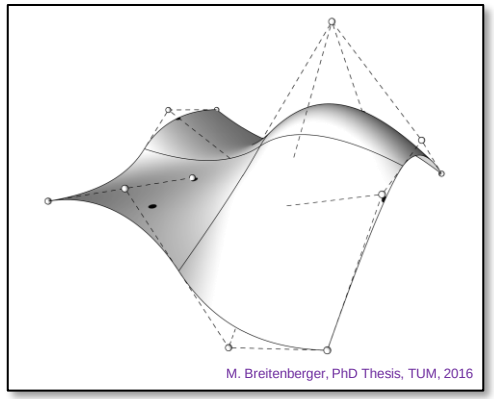


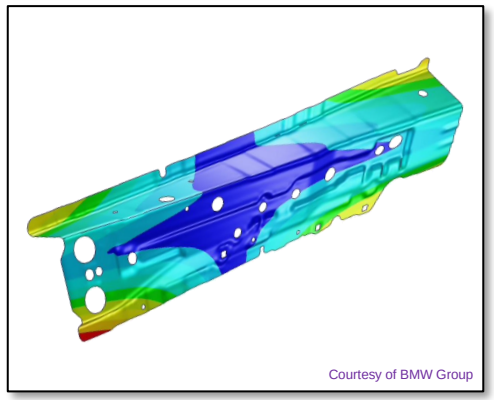


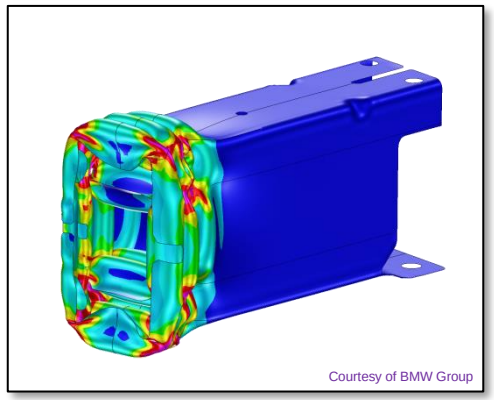


DYNAmore Express Webinar

# Isogeometric Analysis in LS-DYNA with the New CAD-Inspired *IGA Keywords

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April 16, 2021

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# Outline

1. What is Isogeometric Analysis (IGA)?
2. IGA in LS-DYNA and LS-PrePost
3. The New CAD-Inspired *IGA Keywords
   - Motivation
   - Trimmed Multi-Patch Shells
   - Novel Spline Technologies
4. IGA for Industrial Applications
5. Summary and Outlook

# Outline

1. **What is Isogeometric Analysis (IGA)?**
2. IGA in LS-DYNA and LS-PrePost
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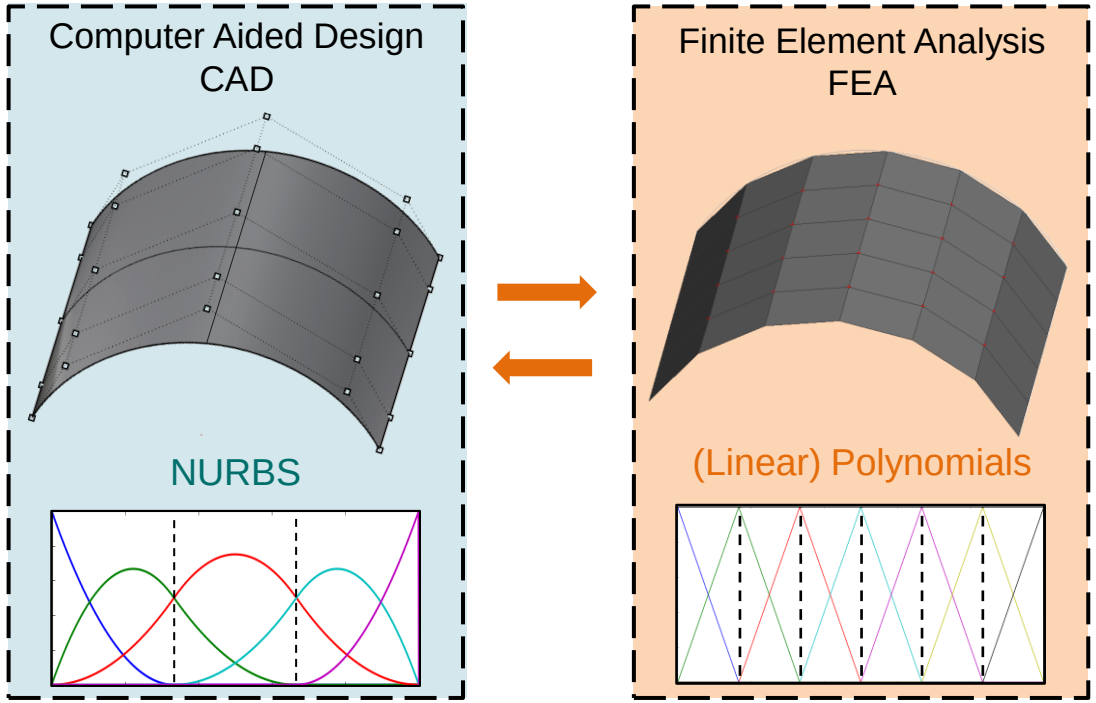
# What is Isogeometric Analysis (IGA)?

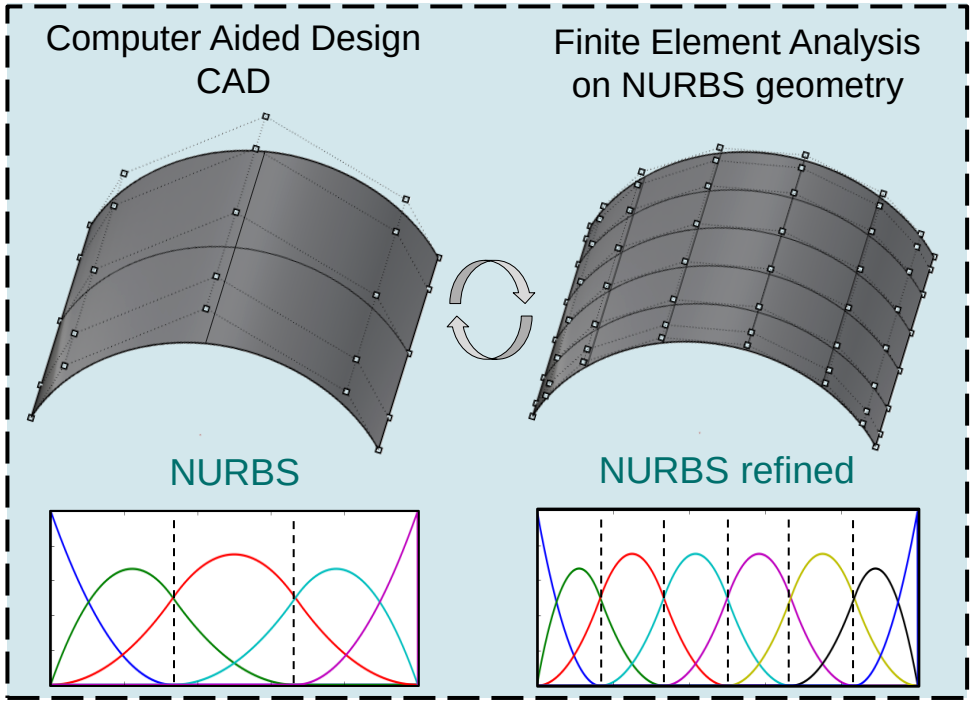
NURBS = Non-Uniform Rational B-Splines

## Conventional Finite Element Analysis (FEA)




- Change of geometry description
- Time- and labor-intensive model conversion
- Synchronization problems

