Beurteilung und Beeinflussung der Zuverlässigkeit von Tiefziehprozessen in der frühen Entwurfsphase

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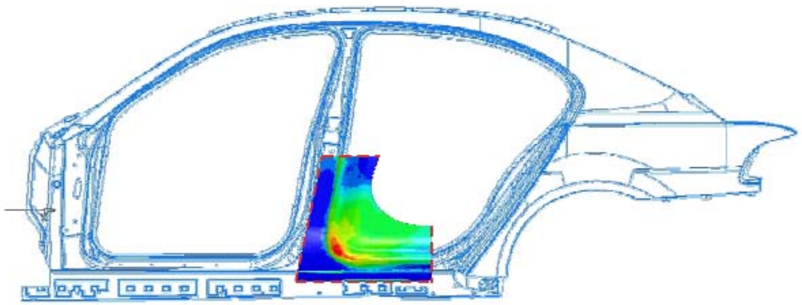
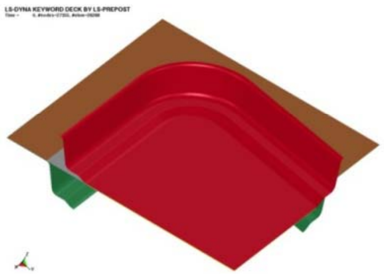
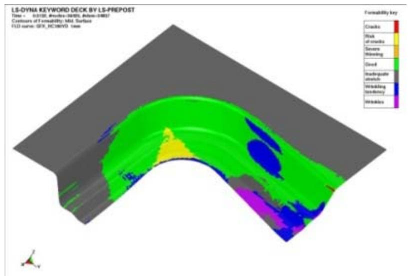
Motivation





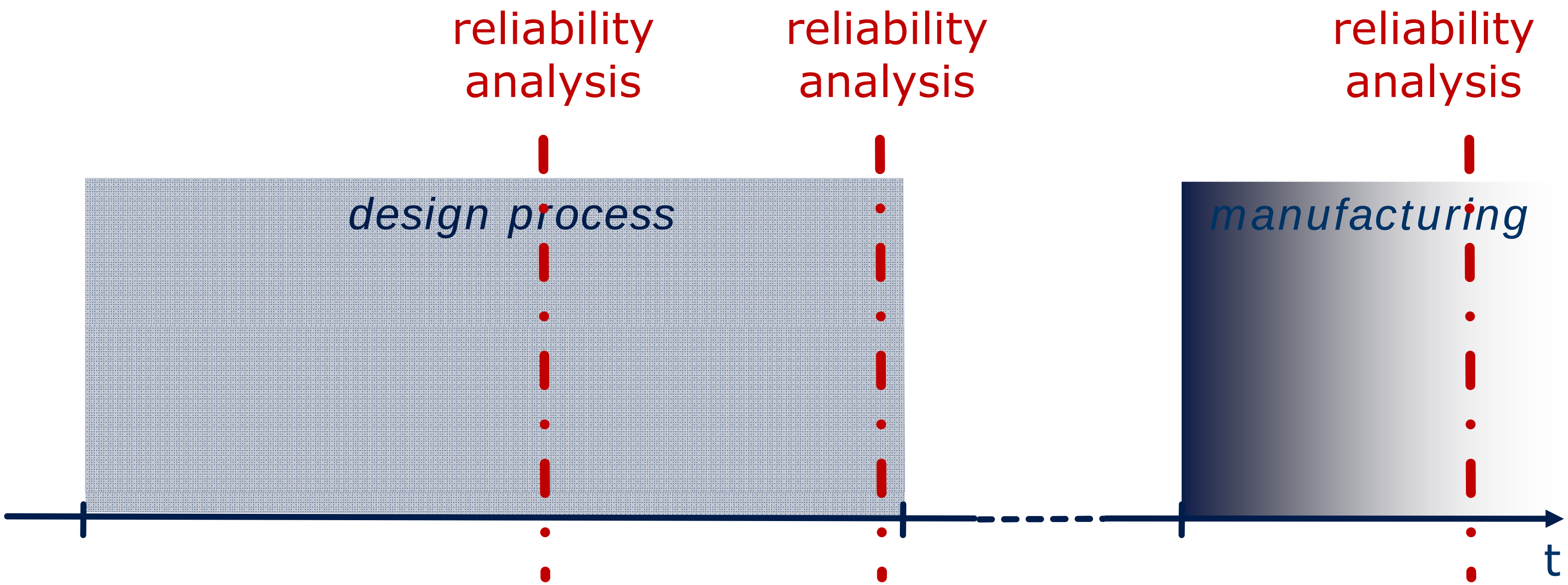


charge A ⇨ too many rejects in production process

charge B ⇨ reliable production process

- numerical verification **afterwards**
- source of trouble - delivery tolerances

Definition

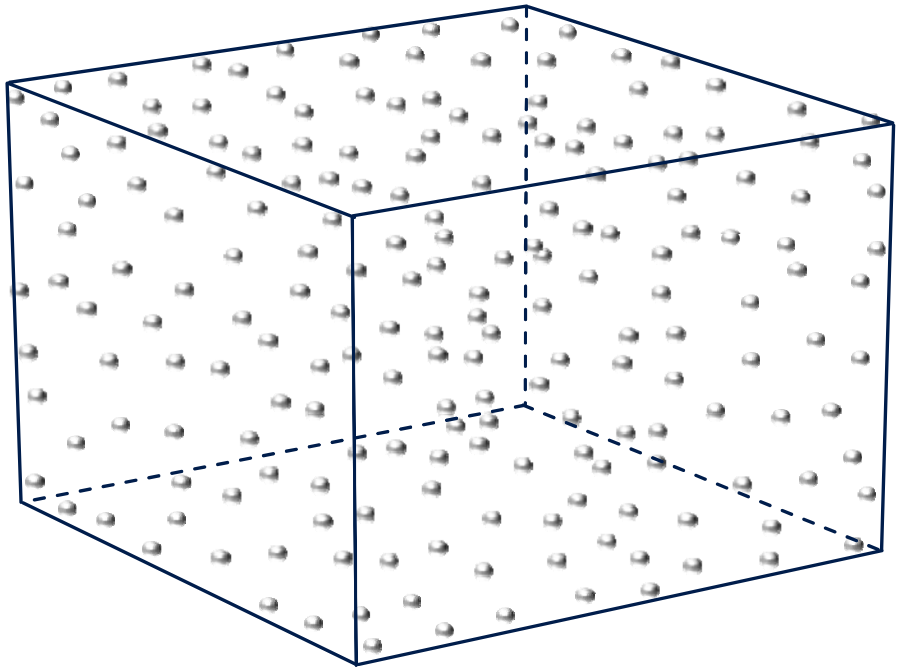


- reliability analysis in an early design stages
  - modifications of design parameters easier
  - less expensive modifications

- identification of alternative design spaces

Example

- simple deep drawing example – 3 input quantities, 1 results quantity
- e.g. input: 2 draw bead forces, 1 binder force
  result: thinning of blank



Example

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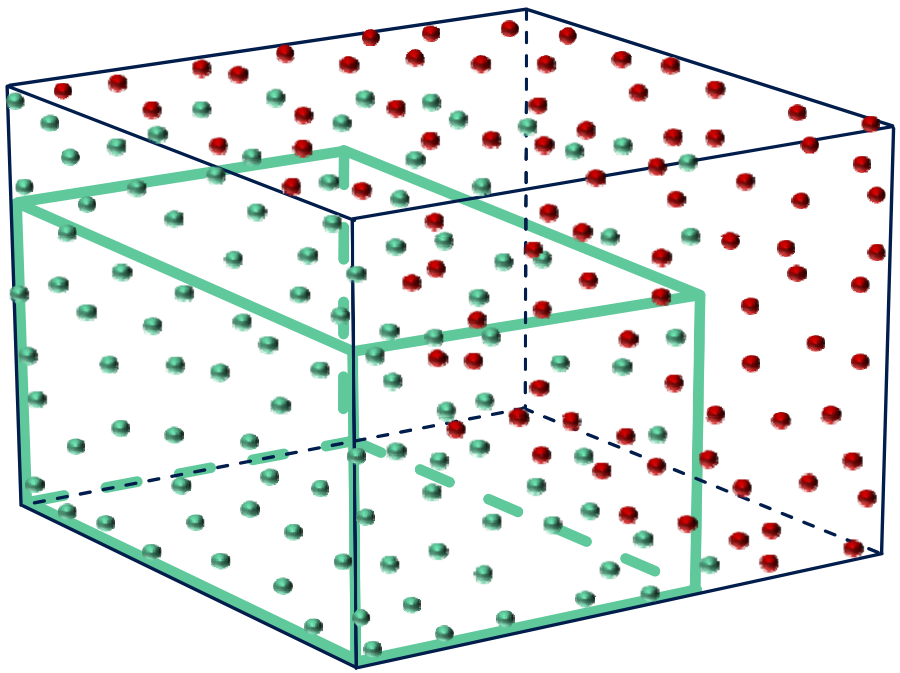
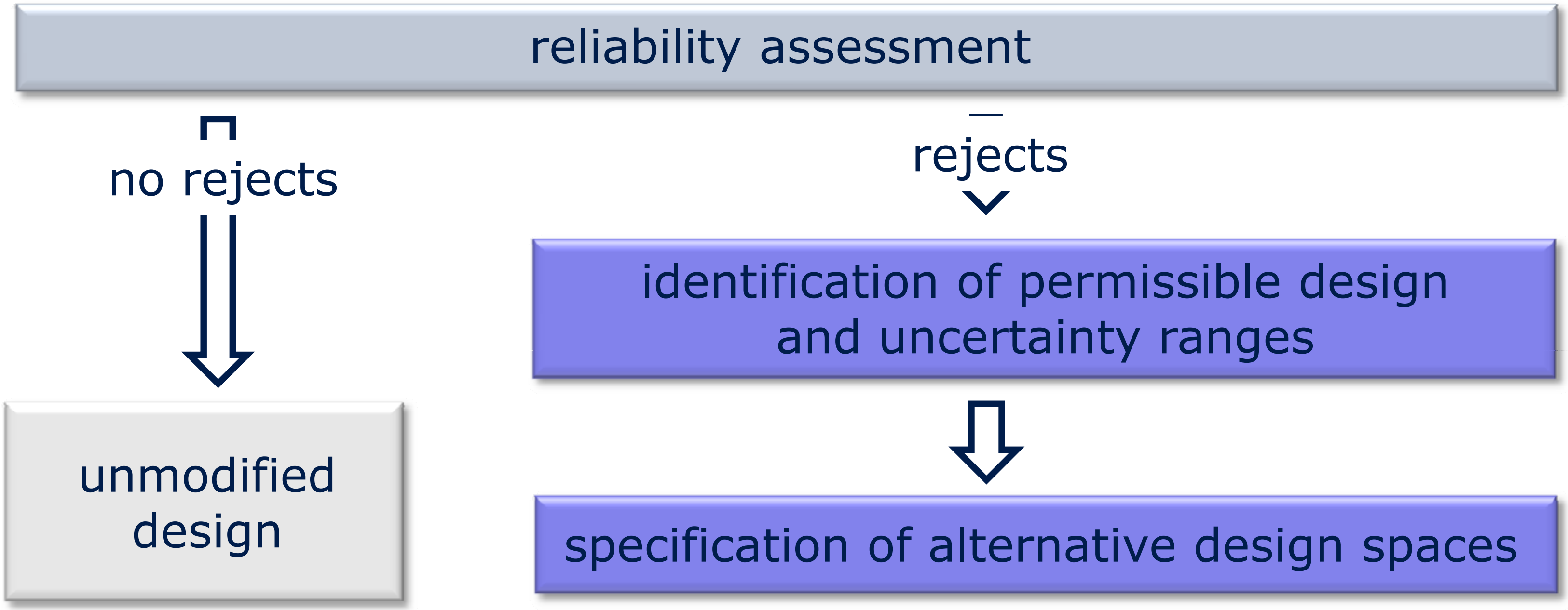


