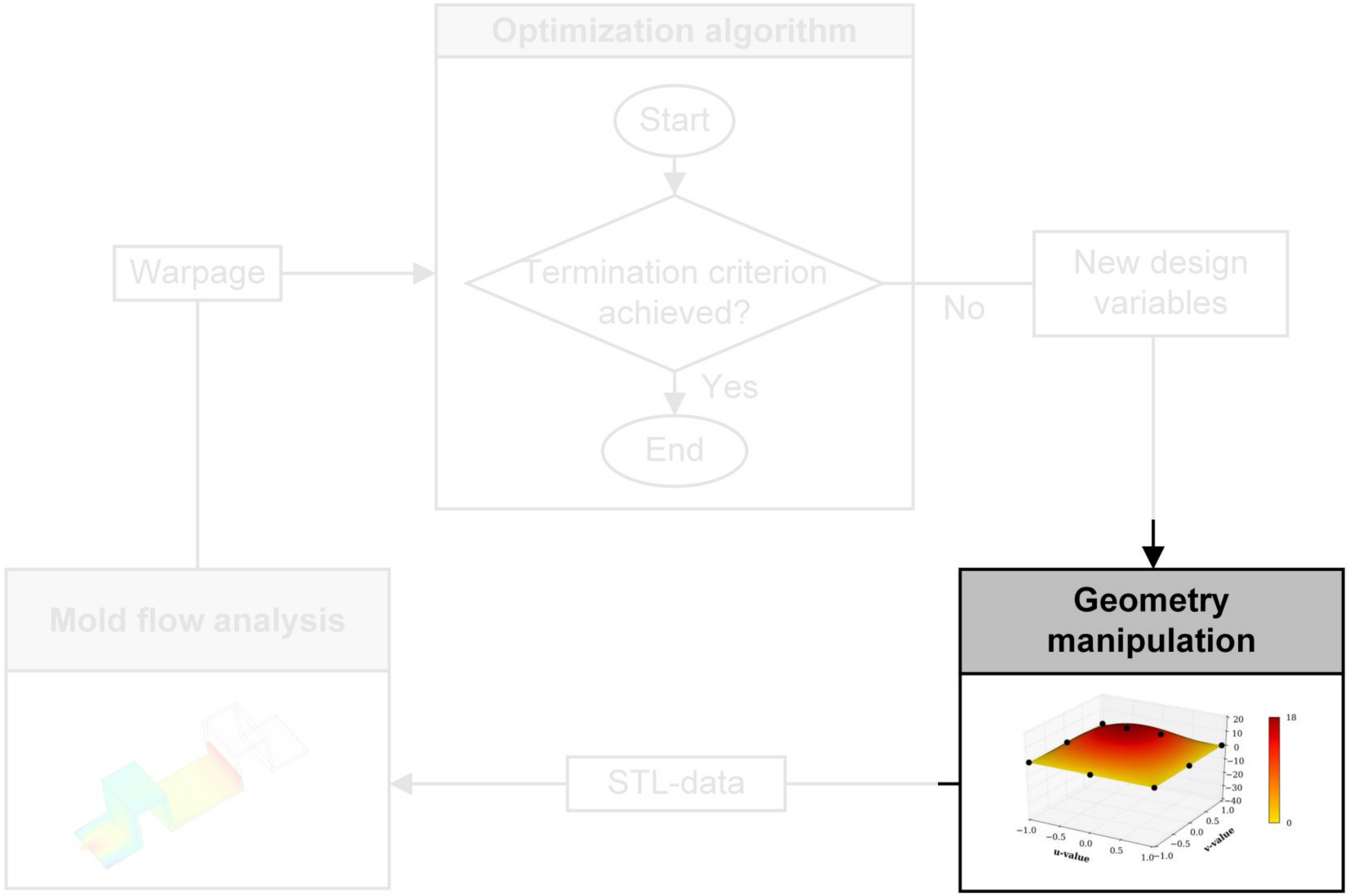
Automatic optimization procedure for warpage minimization



Challenges for the realization of the procedure

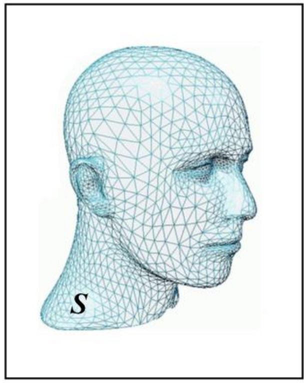
Tool	Challenges
Geometry manipulation	▪ CAD-Software independent variation of wall thickness ▪ Wide-area variation with few parameters ▪ Fast STL-Data generation of manipulated geometry
Mold flow analysis	▪ High computational effort ▪ Automatic control and evaluation of warpage
Optimization algorithm	▪ No formula ▪ Function with many variables ▪ Communication between the different tools

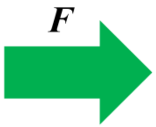
Realization of the procedure – Geometry manipulation



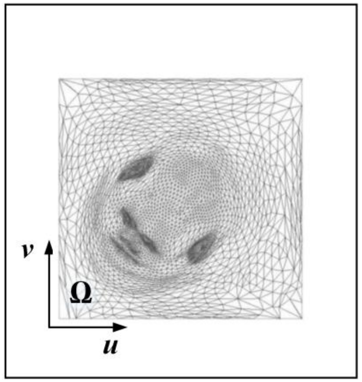
Mesh parameterization – Inspiration for manipulating geometries