## Isogeometric Analysis (IGA)

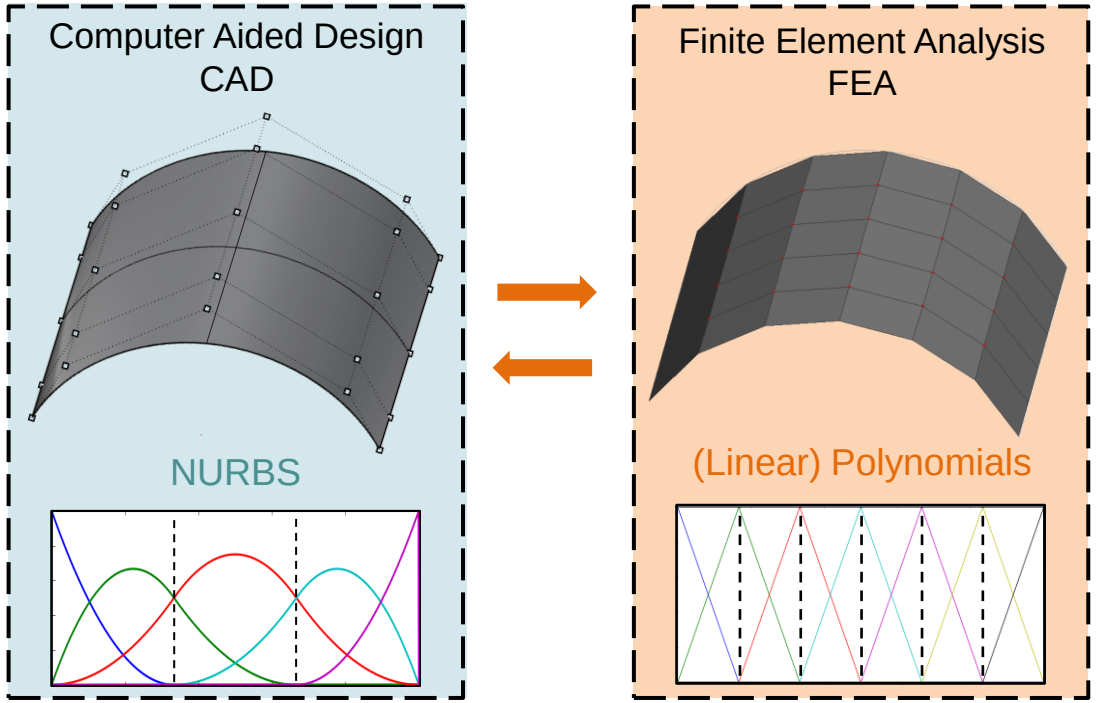



- Analysis directly on CAD geometry
- Finite Element Analysis with new basis functions
- Design and analysis in sync

# What is Isogeometric Analysis (IGA)?

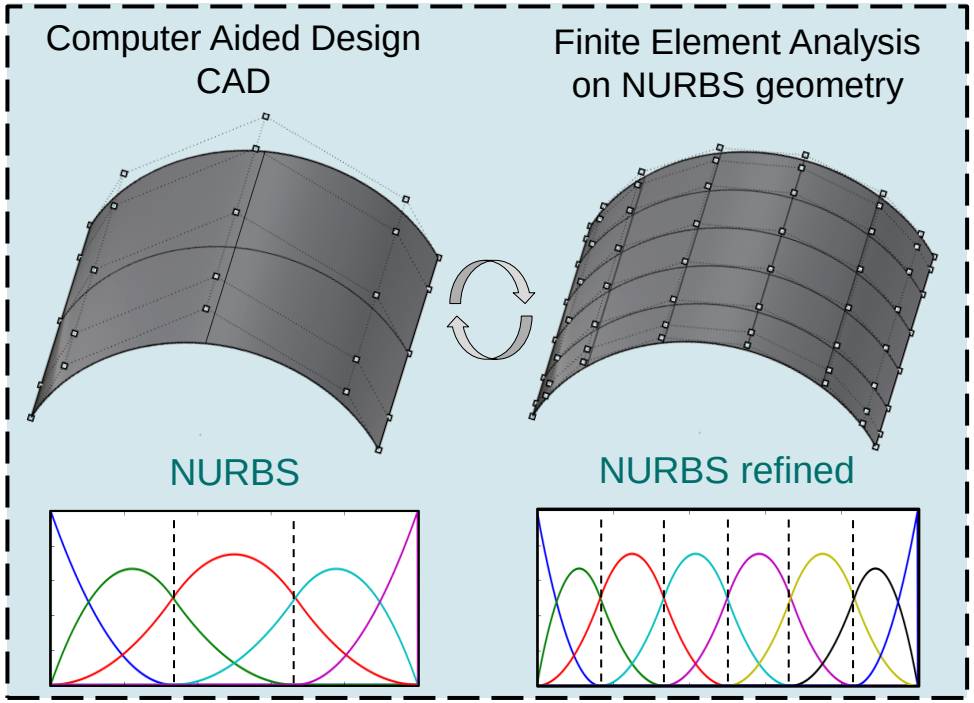
NURBS = Non-Uniform Rational B-Splines

## Conventional Finite Element Analysis (FEA)




- **Approximated** geometry for the analysis
- Geometry and DOFs defined by **nodes**
- Nodes located on geometry

## Isogeometric Analysis (IGA)




- **Accurate** geometry for the analysis
- Geometry and DOFs defined by **control points**
- Control points in general not located on geometry

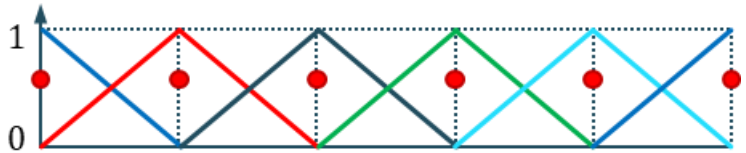
# What is Isogeometric Analysis (IGA)?