Solution statement



- preconditions
  - rare, vague information about uncertainty ranges
  - arbitrary structural behavior, no one-to-one functions
  - applicability of alternative design ranges in industrial environment

Reliability analysis

Uncertainty modeling

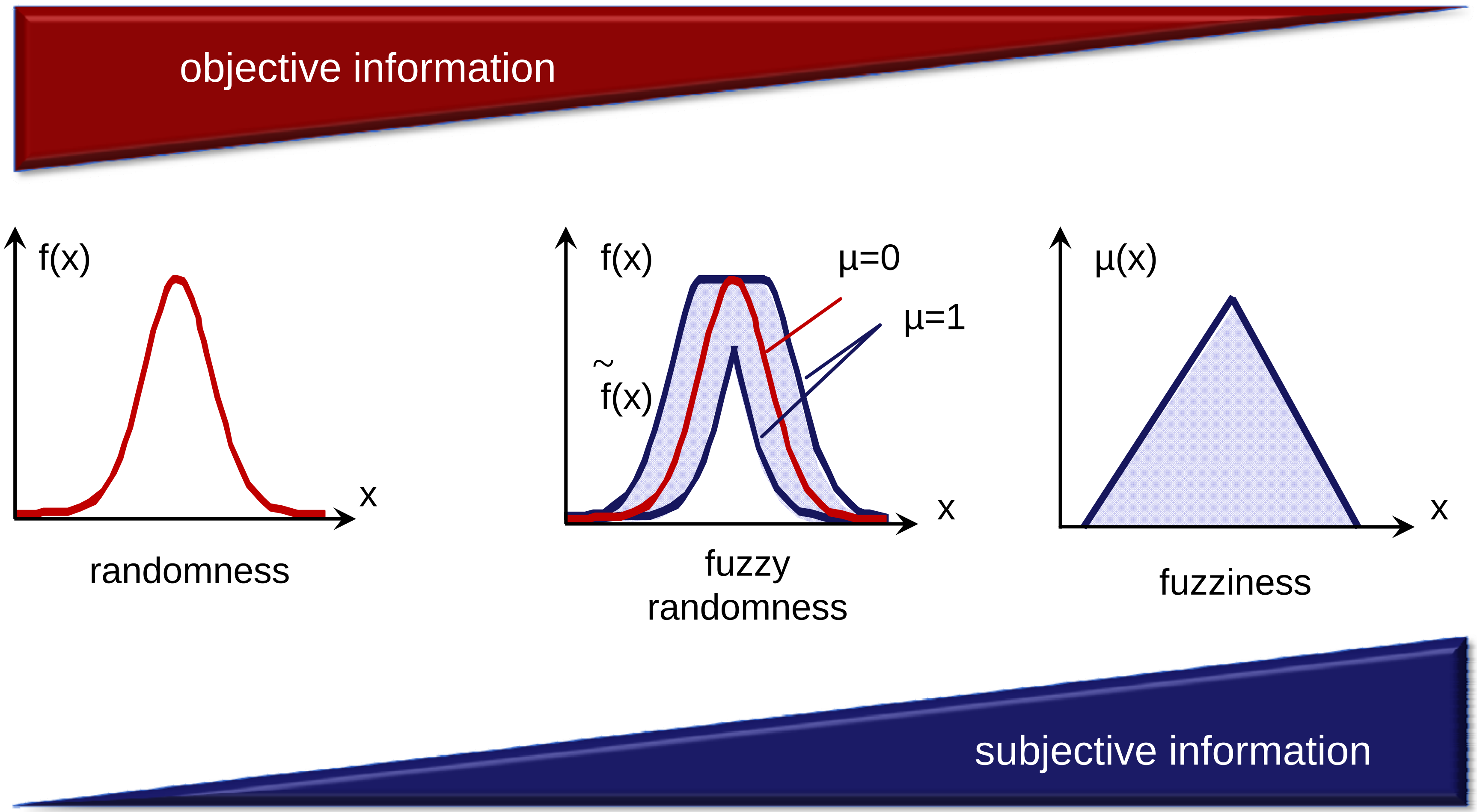
uncertainty

aleatoric	epistemic
randomness	perception/evaluation
objective data	subjective assessment

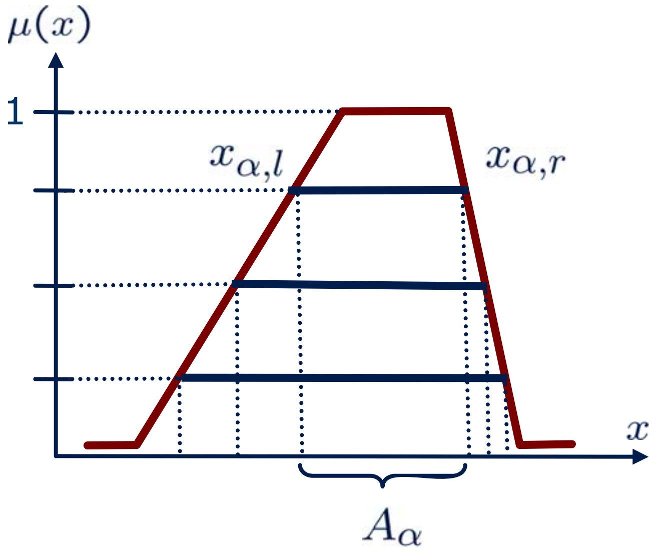
- abundant (objective) data
- discrete random events
- gambling

- limited (subjective) data
- imprecise measurements
- linguistic quantification
- experience/expert knowledge

Uncertainty modeling



Fuzzy set



- general definition

$$\tilde{A} = \left\{ \left(x, \mu_{\tilde{A}}(x) \right) \mid x \in \mathbb{R}, \mu_{\tilde{A}}(x) \in [0,1] \right\}$$

$$\mu_{\tilde{A}} : \mathbb{R} \to [0,1]$$

- convexity

$$\forall \lambda \in [0,1],\ x_1, x_2 \in \mathbb{R} :$$

$$\mu_{\tilde{A}}(\lambda x_2 + (1-\lambda) x_1) \geq \min \left(\mu_{\tilde{A}}(x_1)\, \mu_{\tilde{A}}(x_2) \right)$$

- α-level discretization

$$\tilde{A} = (A_\alpha \mid \alpha \in [0,1])$$

$$A_\alpha = \left\{ x \in \mathbb{R} \mid \mu_{\tilde{A}} \geq \alpha \right\}$$

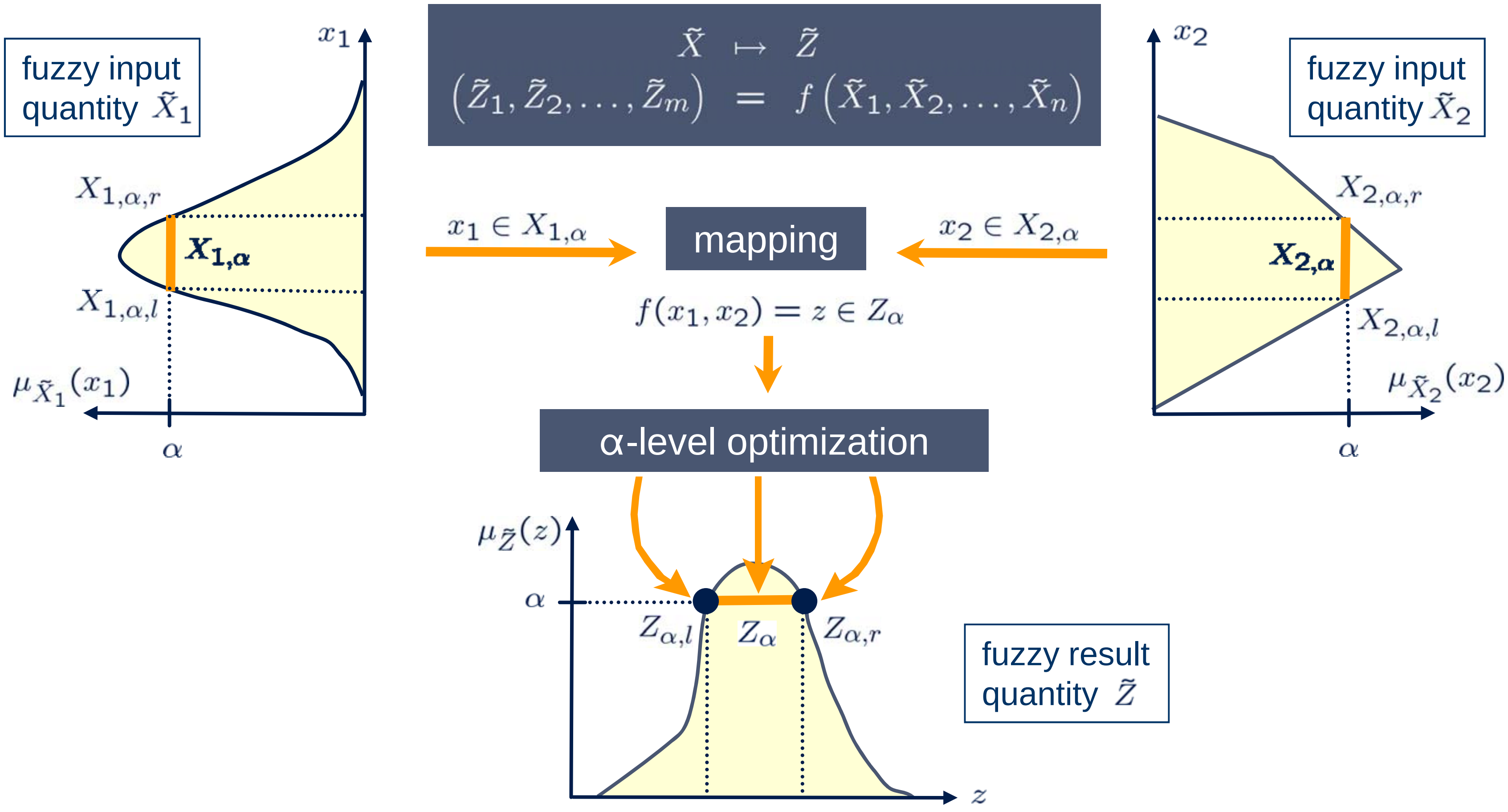
$$A_{\alpha_i} \subseteq A_{\alpha_k} \quad \forall\, \alpha_i \geq \alpha_k$$