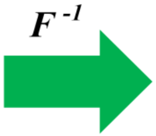
3D-Mesh



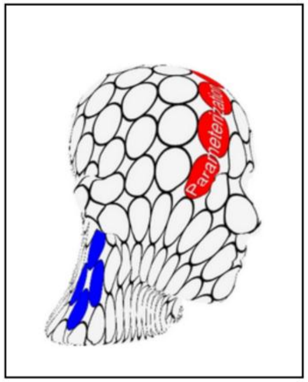


Unit square parameterization

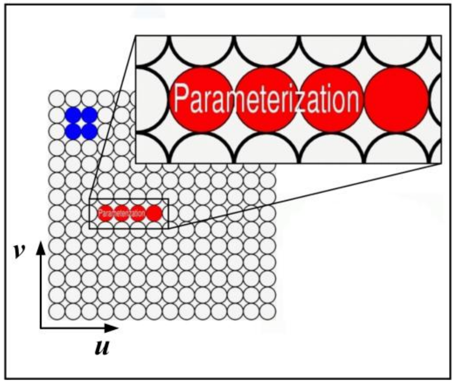




3D-Mesh with applied texture



Texture to apply

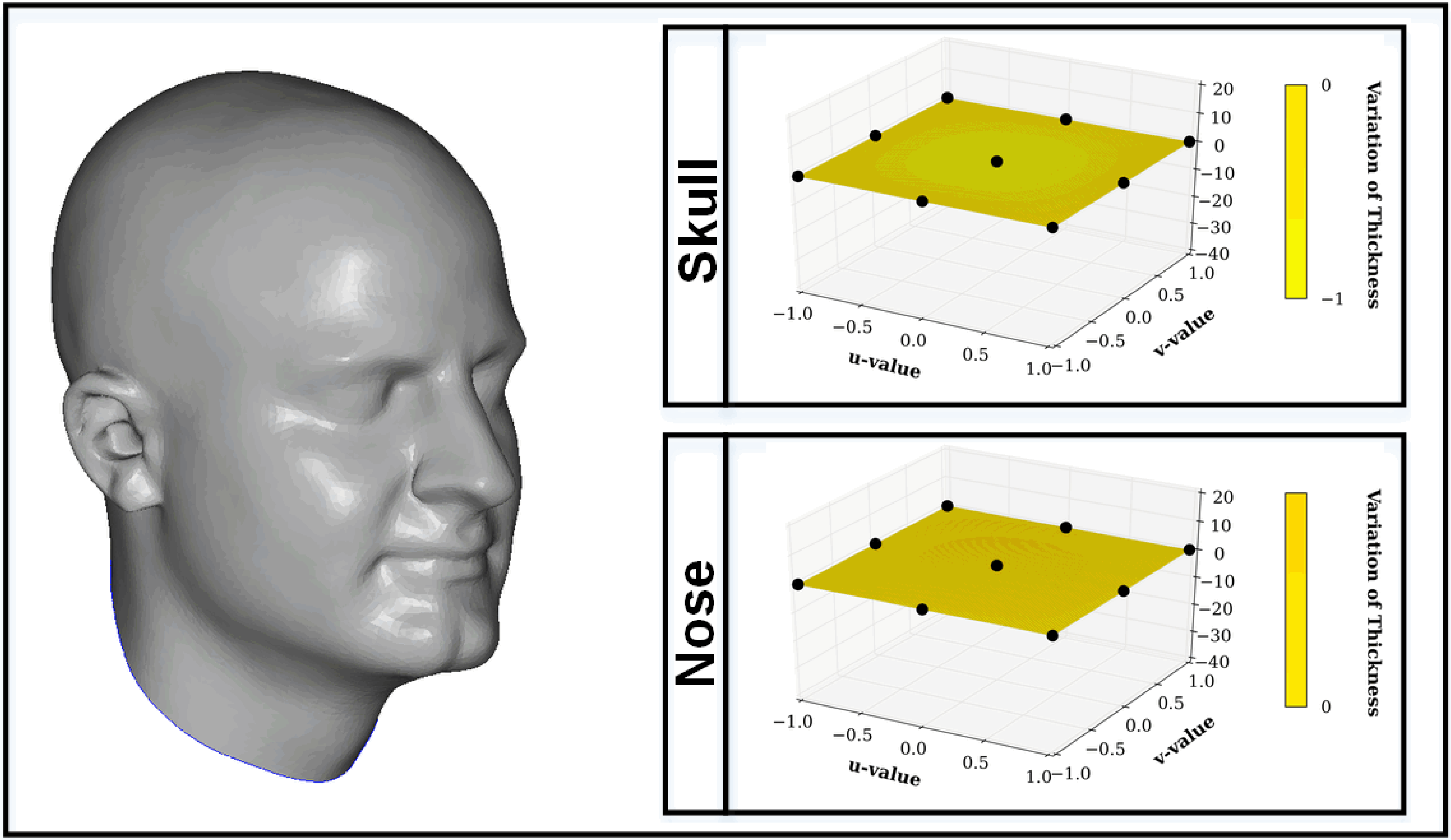


Widely used technique for many applications in computer graphics and geometric modeling:

- texture mapping
- shape morphing
- surface reconstruction

[Yoshizawa, Belayev, Seidel, 2004]

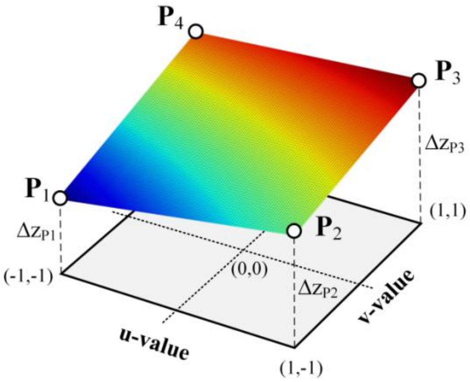
The idea – Transformation of changes in wall thickness