NURBS = Non-Uniform Rational B-Splines
(Generalization of B-Splines)

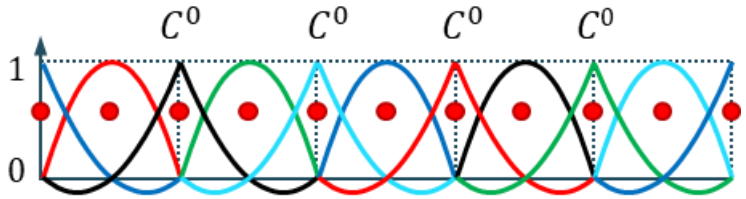
## Conventional Finite Element Analysis (FEA)

### Lagrange Polynomials

Linear




Quadratic

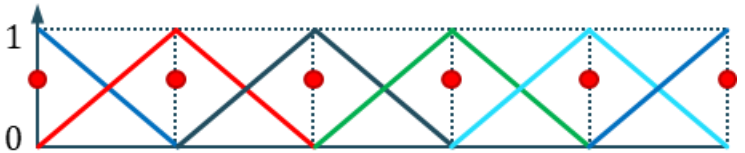



- Max. inter-element continuity: $C^0$
- Basis functions span across max. 2 elements
- Basis functions are also negative
- $p$ nodes per element (asymptotically)
- $h$- and $p$-refinement only

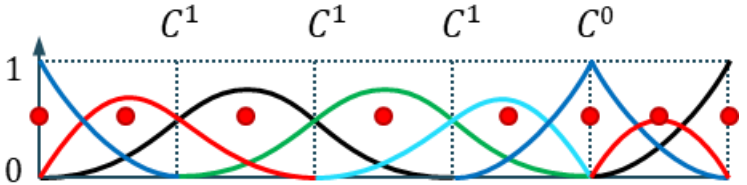
## Isogeometric Analysis (IGA)

### B-Splines

Linear



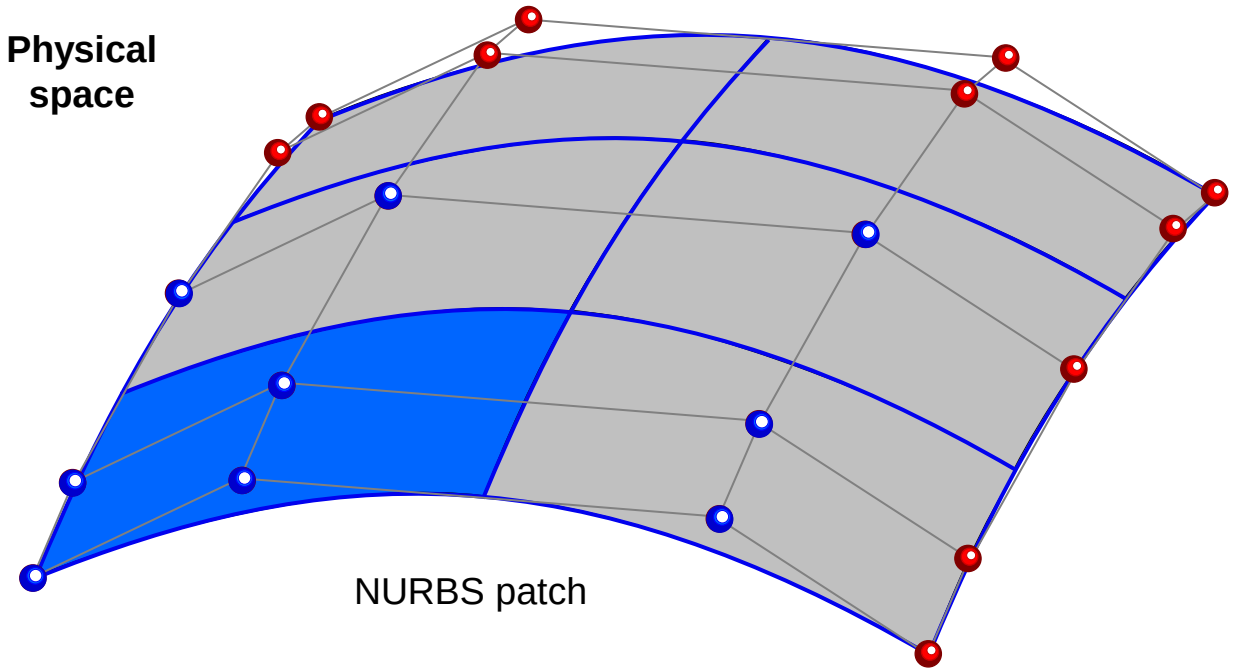

Quadratic

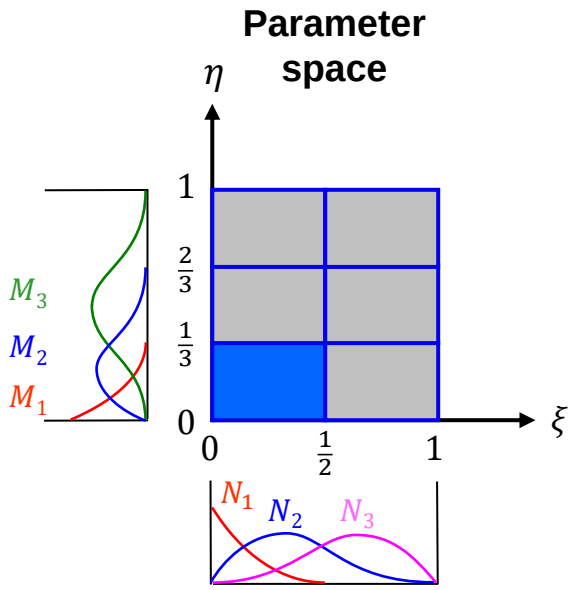


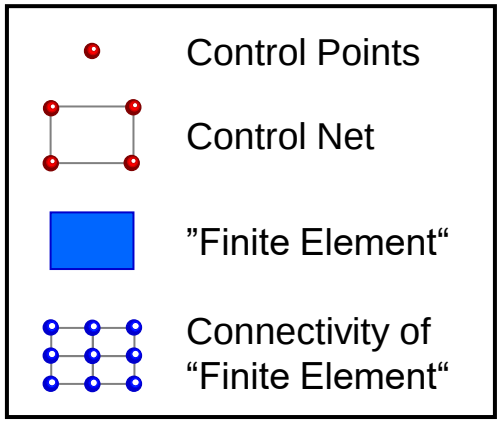

- Max. inter-element continuity: $C^{p-1}$
- Basis functions span across max. $p+1$ elements
- Basis functions are non-negative
- 1 node per element (asymptotically for $C^{p-1}$)
- $h$-, $p$- and $k$-refinement + variations