- α-level optimization

$$z_{\alpha,l} = \min_{x \in A_\alpha} f(x)$$

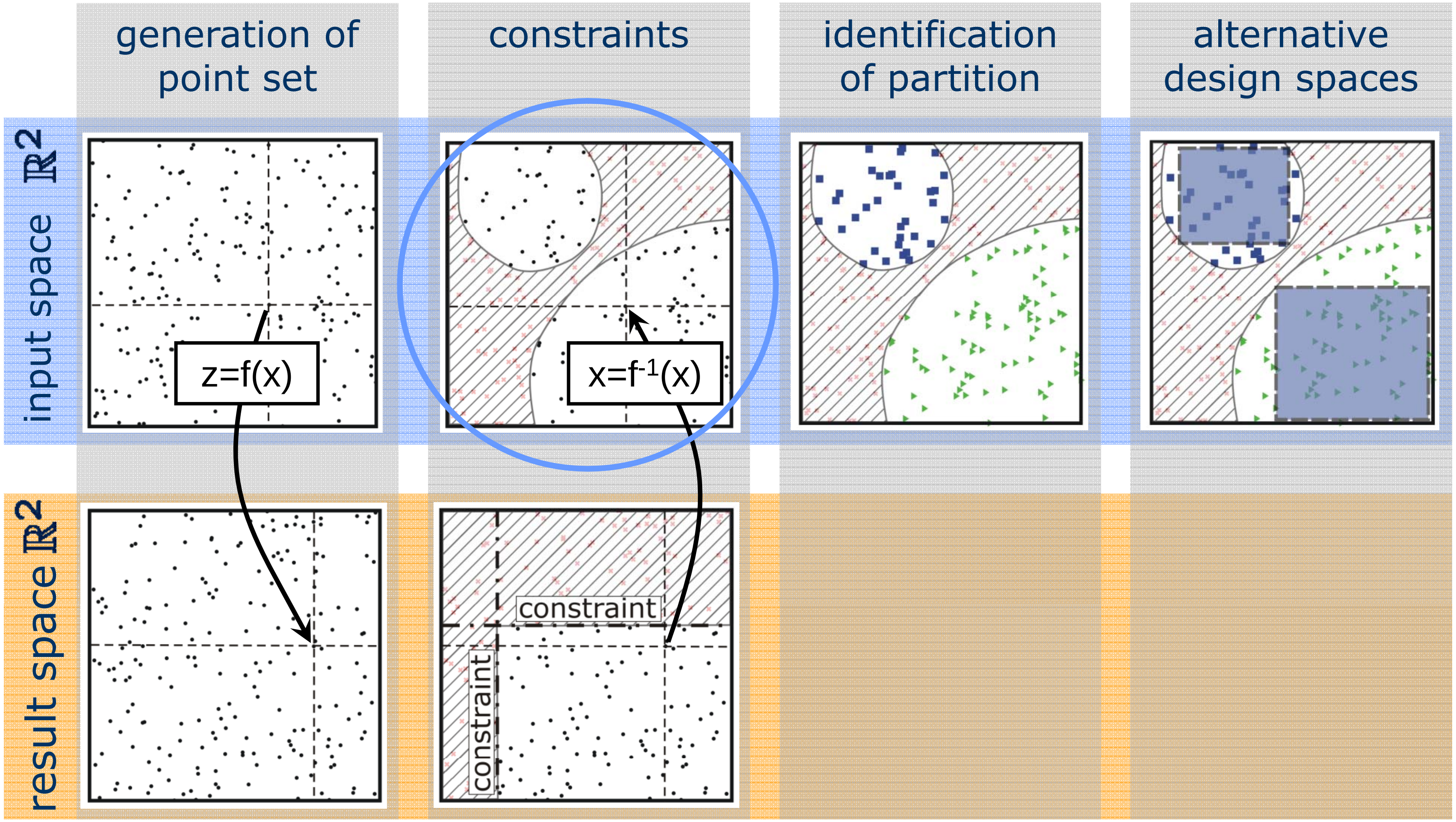
$$z_{\alpha,r} = \max_{x \in A_\alpha} f(x)$$