The three main steps of geometry manipulation

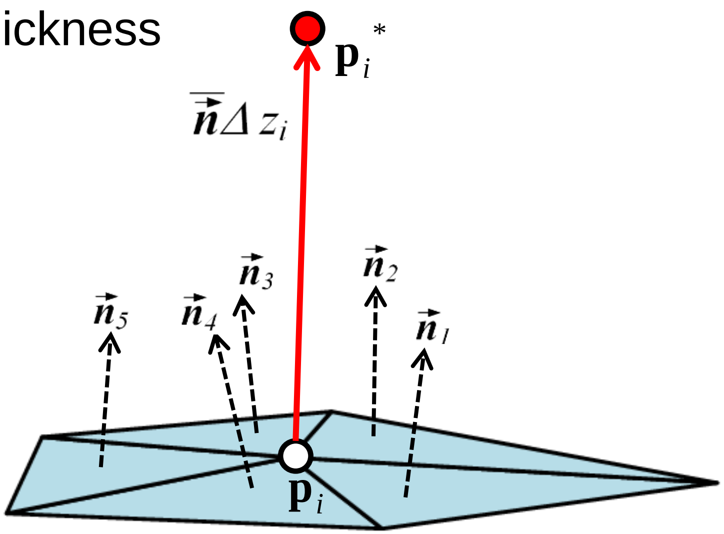
- **Step 1:** Solving of the parameterization
- **Step 2:** Modeling the distribution of changes in wall thickness

$$\Delta z(u,v) = \sum_{i=0}^{n_p} \sum_{j=0}^{n_p} C_{i,j} u^i v^j \qquad \Big| \, u,v \in [-1,\ldots,1]$$

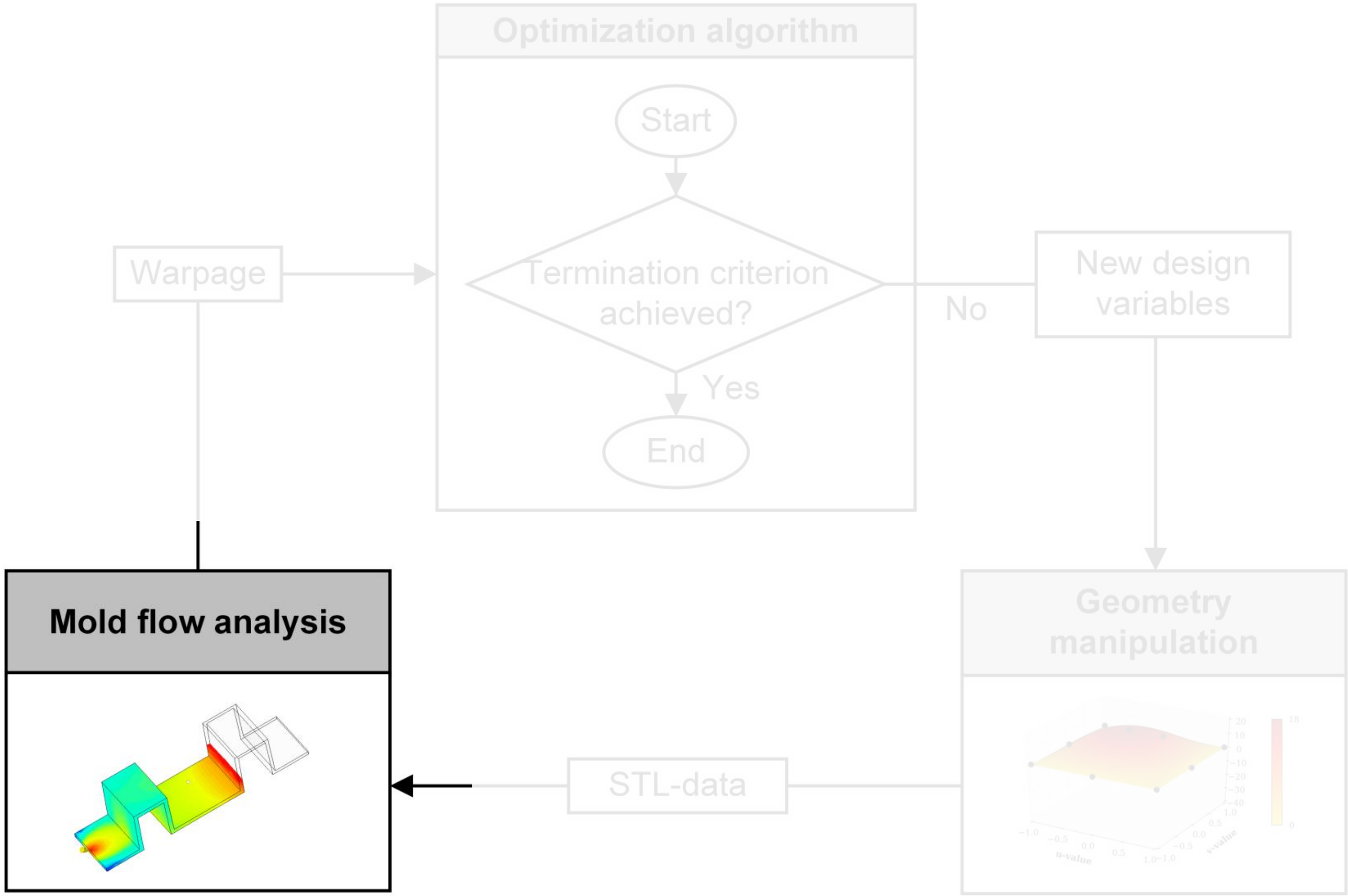


- **Step 3:** Applying the changes in wall thickness

$$\mathbf{p}_i^* = \mathbf{p}_i + \frac{1}{n_{Nb}} \sum_{j=1}^{n_{Nb}} \vec{n}_j \Delta z(\mathbf{u}_i) g_w$$