# What is Isogeometric Analysis (IGA)? – FEA with NURBS

- Elements are defined patch-wise (kind of macro-element or subdomain)
- Elements within a patch have same degrees, material, integration rule, etc.
- Basis functions exist in the **parameter space**
- Control points define the geometry in the **physical space**
- Control points form a control net

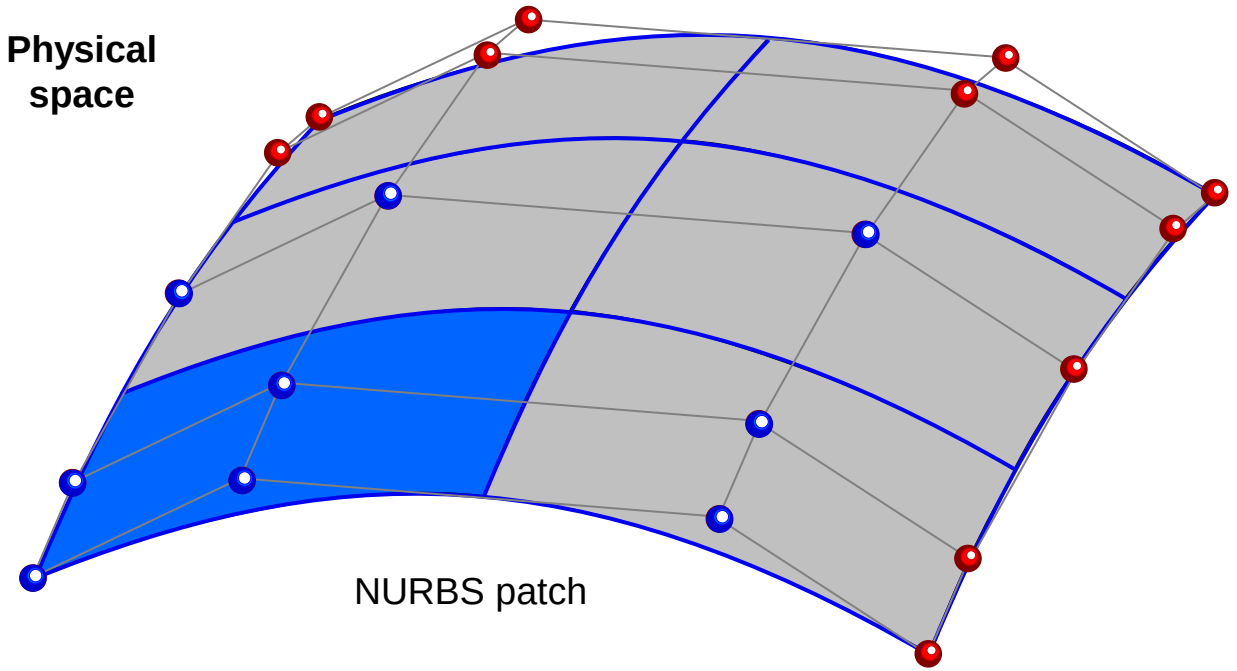


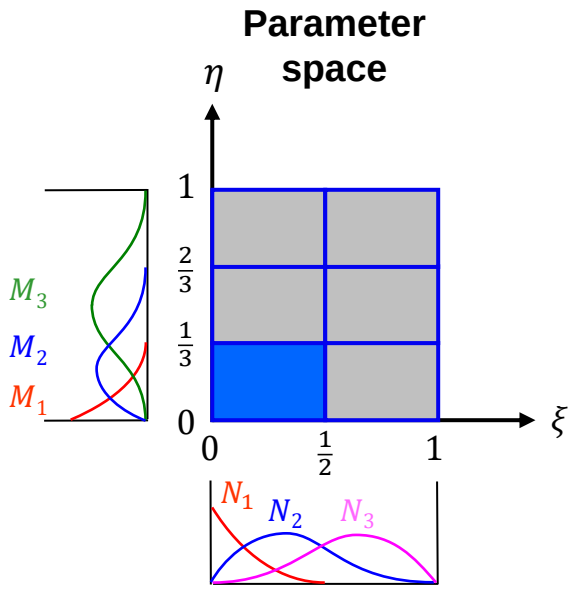



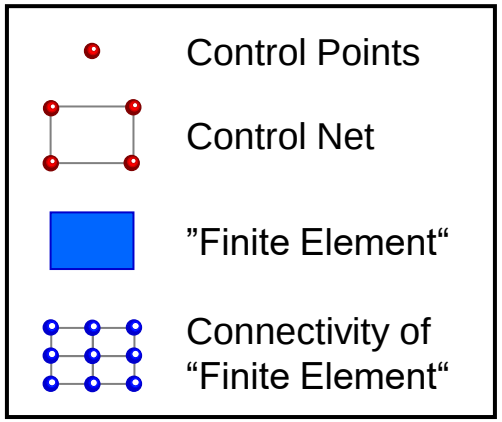



# What is Isogeometric Analysis (IGA)? – FEA with NURBS

- A typical NURBS patch – Connectivity of elements
  - Possible ”overlaps“ due to higher continuity
  - A control point may belong to multiple elements
  - Size of ”overlap“ depends on polynomial degree



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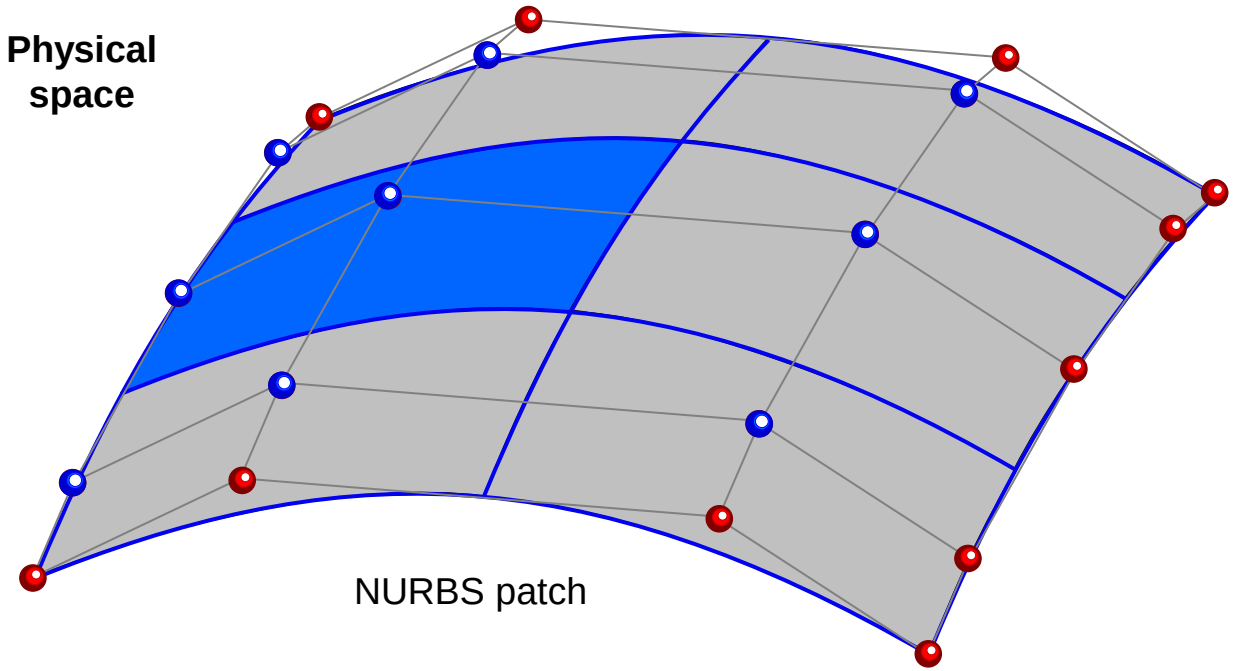