Fuzzy structural analysis



Specification of alternative design spaces

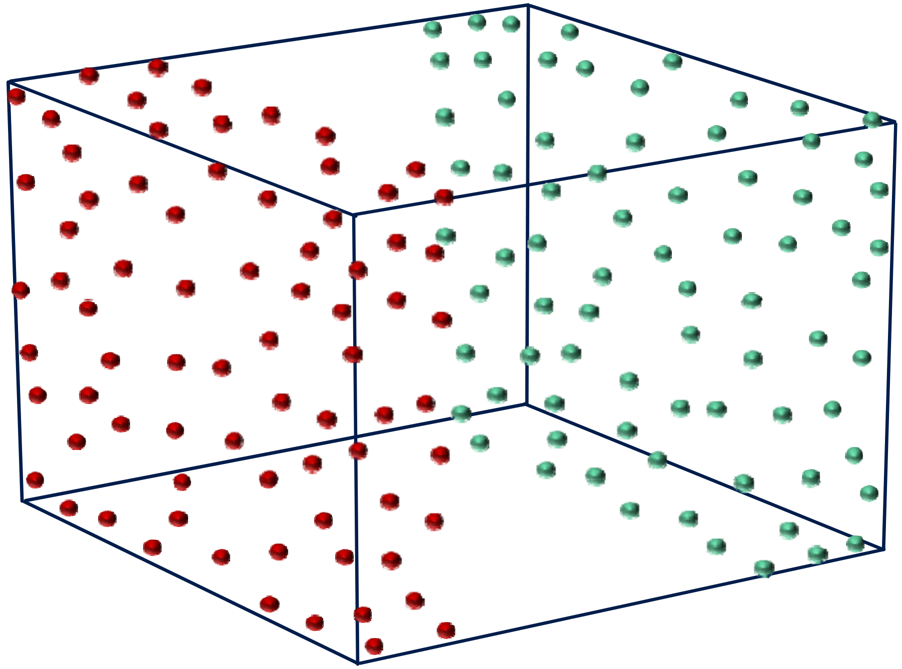
General scheme



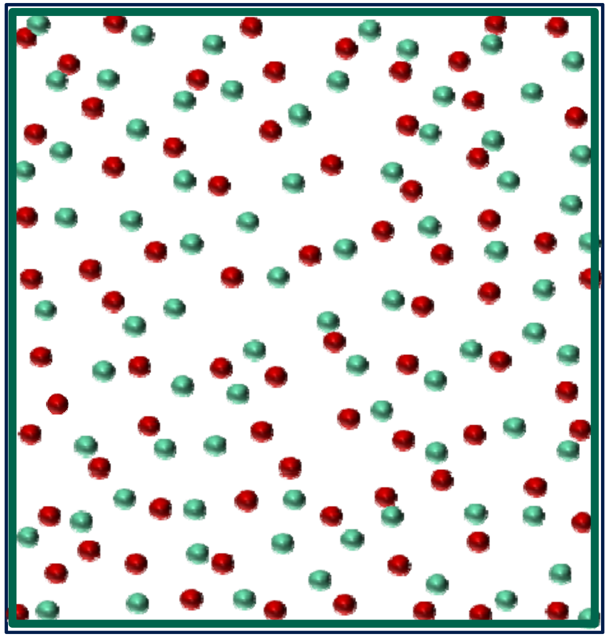
Dimensionality problem

- more than sensitive 3 input quantities

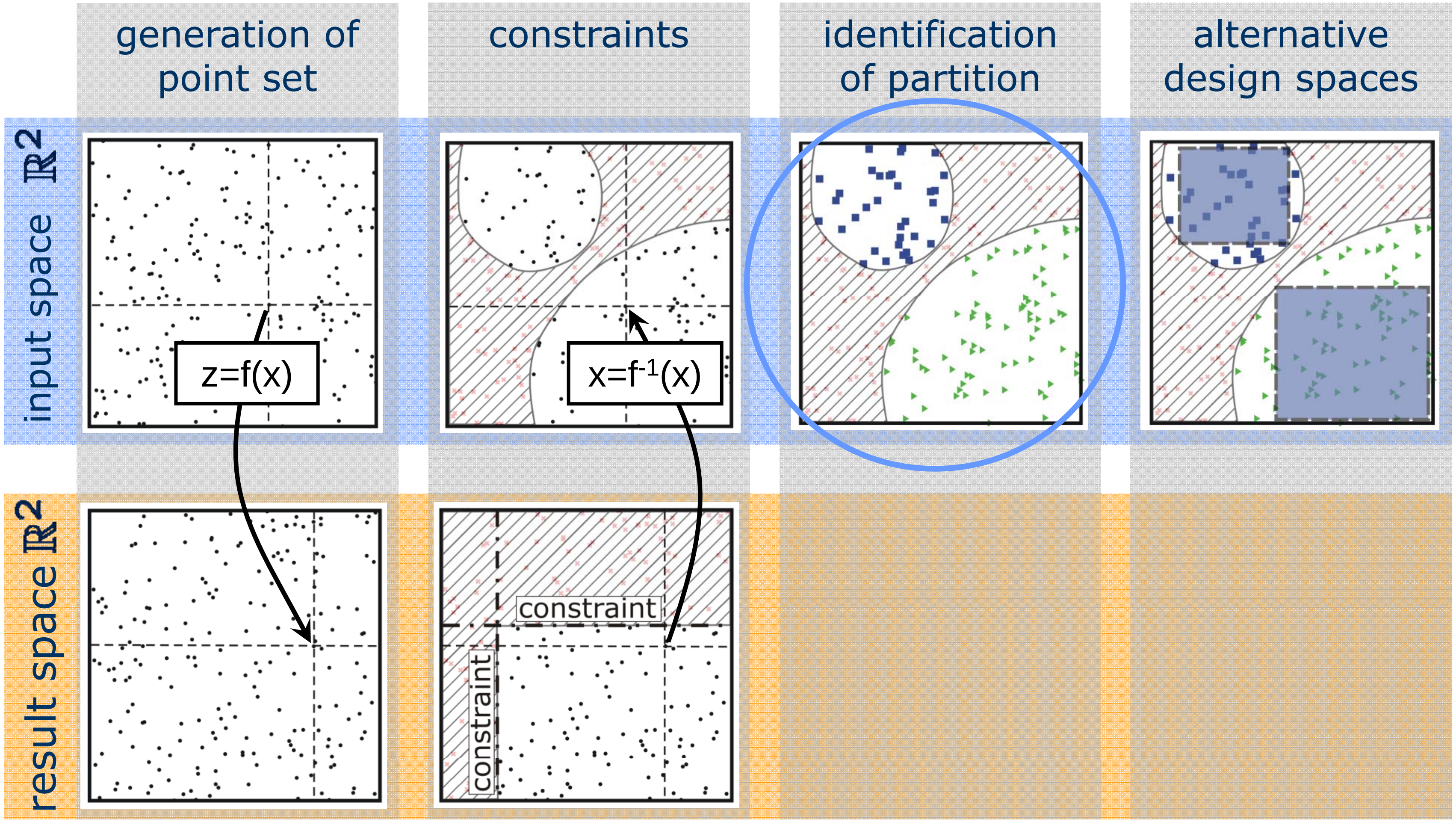
- 3D



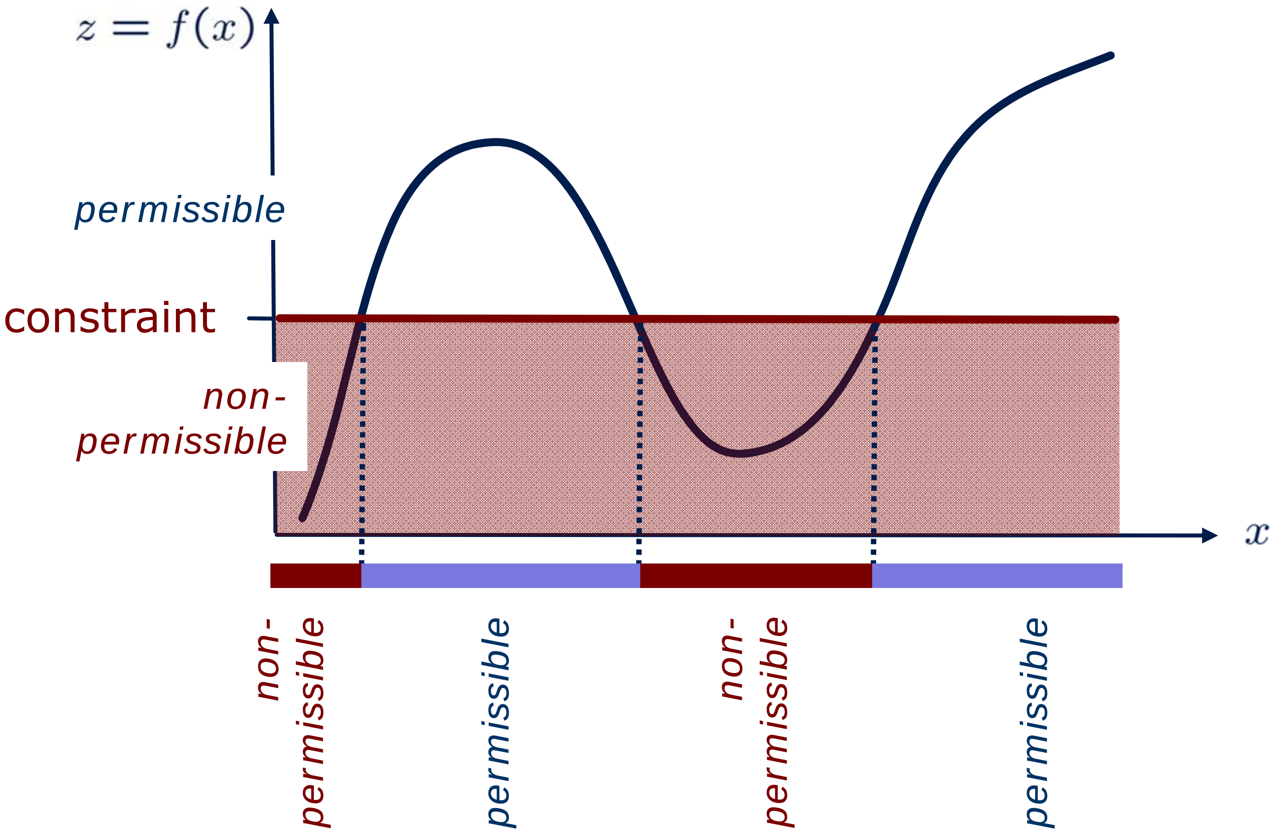
- 2D



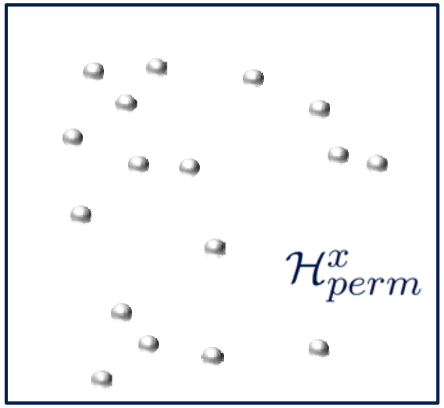
General scheme



Partition

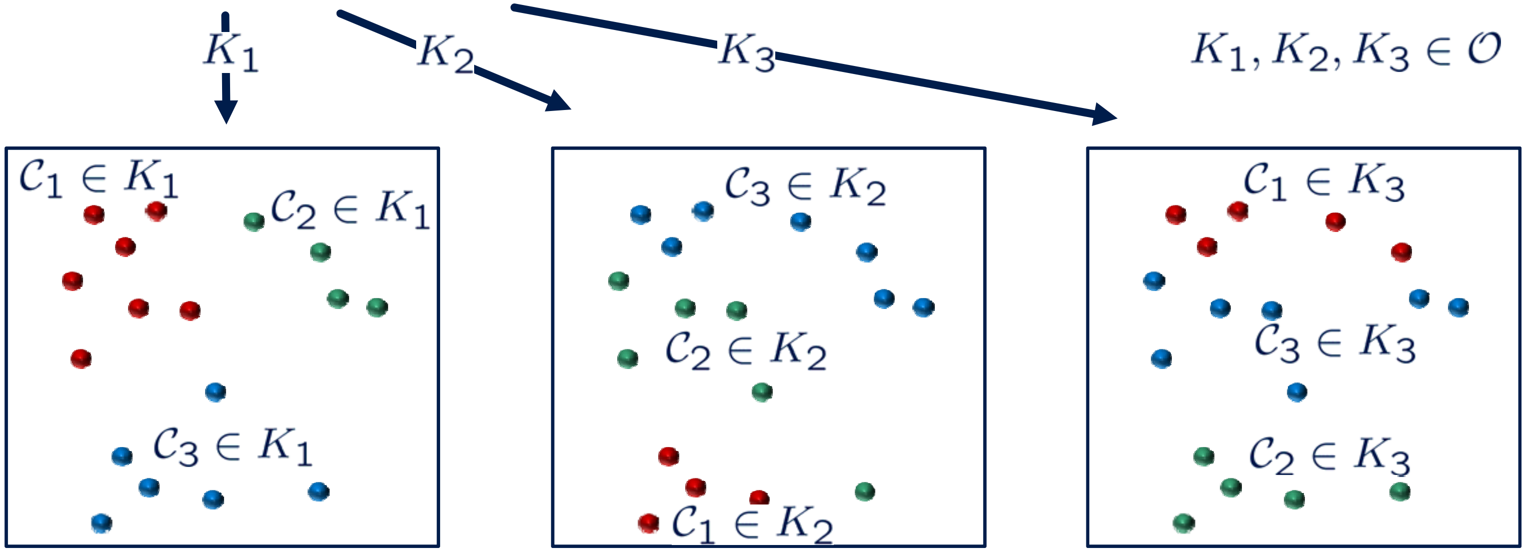

$z = f(x)$
permissible
constraint
non-
permissible
x
non-
permissible
permissible
non-
permissible
permissible

Cluster analysis – objective

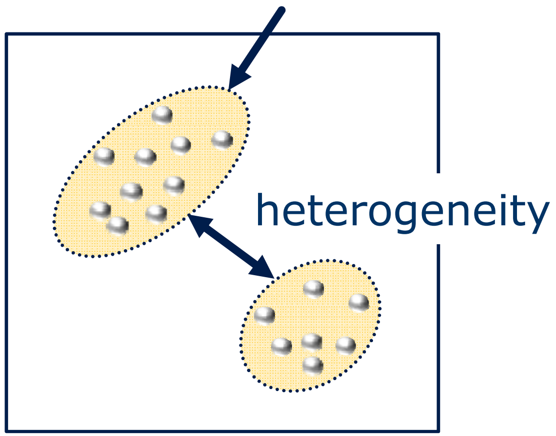


preconditions on clusters

- pairwise disjoint $\mathcal{C}_i \cap \mathcal{C}_j = \varnothing, \quad \mathcal{C}_i \neq \mathcal{C}_j$
- nonempty $\mathcal{C}_i \neq \varnothing$
- reproduce point set $\bigcup_i^{n_c} \mathcal{C}_i = \mathcal{H}^x_{perm}$



Cluster analysis – objective



- homogeneity

  points in a same cluster should be as similar as possible

  $\sum_{p,q \in \mathcal{C}_i} d(p,q) \to$ min

- heterogeneity

  points of different clusters should be as dissimilar as possible

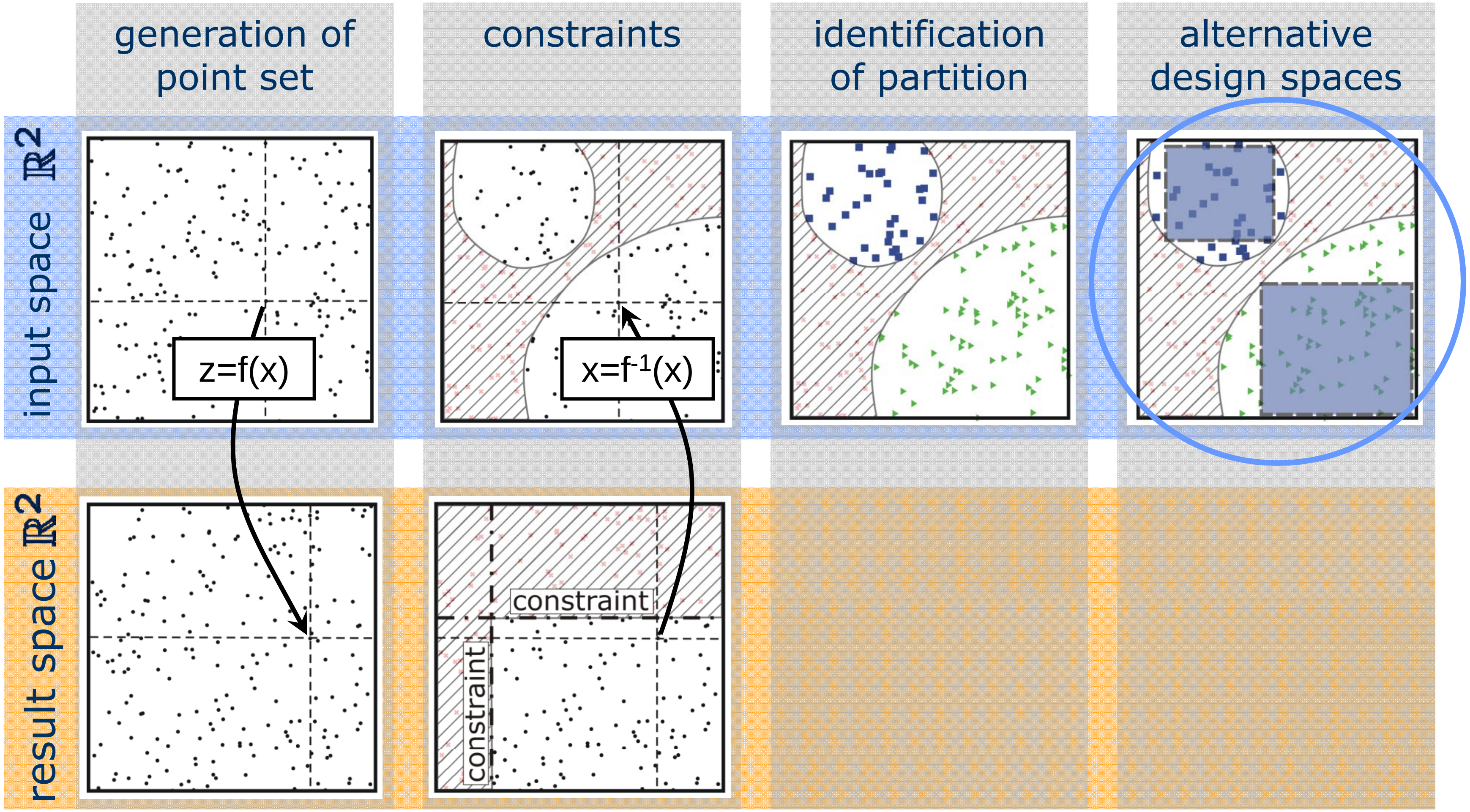
  $\sum_{p \in \mathcal{C}_i, q \in \mathcal{C}_j, i \neq j} d(p,q) \to$ max

determination of an appropriate cluster configuration K ;
optimization task $D(K) \to$ min

$$D: \mathcal{O} \to \mathbb{R}: \; K \mapsto \sum_{\mathcal{C}_i \in K} \sum_{p \in \mathcal{C}_i} d(p, \nu_i)^2$$