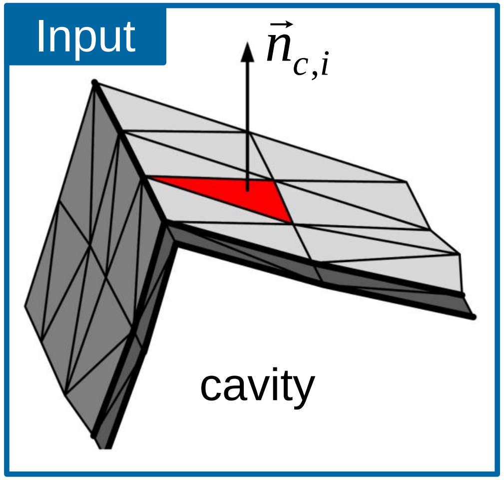


Realization of the procedure – Mold flow analysis



Mold flow analysis with Cadmould 3D-F CMV6

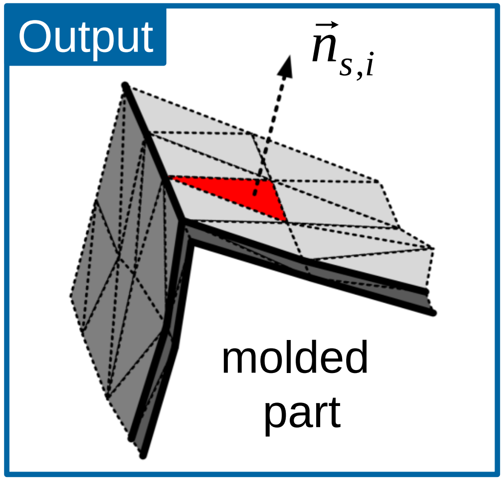
- Patented 3D-framework technology, which solves the generalized Hele-Shaw equations along and between the surfaces → fast computation
- Automatic FE-mesh generation on the STL-data for the geometry
- Uses commands and log-files for automatic control of the simulation runs
- Calculates the deformation trajectory caused from molding process:



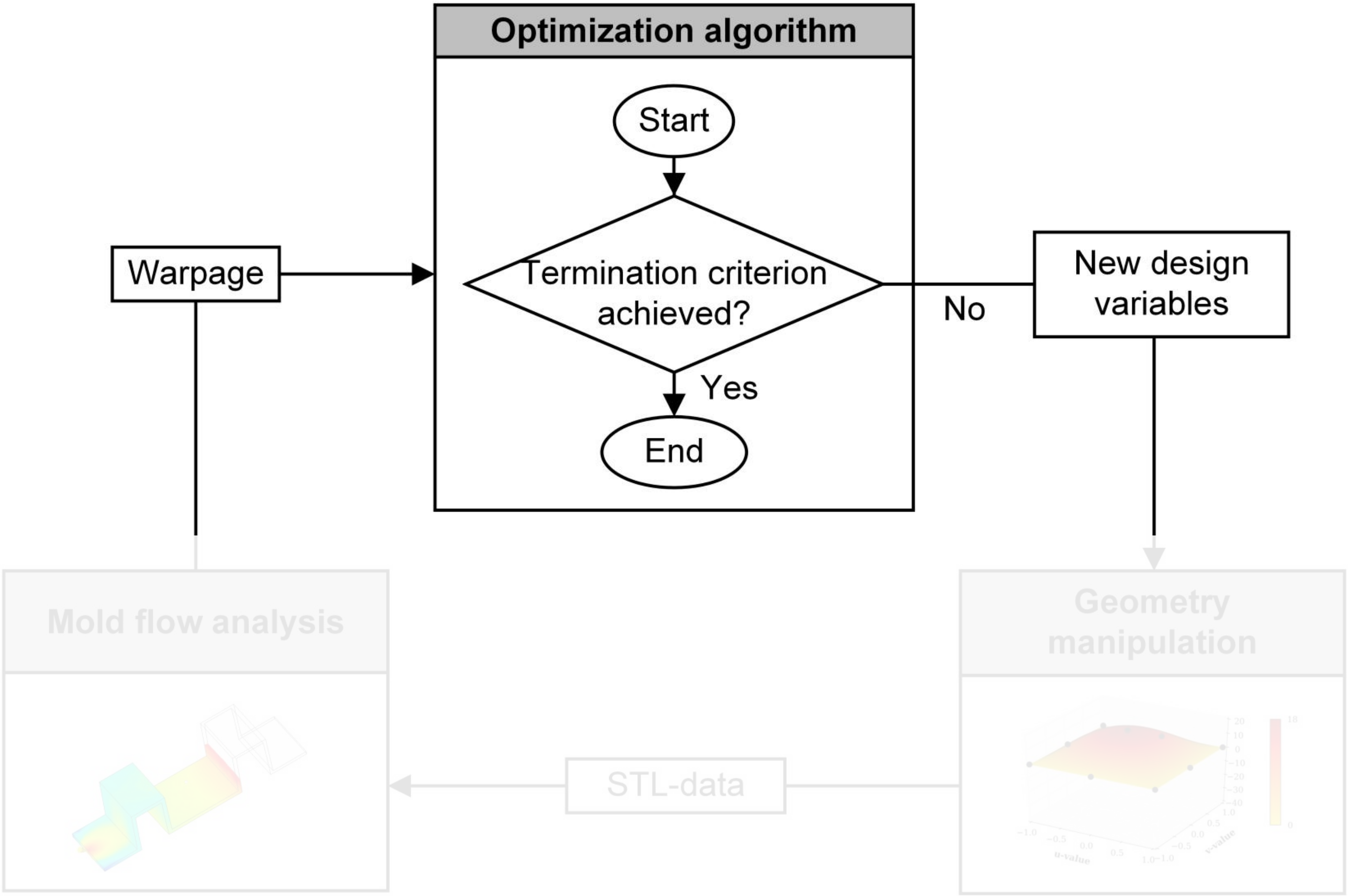
Comparison of surfaces element normal before and after molding

$$\varphi_{w,i} = \angle\left(\vec{n}_{c,i}, \vec{n}_{s,i}\right)$$

Measure for the warpage



Realization of the procedure – Optimization algorithm



Formulation of the optimization problem

- **Objective of optimization:**
  - Consideration of average and maximum change in the surfaces normal

Average: $\bar{\varphi}_w = \frac{1}{n_{el}} \sum_{i=1}^{n_{el}} \varphi_{w,i}$

Maximum: $\varphi_{w,\max} = \max\{\varphi_{w,i}\}$

Objective function:

$$F_w = \frac{\bar{\varphi}_w}{\bar{\varphi}_w^0} + \frac{\varphi_{w,\max}}{\varphi_{w,\max}^0}$$

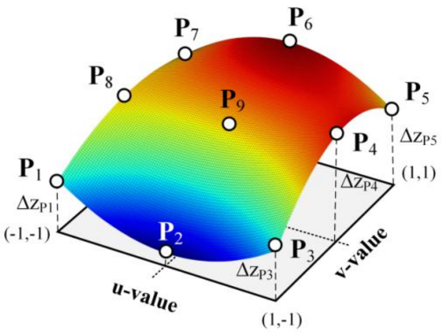
Values of the initial geometry for the cavity