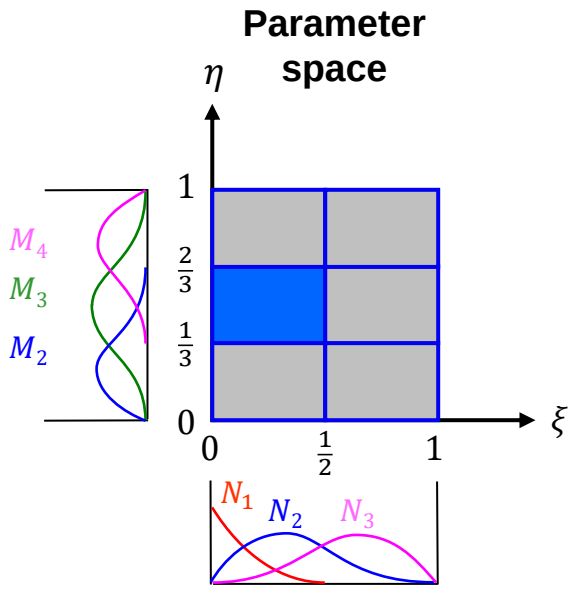


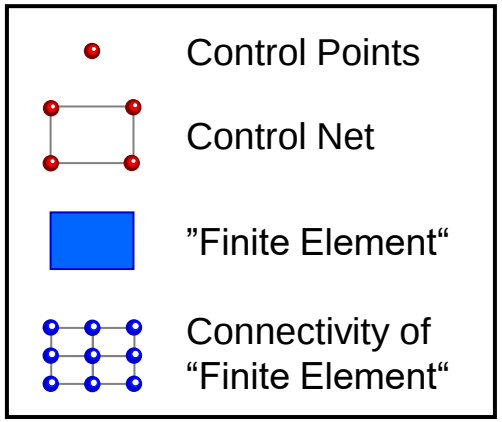

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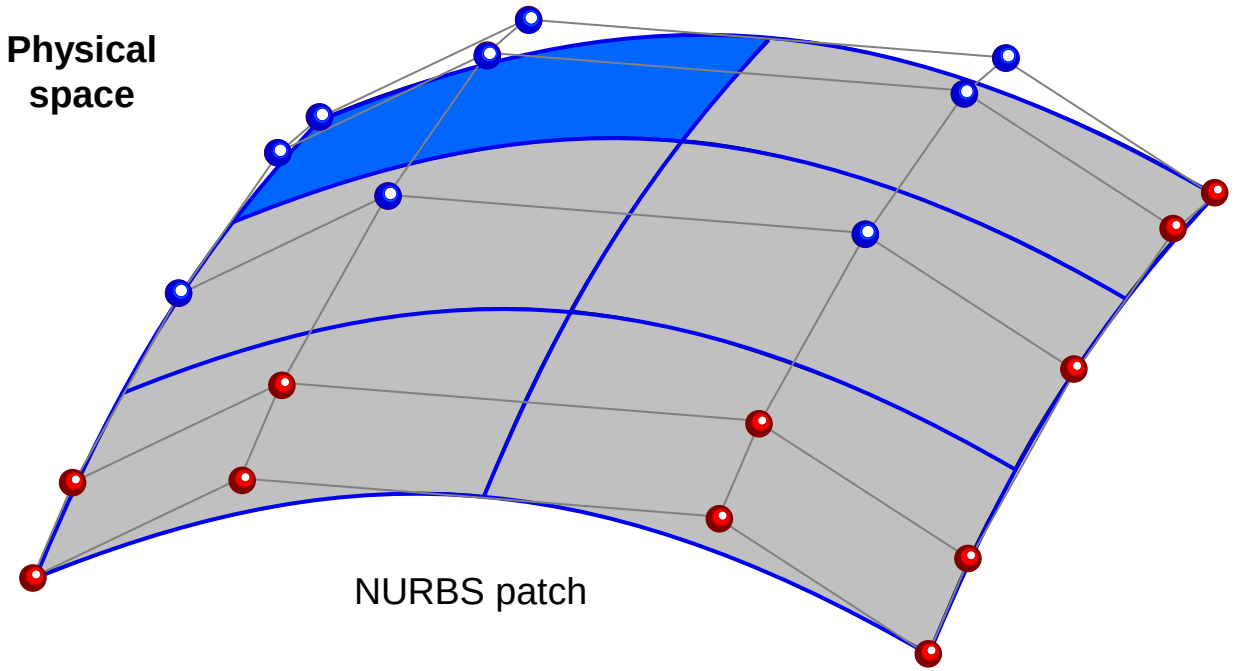
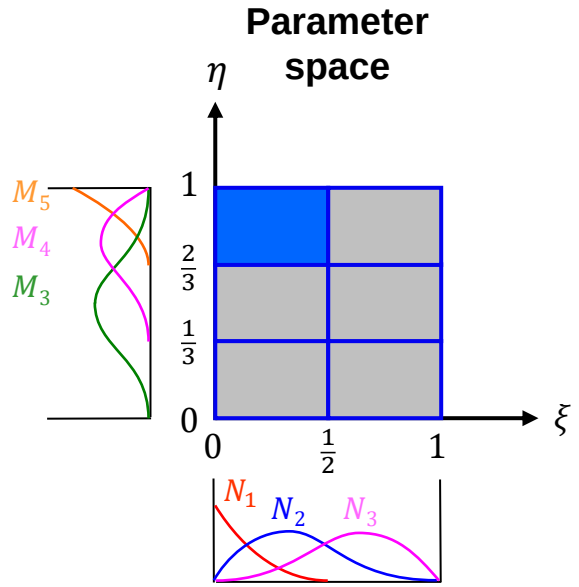
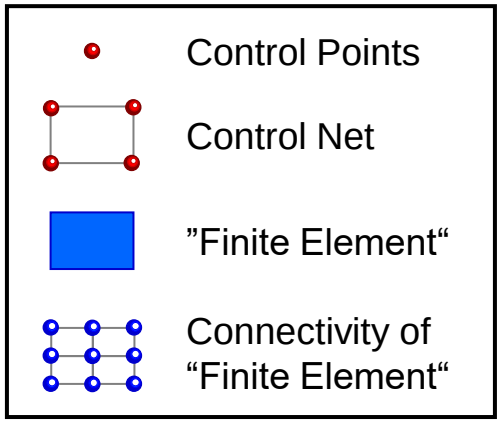
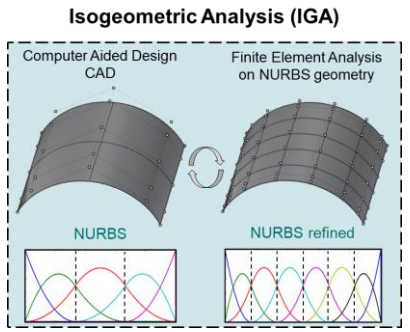