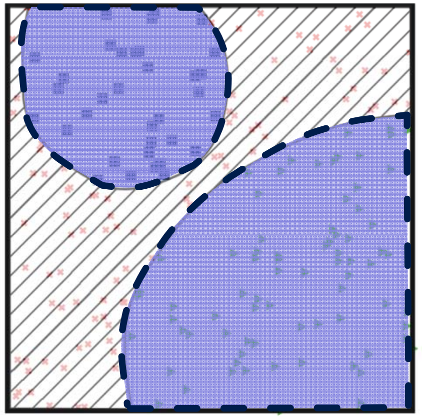
➡ predefined number of clusters - challenge

General scheme

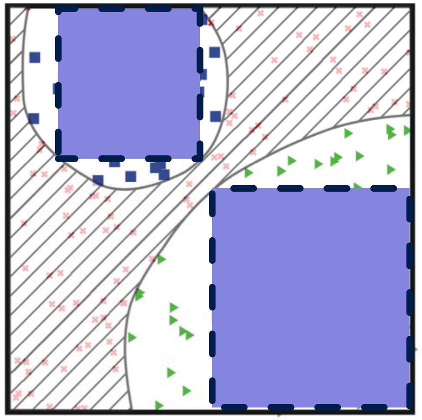


Alternative design space(s)

convex hull **vs.**
hypercuboid

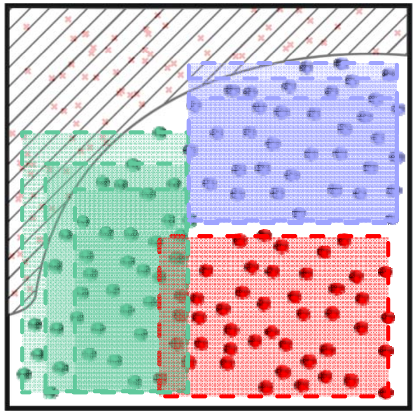


interacted design variables
↓
ambitious and expensive

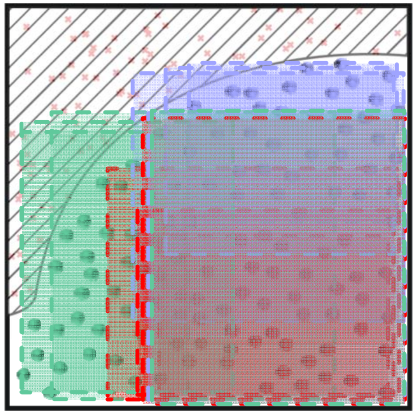


interaction-free design variables

hypercuboids per cluster **vs.**
maximal possible hypercuboids



hypercuboid bases on available point set



detection of number of non-connected input spaces

Examples

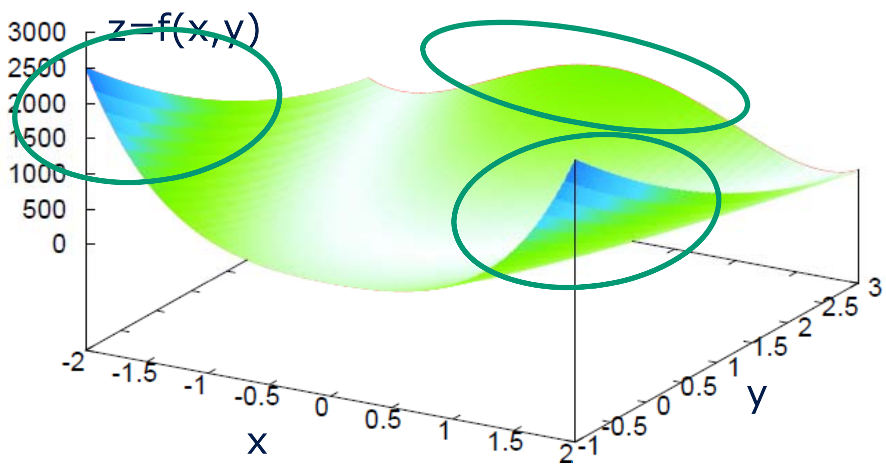
Rosenbrock function

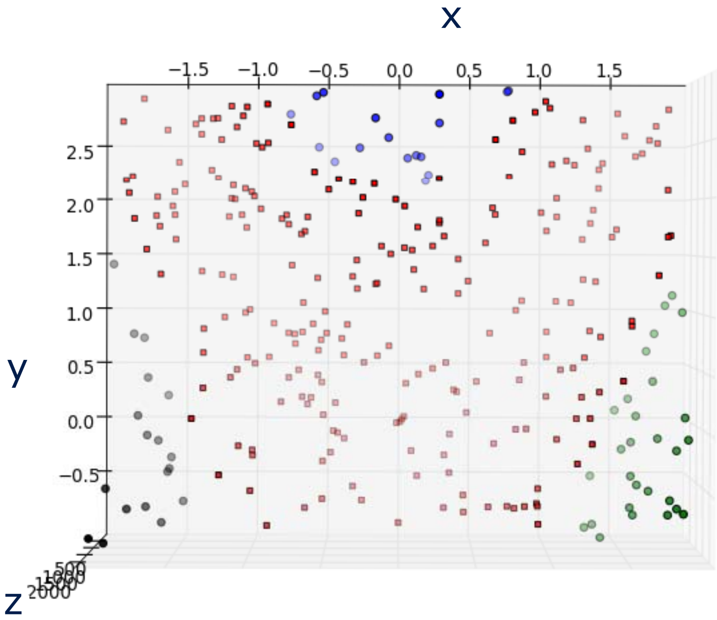
$$z = f(x,y) = (1-x)^2 + 100\left(y - x^2\right)^2$$

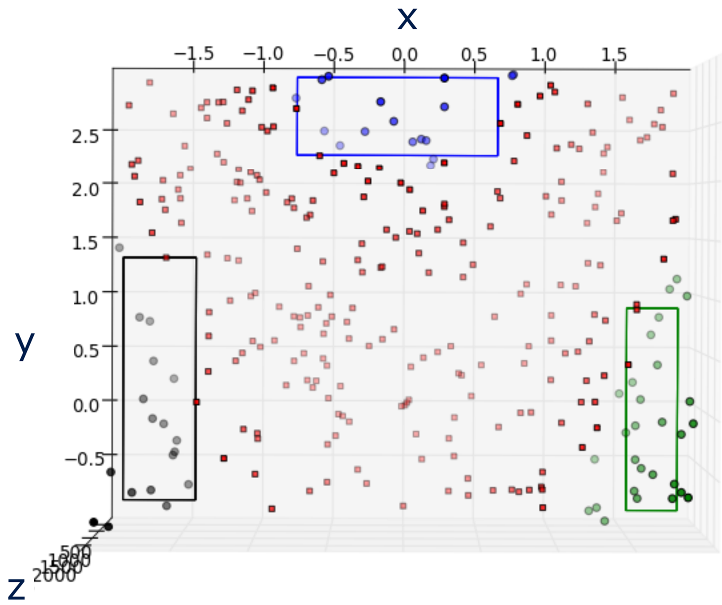
$$x \in [-2;2] \quad y \in [-1;3]$$

permissibility condition

$$z \geq 400$$

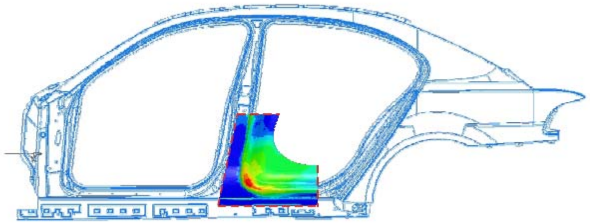




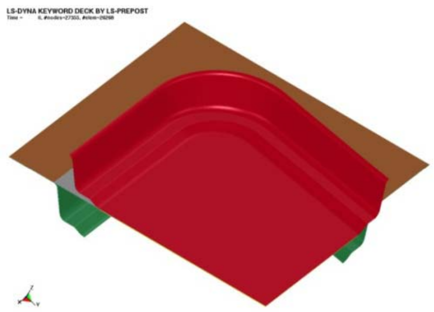


Model

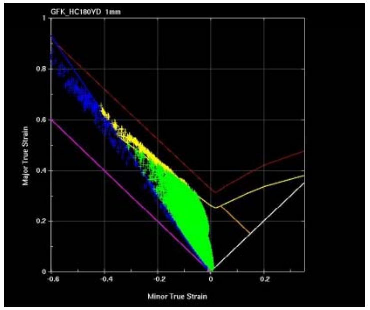
crack sensitive area



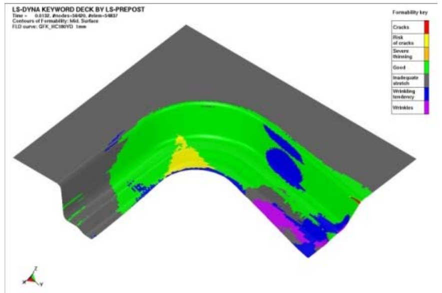
computational model



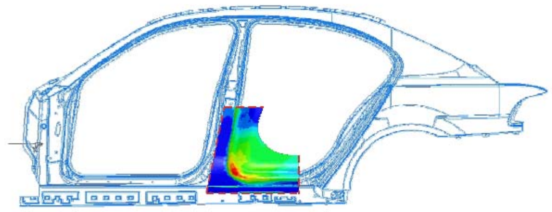
FLD



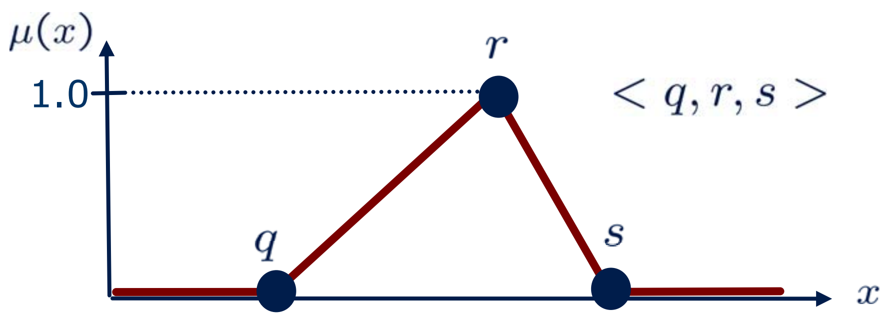
results



Reliability assessment – Fuzzy Analysis



Input parameters		Delivery tolerances	Fuzzy quantities
yield stress	Rp02	180 … 230	<180, 205, 230>
tensile strength	Rm	340 … 420	<340, 380, 420>
hardening exponent	n	0.20 … 0.30	<0.20, 0.22, 0.30>
anisotropy	R90	1.80 … 4.00	<1.80, 2.40, 4.00>