- **Optimization problem:**

$$\min_{\mathbf{x}} \{F_w(\mathbf{x})\}$$

Boundaries:

$$\Delta z_{\min,i} \le \Delta z_{P,i} \le \Delta z_{\max,i}$$



Solving the optimization problem

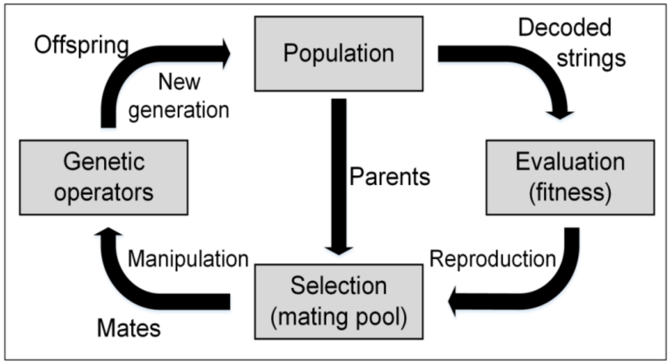
- **No analytical model**
  - Information on local gradients cannot be easily and accurate obtained
- **Using derivative free optimization (DFO) algorithms from each class:**

a) Meta heuristic optimization strategy → Genetic algorithm (GA)

b) Direct search method → Constraints by linear approximation (COBYLA)

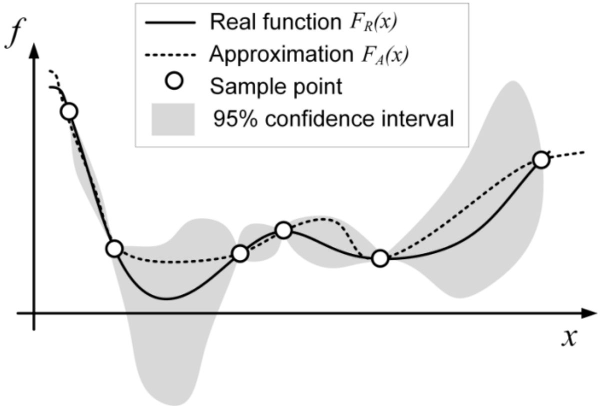
c) Surface response method → Surrogate based optimization (SBO)

GA



[Filho, Treleaven, 1994]

SBO



Terminology and data flow of optimization

Start with initial geometry (STL)

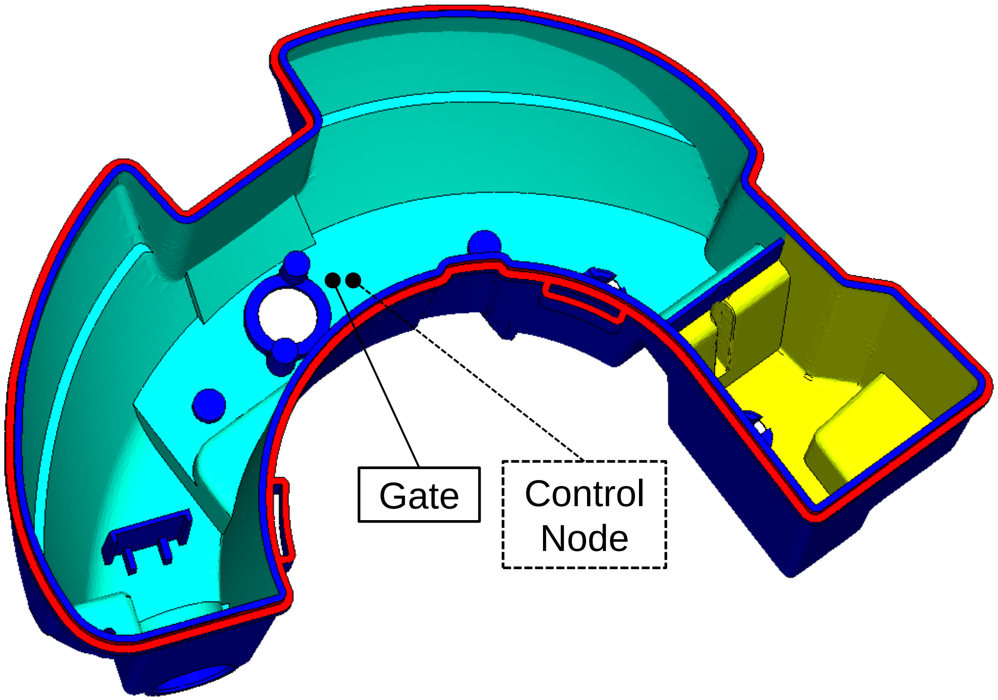
Preprocessing

- Determination of process variables (best practice)
- Initialization of parameterization trough definition of
  - Area sections for the variation
  - Polynomial degree
  - Bounds for variation
- Run the parameterization

Optimization

End with optimized geometry (STL)

Verification of the procedure on an industrial part



Initial thickness [mm]
2.5 / 2.0

Dimensions [mm]
260 x 225 x 125

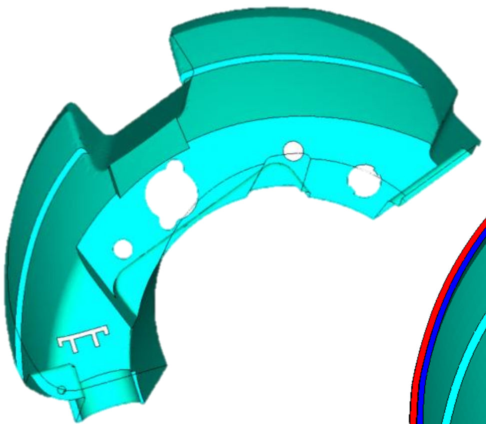
Polymer	ABS
No. triangle elements	23’000
Intel i7 CPU @3.5GHz	16GB RAM