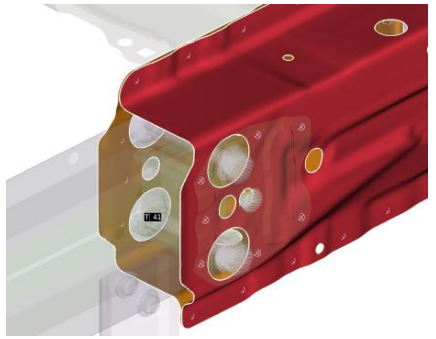



# What is Isogeometric Analysis (IGA)? – Potential benefits

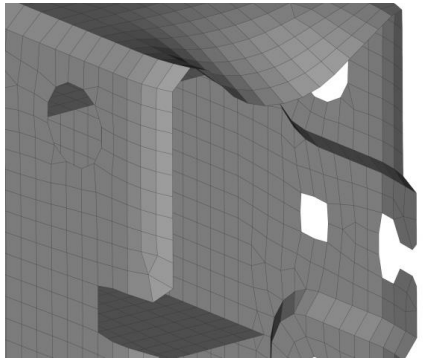
- **Faster development process** by integrating design and analysis
  - Same NURBS-based geometry description, consistent data structure
  - Mesh-independent modeling (spotwelds, connections, etc.)
  - Associative and feature-based model (assembly) as in CAD

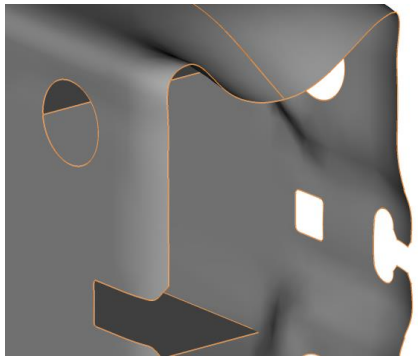


Courtesy of BMW Group

- **Higher predictive accuracy** (for similar element size)
  - More accurate geometry description: Consider details neglected with standard FEA
  - Higher-order AND higher-continuity elements:
    - Smoother displacement/strain/stress fields
    - Capture deformation modes correctly
    - More accurate representation of eigenmodes (NVH)





Courtesy of BMW Group

- **Increased efficiency**
  - Larger element size and fewer DOFs (for similar accuracy, depending on application, e.g. sheet metal forming)
  - Larger time step size in explicit dynamics (for similar element size, $C^{p-1}$ continuity and interior elements)

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3. The New CAD-Inspired *IGA Keywords
   - Motivation
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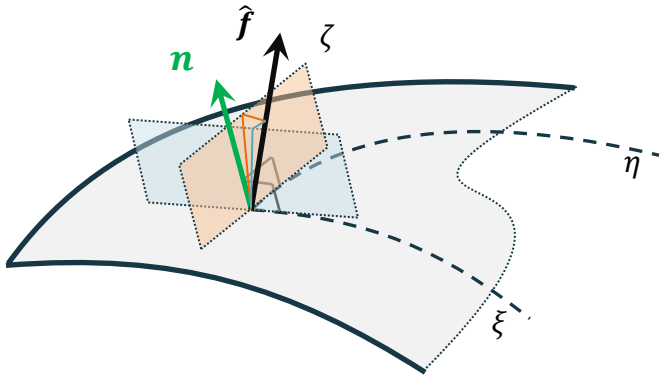
# IGA in LS-DYNA and LS-PrePost

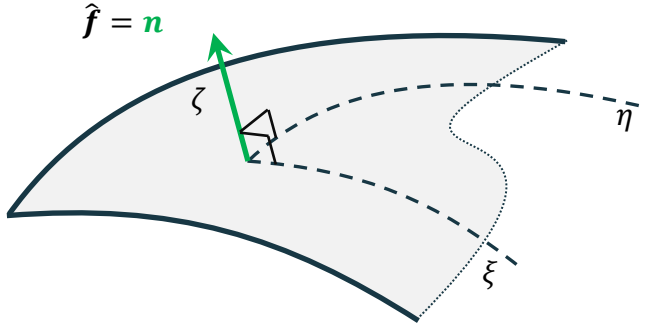
## IGA in LS-DYNA

- Shells and solids
- Explicit and implicit analysis, SMP and MPP
- Basically all material models available