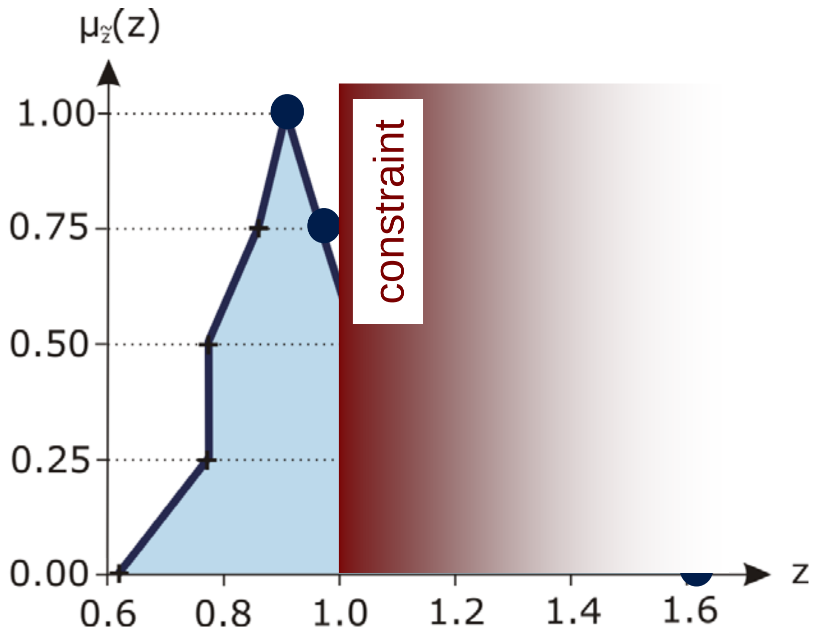
Reliability assessment – fuzzy analysis

- evaluated results (Grossenbacher 2008)

cracking $z_c = f_1(x)$
thinning $z_t = f_2(x)$

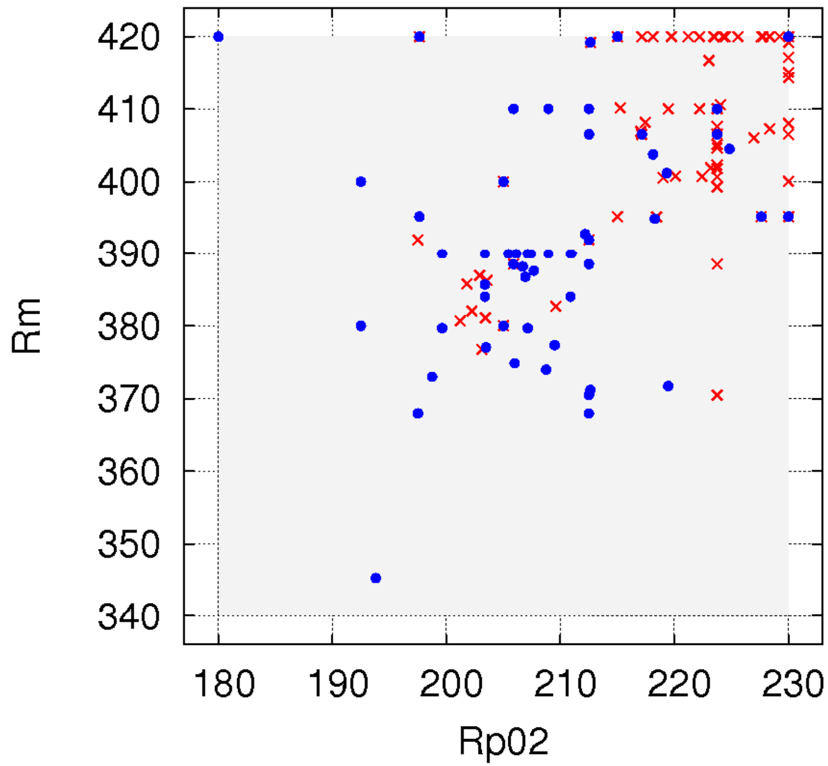
$$z := \max(z_c, z_t) \quad z_{lim} = 1.0$$

- fuzzy result quantity $\tilde{z}$
  - number of α-levels: 5
  - determined interval bounds of α-level:
    $z_{\alpha=0,r}$, $z_{\alpha=0.25,r}$, $z_{\alpha=0.5,r}$
    $z_{\alpha=0.75,r}$, $z_{\alpha=0.25,r}$
  - simulations runs: 150