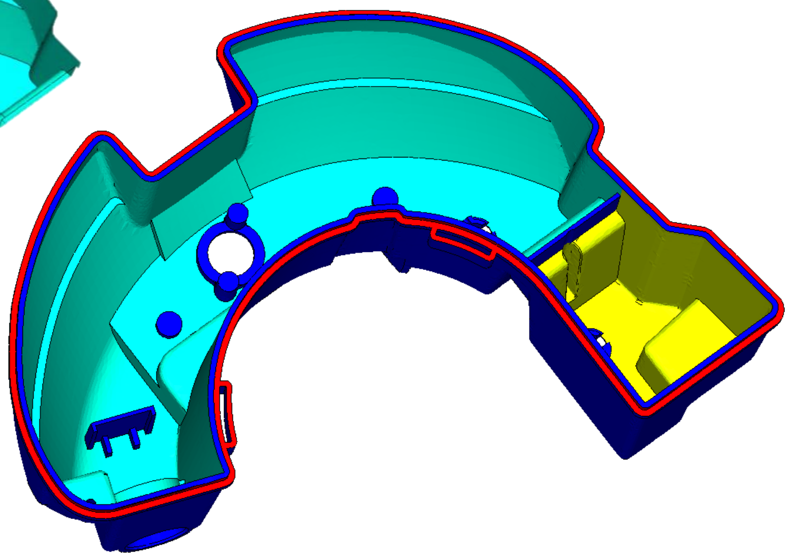
Process conditions		Value
Injection time	[s]	1.8
Post-fill time	[s]	25
Packing time	[s]	15
Packing pressure	[MPa]	60
Melting temperature	[°C]	240
Temperature of cavity	[°C]	27

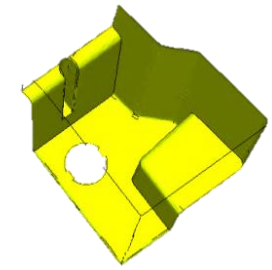
Verification of the procedure on an industrial part

Section 1		**Value**
Δz_{max}	[mm]	0.7
Δz_{min}	[mm]	-0.7
Polynomial degree	[-]	2

Section 2		**Value**
Δz_{max}	[mm]	0.7
Δz_{min}	[mm]	-0.7
Polynomial degree	[-]	2