**2 Reissner-Mindlin (RM) shells**
(with rotational DOFs, shear-deformable)



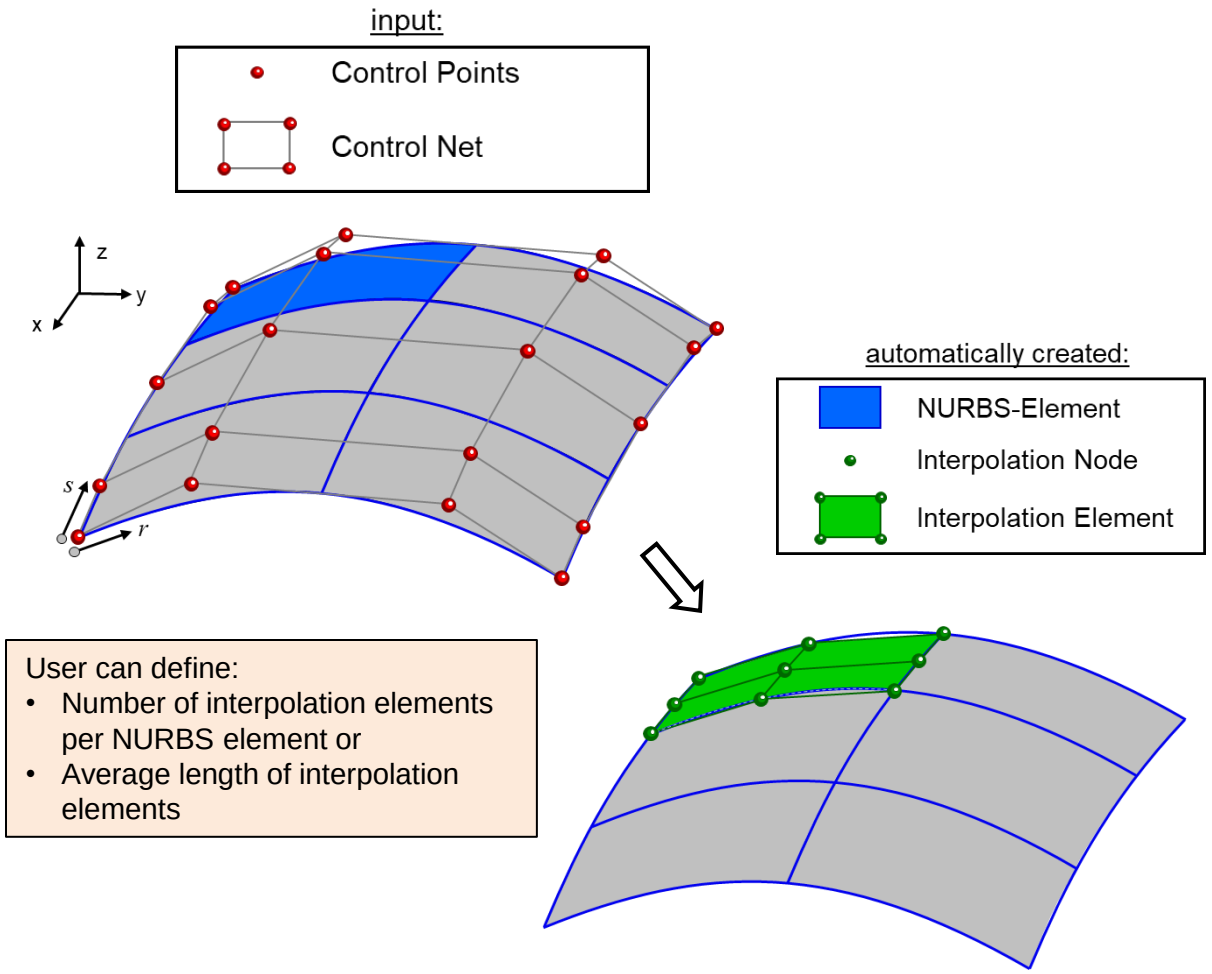

**2 Kirchhoff-Love (KL) shells**
(no rotational DOFs, no transverse shear)



# IGA in LS-DYNA and LS-PrePost

## IGA in LS-DYNA

- Shells and solids
- Explicit and implicit analysis, SMP and MPP
- Basically all material models available
- FE interpolation mesh: postprocessing + contact



# IGA in LS-DYNA and LS-PrePost

## IGA in LS-DYNA

- Shells and solids
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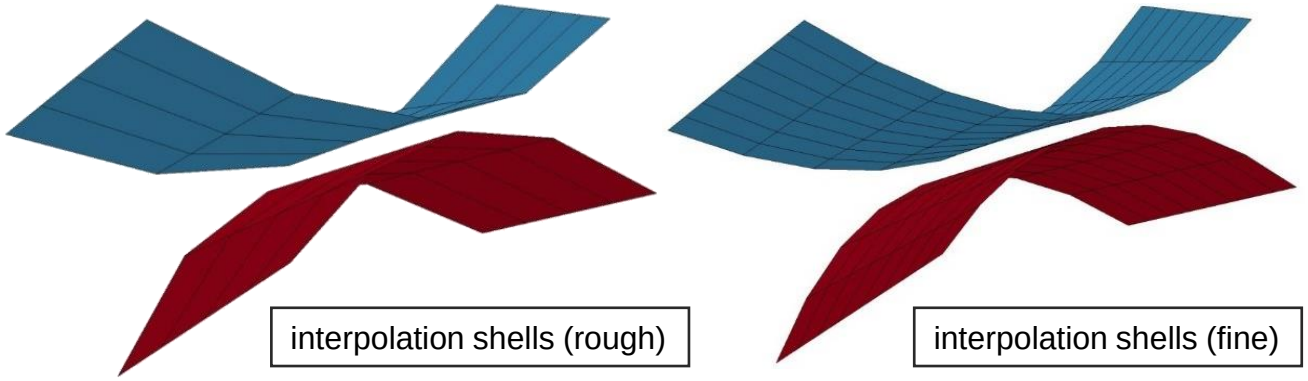
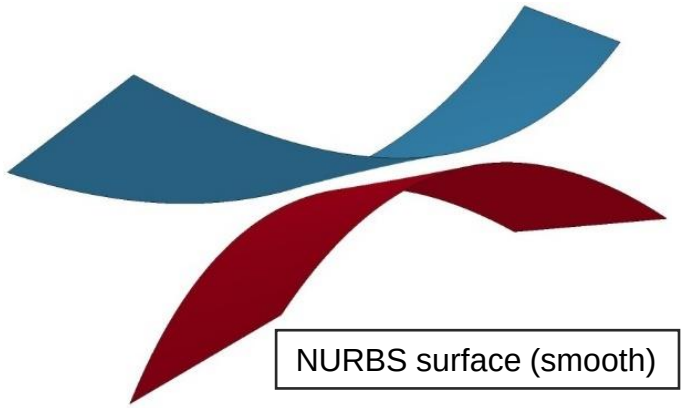
- Basically all material models available
- FE interpolation mesh: postprocessing + contact
- Contact + boundary conditions (e.g. spotwelds)
- Time step estimation and mass scaling for explicit