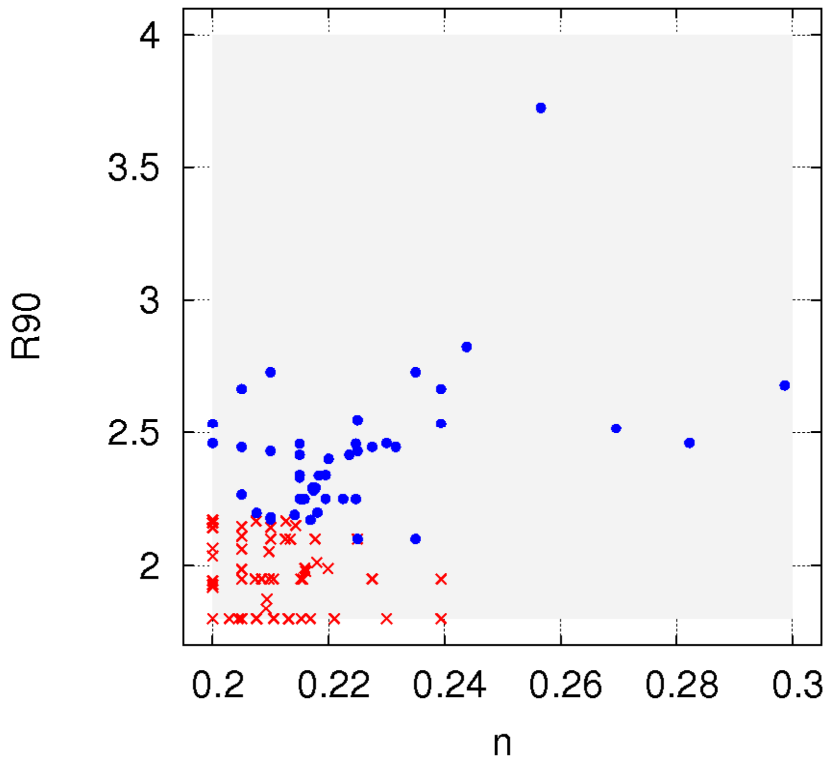


Constraints

cross-plot: Rp02 – Rm



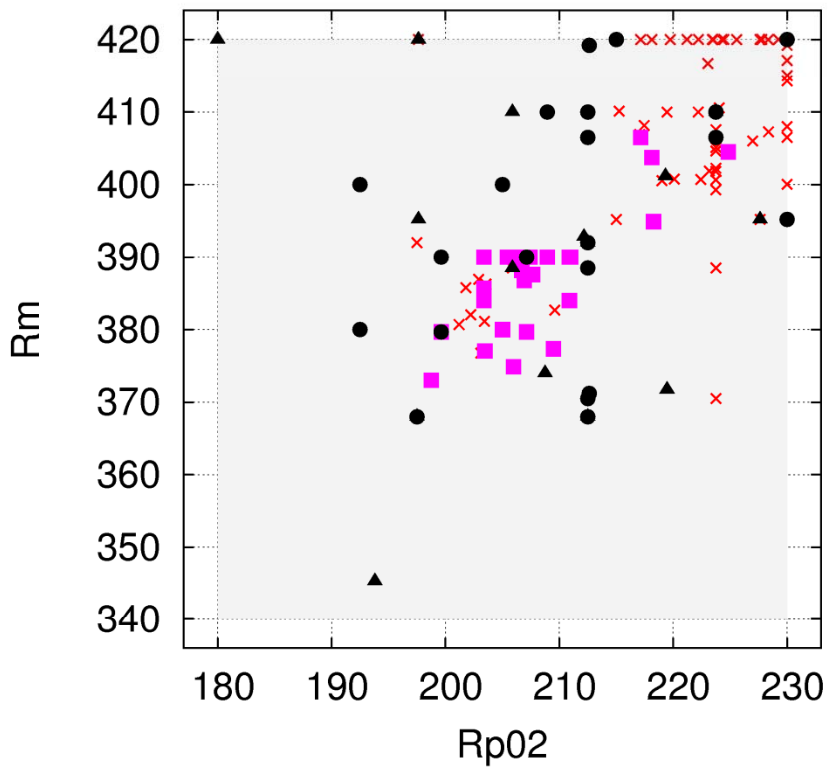
cross-plot: n – R90



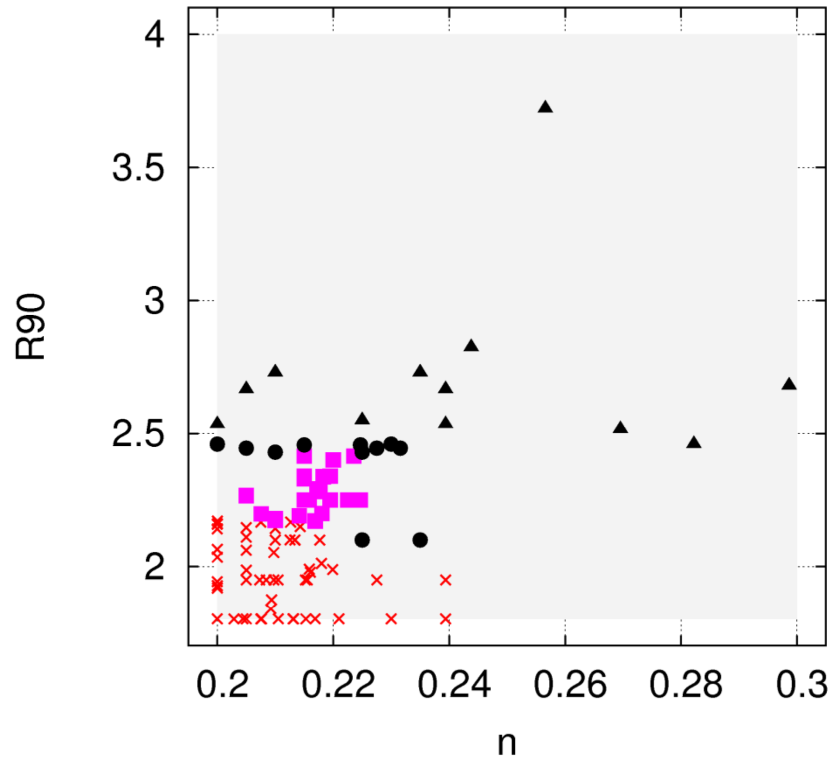
● *permissible* ✕ *non-permissible*

Partitioning – cluster analysis

cross-plot: Rp02 – Rm



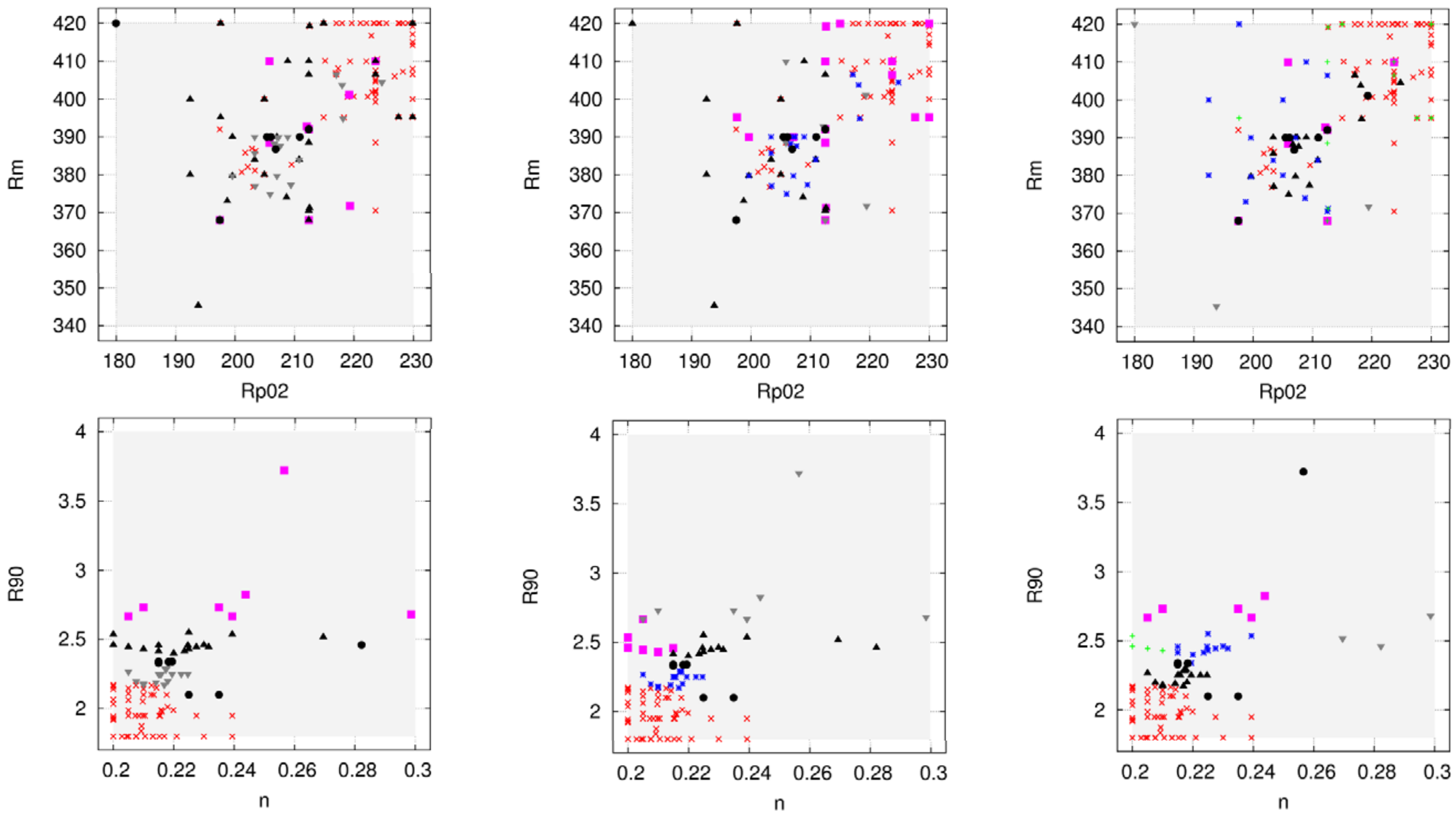
cross-plot: n – R90



● *not assigned* ▲ *Cluster* $\mathcal{C}_1$ ■ *Cluster* $\mathcal{C}_2$ ✕ *non-permissible*

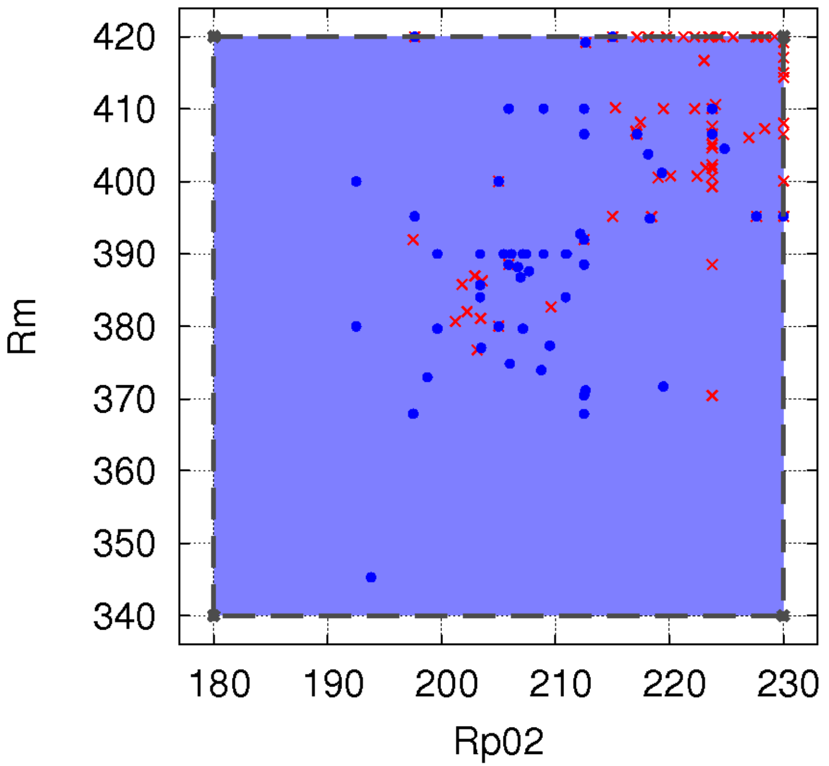
Partitioning – cluster analysis

3 cluster | 4 cluster | 5 cluster

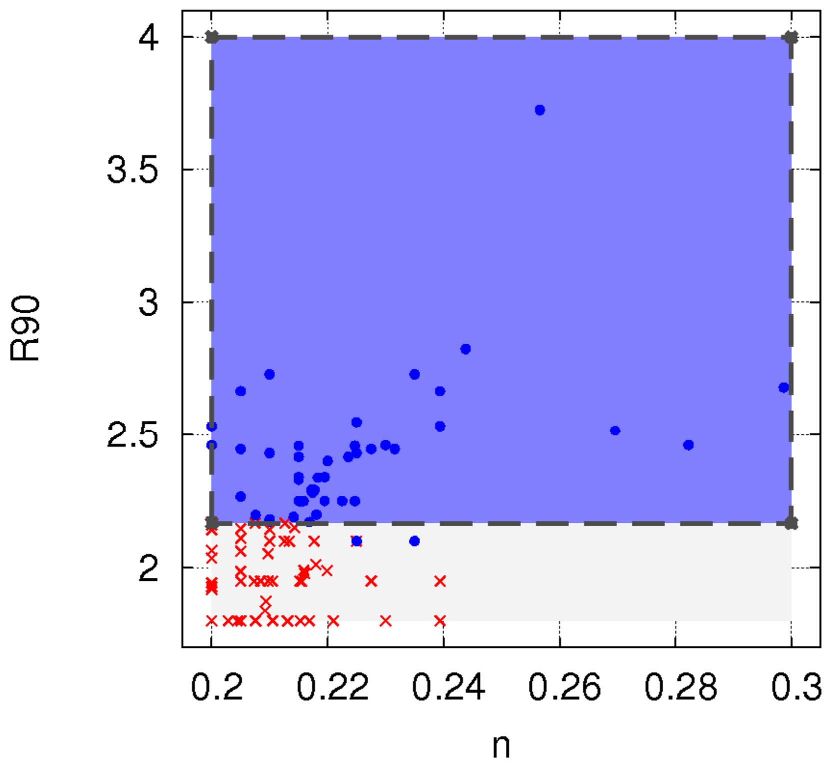


Alternative design space

cross-plot: Rp02 – Rm

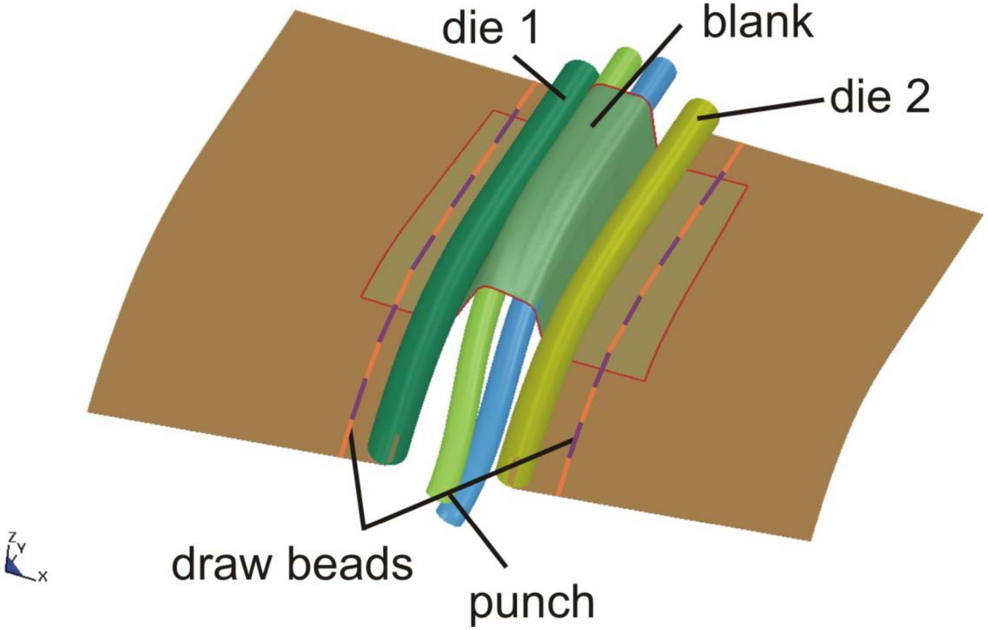


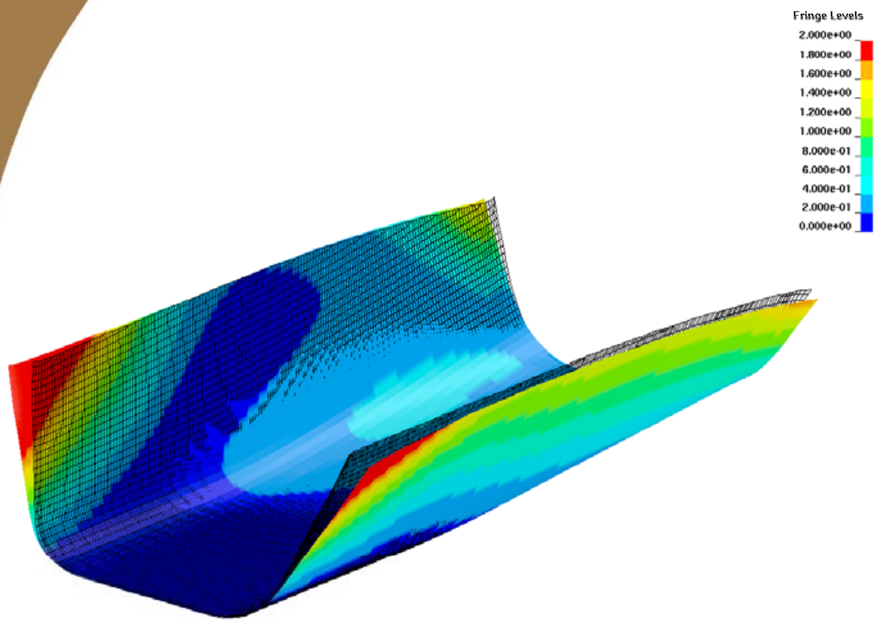
cross-plot: n – R90



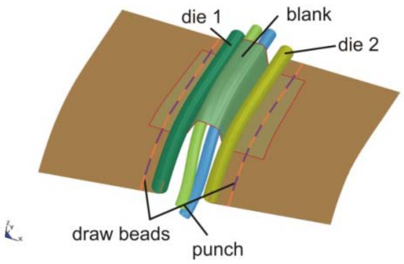
alternative design space ● *permissible* ✕ *non-permissible*