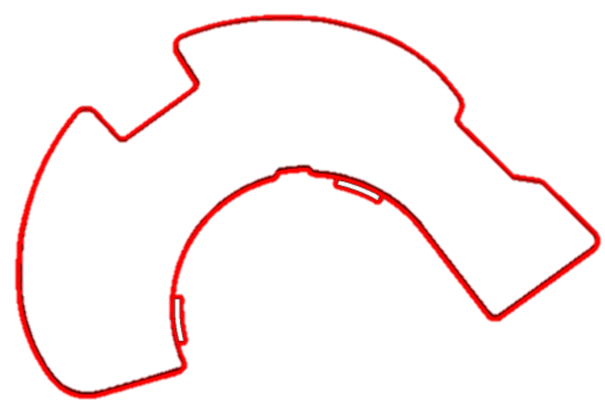




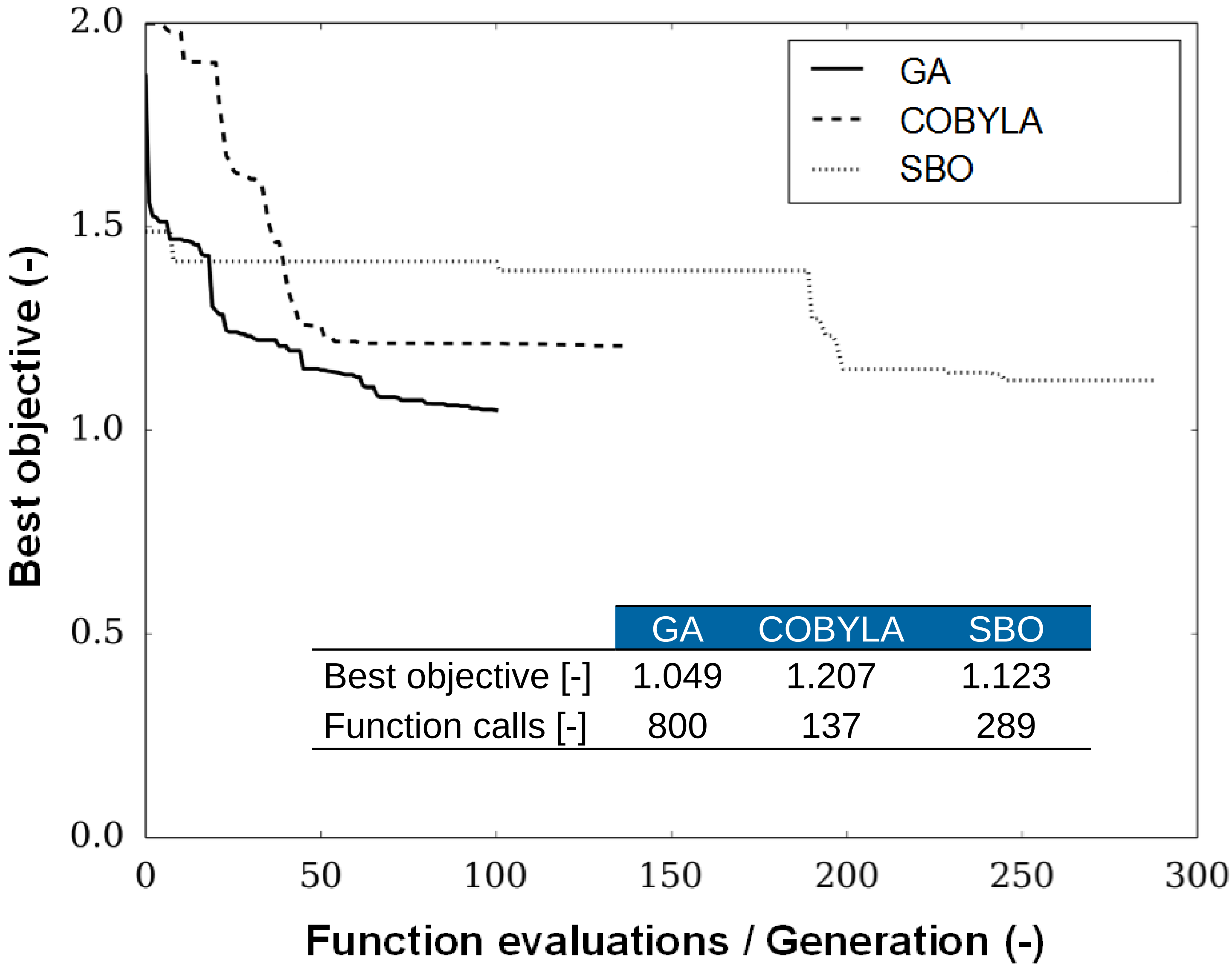


Area section for warpage optimization

→ Welding process after assembly

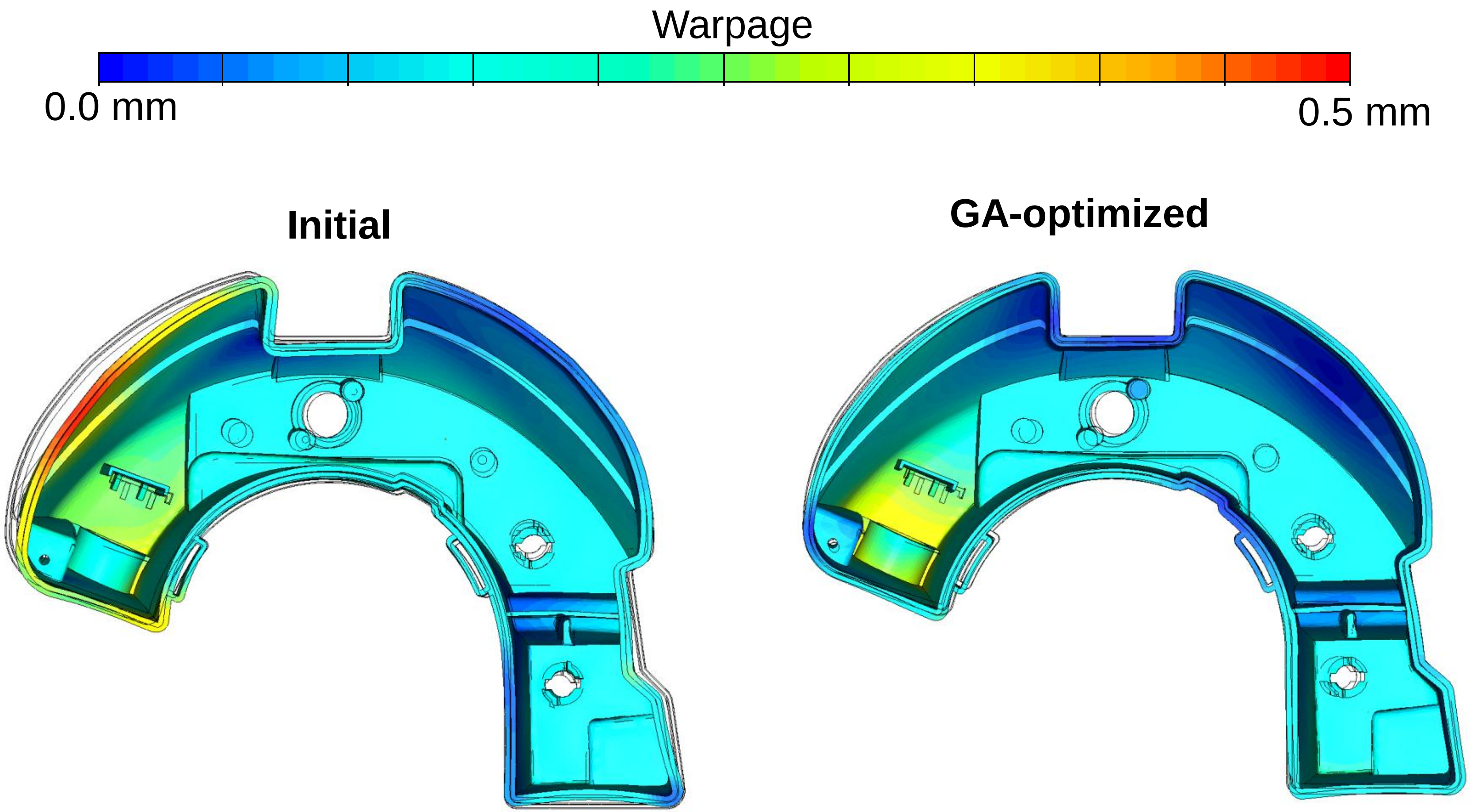


Results: a) History of optimization



	GA	COBYLA	SBO
Best objective [-]	1.049	1.207	1.123
Function calls [-]	800	137	289