Model

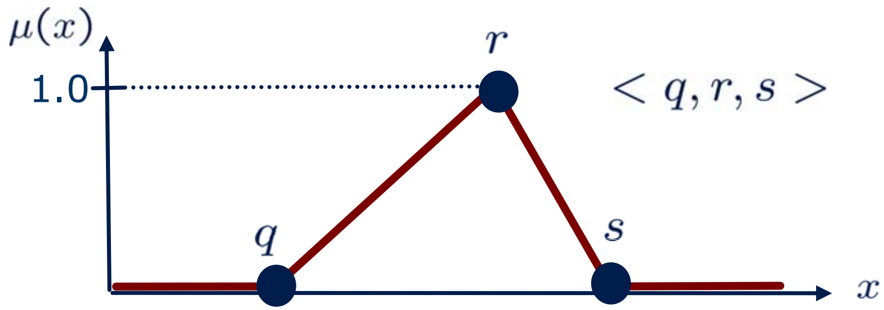

die 1
blank
die 2
draw beads
punch
z
y
x


Fringe Levels
2.000e+00
1.800e+00
1.600e+00
1.400e+00
1.200e+00
1.000e+00
8.000e-01
6.000e-01
4.000e-01
2.000e-01
0.000e+00

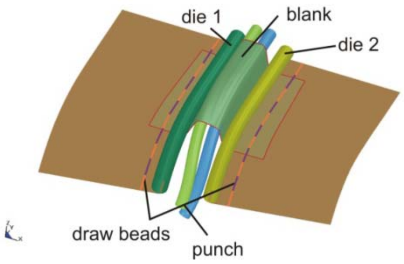
Input quantities



input parameter	ranges	fuzzy quantities
radius die 1	$8 \dots 12$	$< 8, 10, 12 >$
radius die 2	$8 \dots 12$	$< 8, 10, 12 >$
draw bead force 1	$0 \dots 300$	$< 0, 200, 300 >$
⋮	⋮	⋮
draw bead force 22	$0 \dots 300$	$< 0, 200, 300 >$
shell thickness	$0.45 \dots 0.5$	$< 0.45, 0.475, 0.5 >$
binder force	$100 \dots 300$	$< 100, 200, 300 >$
positioning blank x-direction	$-2 \dots 2$	$< -2, 0, 2 >$
positioning blank y-direction	$-2 \dots 2$	$< -2, 0, 2 >$



Reliability assessment – fuzzy analysis



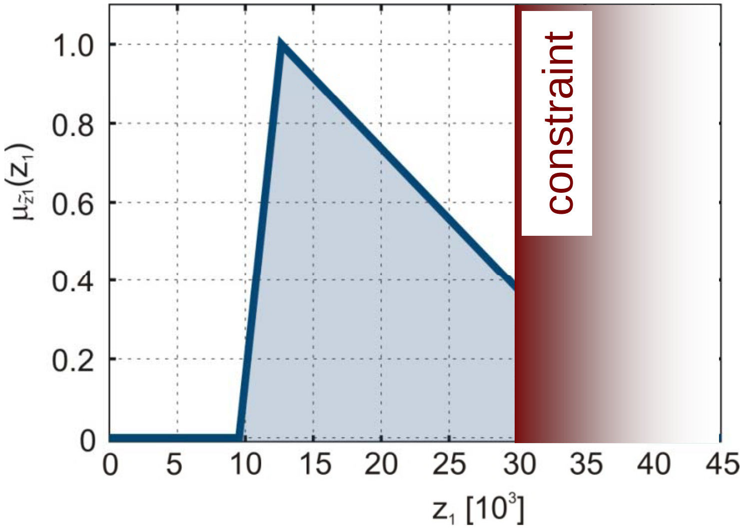
- evaluated results

$f_1(x)$ – geometry $\quad f_1(x) \leq 30{,}000$

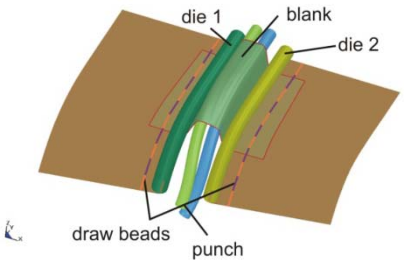
$f_2(x)$ – cracking (FLC) $\quad f_2(x) \leq 1.0$

$f_3(x)$ – manufacturing $\quad f_3(x) \leq 30.5$

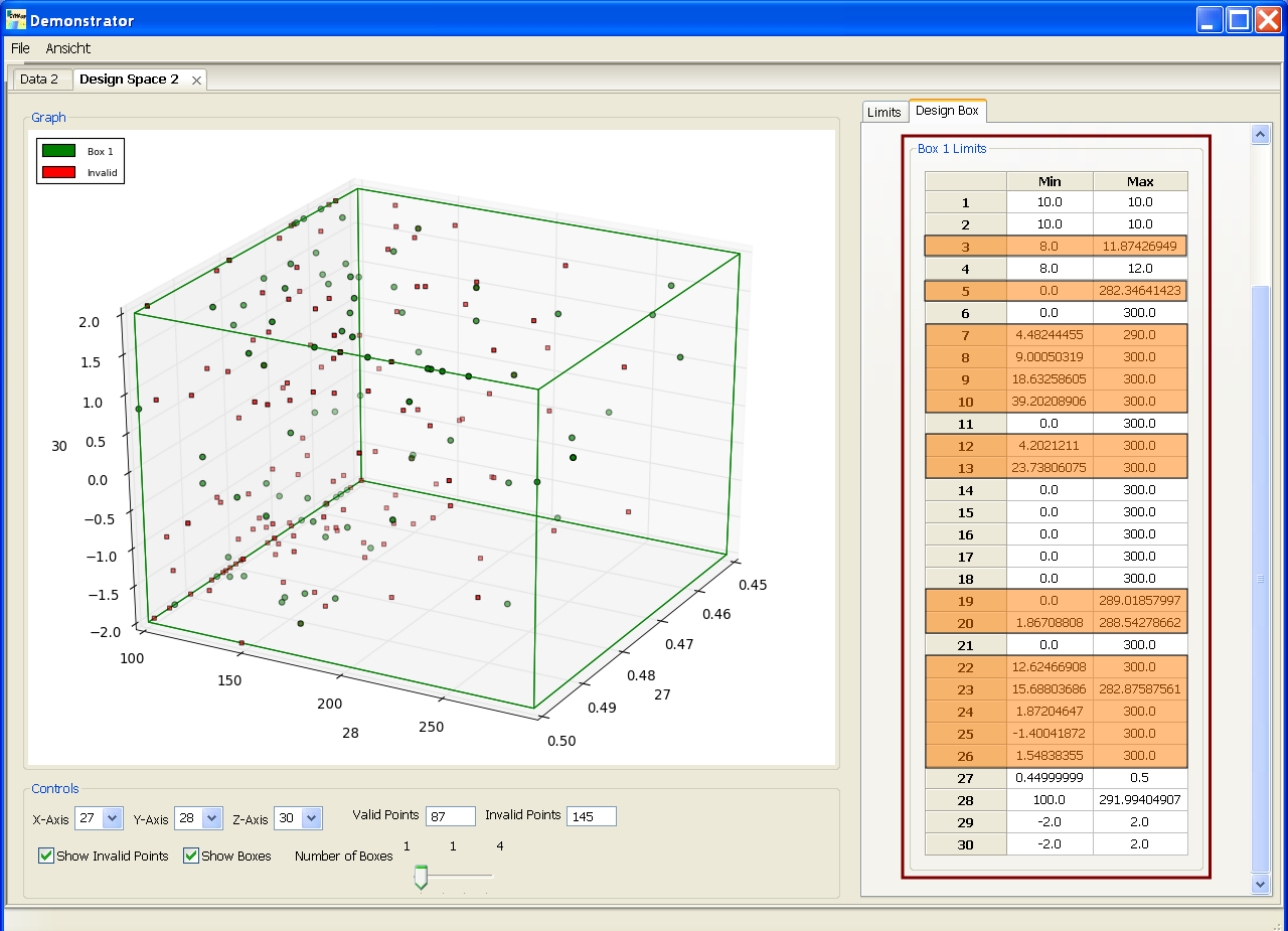
- fuzzy result quantity $\tilde{z}_1$
  - number of α-levels: 2
  - determined interval bounds of α-level: $z_{\alpha=0,r}, z_{\alpha=1.0,r}$
  - simulations runs: 232



Demonstrator



Determination of alternative design spaces



	Min	Max
1	10.0	10.0
2	10.0	10.0
3	8.0	11.87426949
4	8.0	12.0
5	0.0	282.34641423
6	0.0	300.0
7	4.48244455	290.0
8	9.00050319	300.0
9	18.63258605	300.0
10	39.20208906	300.0
11	0.0	300.0
12	4.2021211	300.0
13	23.73806075	300.0
14	0.0	300.0
15	0.0	300.0
16	0.0	300.0
17	0.0	300.0
18	0.0	300.0
19	0.0	289.01857997
20	1.86708808	288.54278662
21	0.0	300.0
22	12.62466908	300.0
23	15.68803686	282.87587561
24	1.87204647	300.0
25	-1.40041872	300.0
26	1.54838355	300.0
27	0.44999999	0.5
28	100.0	291.99404907
29	-2.0	2.0
30	-2.0	2.0

Conclusions

- assessment of reliability in an early design stages reasonable
- determination of alternative design spaces
  instead of an optimal design
- detection of non-connected point sets with cluster analysis
- assignment of hypercuboids to clusters – only permissible points
- applicability is underlined
  by means of an industry-relevant example

Beurteilung und Beeinflussung der Zuverlässigkeit von Tiefziehprozessen in der frühen Entwurfsphase

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