Results: b) Warpage plot



ADMOULD® 3D-F

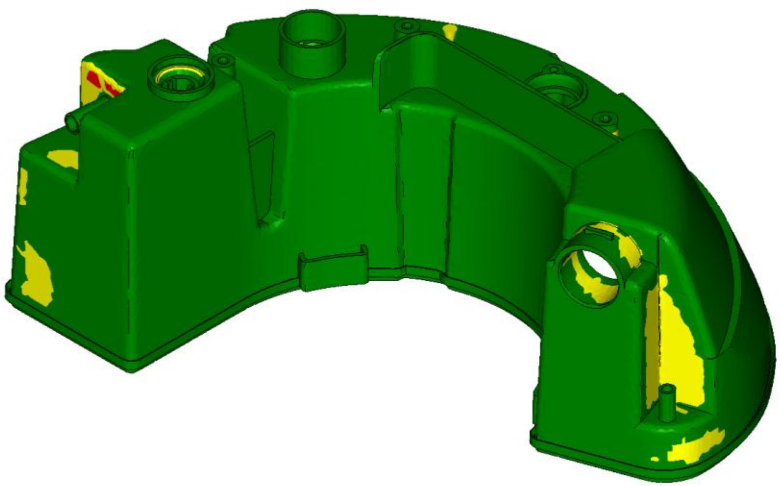
Geometrical scaling factor = 20

Results: c) risk for sink marks

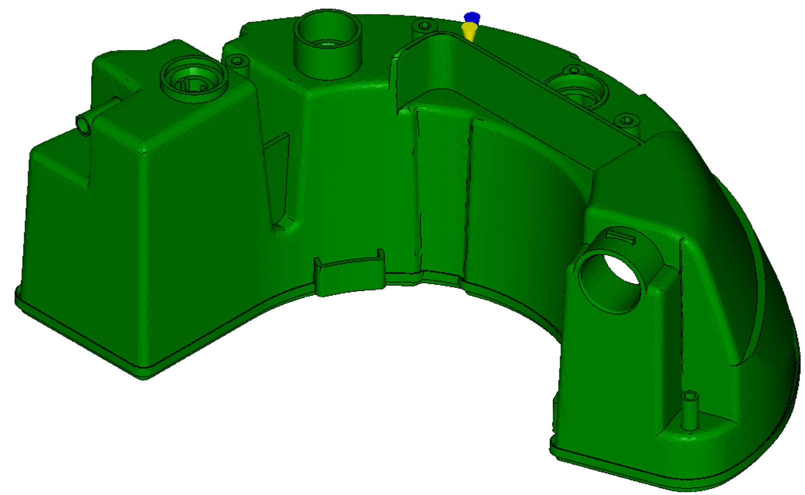
low | medium | high

risk for sink marks

Initial

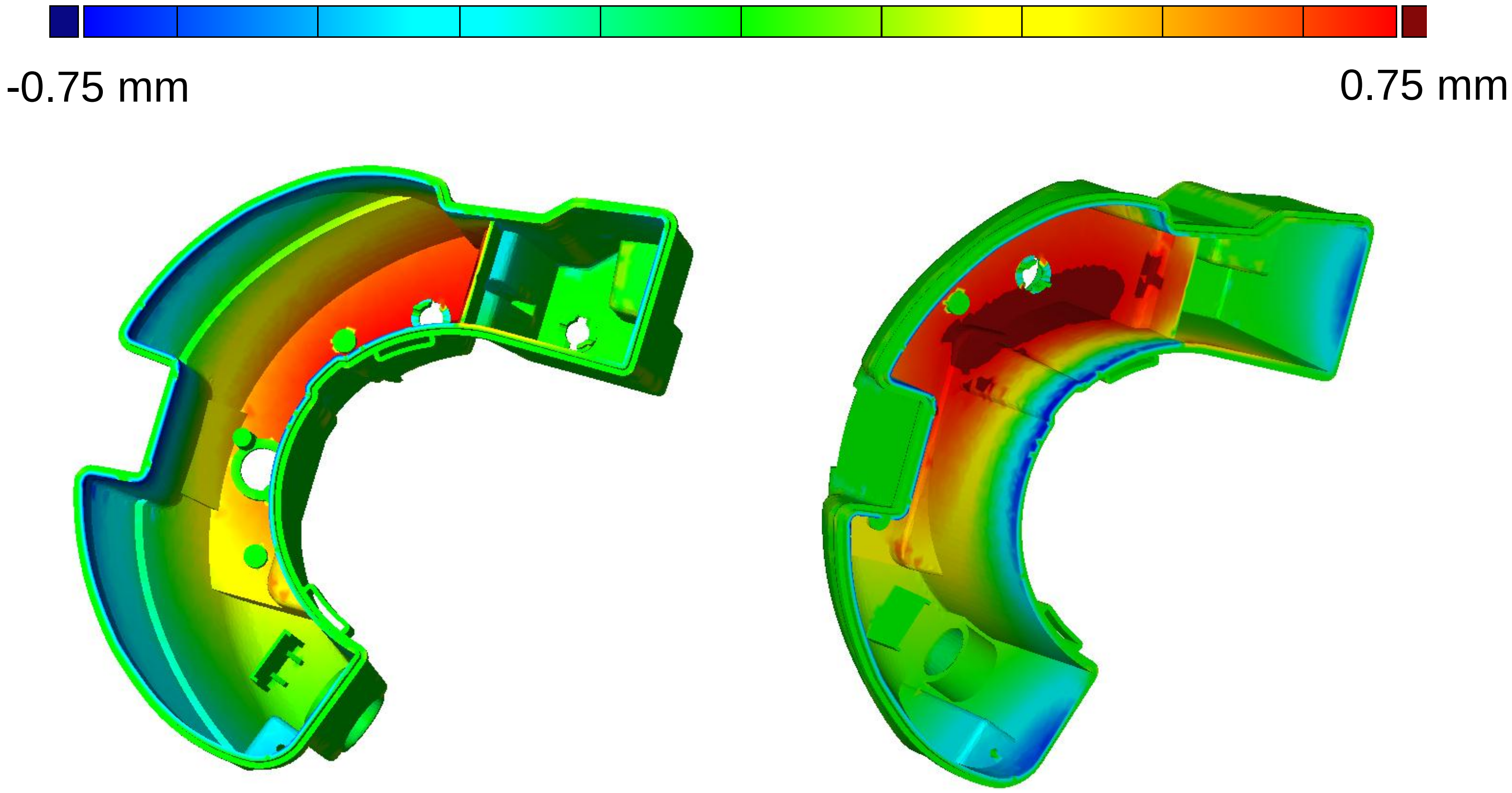


GA-optimized



Results: d) comparison of wall thicknesses

Changes in wall thickness (initial vs. GA-optimized)



FREE GOM Inspect

Conclusions and outlook

- **The warpage of injection-molded parts is an omnipresent problem in new product developement**
- **Optimizing the wall thickness distribution is an effective method to minimize part warpage**
- **Mesh-parameterization enables fast thickness variations without use of commercial CAD-software**
- **Derivative free optimization algorithms leads to impressive reductions in part warpage**
- **High plausibility of the optimized wall thickness distribution**
- **The presented methodology will be developed further**

Thank you for your kind attention!

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