**Option 1:** Via interpolation nodes/elements



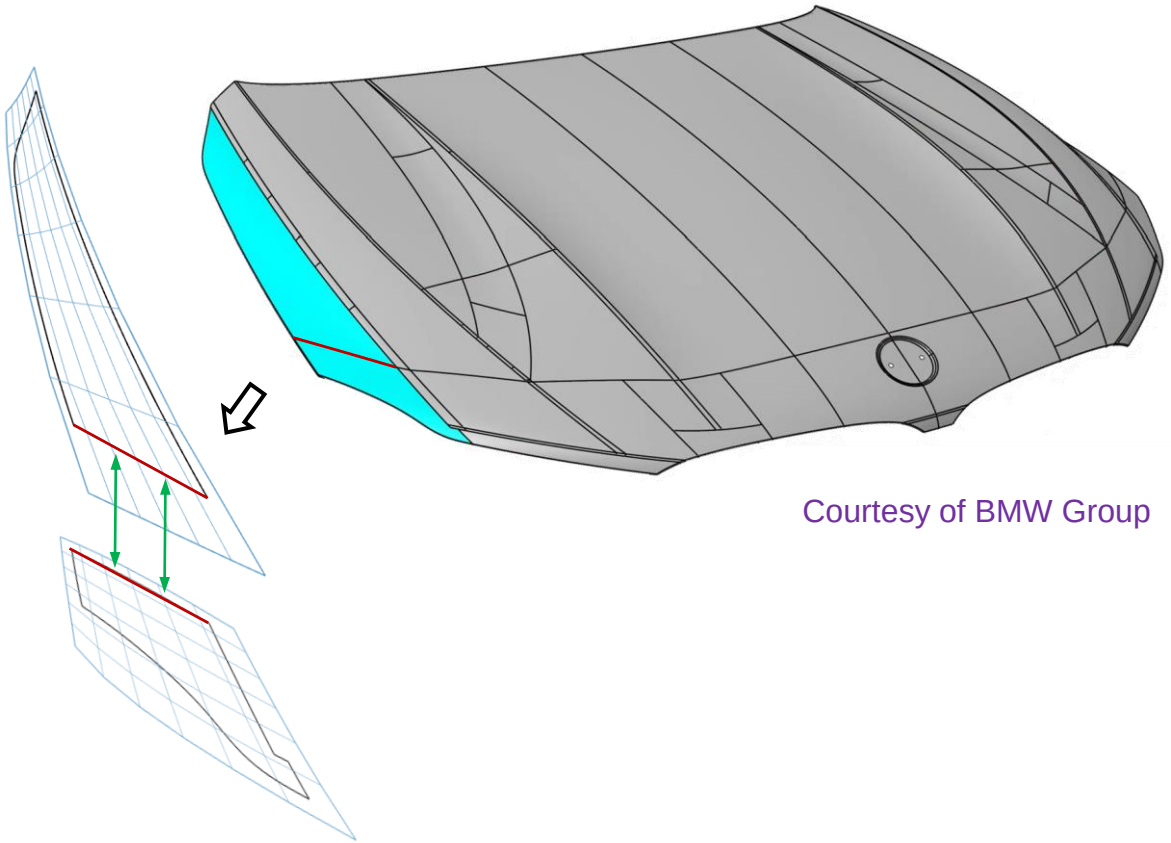

**Option 2:** Use NURBS representation for master side



# IGA in LS-DYNA and LS-PrePost

## IGA in LS-DYNA

- Shells and solids
- Explicit and implicit analysis, SMP and MPP
- Basically all material models available
- FE interpolation mesh: postprocessing + contact
- Contact + boundary conditions (e.g. spotwelds)
- Time step estimation and mass scaling for explicit
- Trimming and coupling of shell patches
- Hybrid models: Combine FEA and IGA components
- Stress/strain/thickness initialization
- Keyword format
  - Original keywords: “NURBS-based FEA”
    - *ELEMENT_SHELL/SOLID_NURBS_PATCH
  - New *IGA keywords: “CAD-inspired” structure
    - *IGA_SHELL/SOLID (from R13)

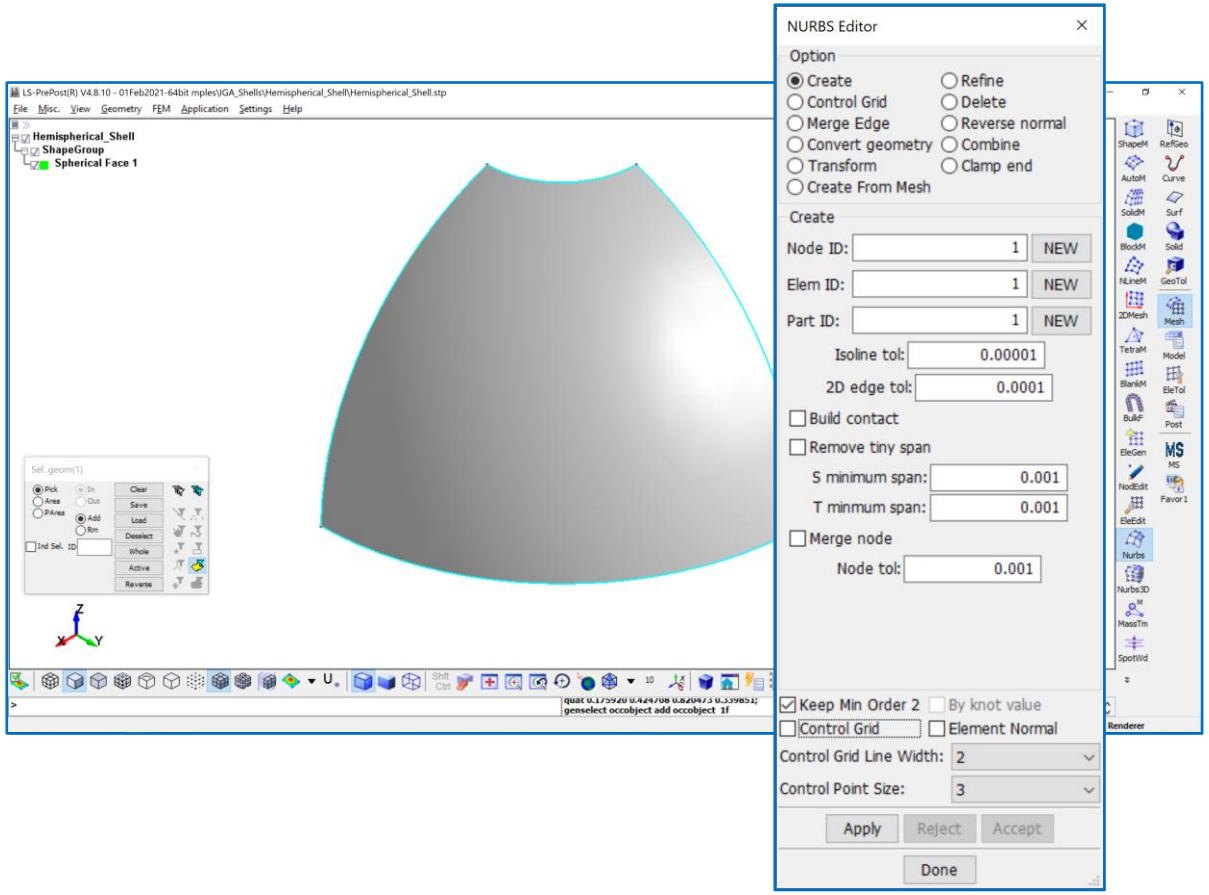


Courtesy of BMW Group

# IGA in LS-DYNA and LS-PrePost

## IGA in LS-PrePost

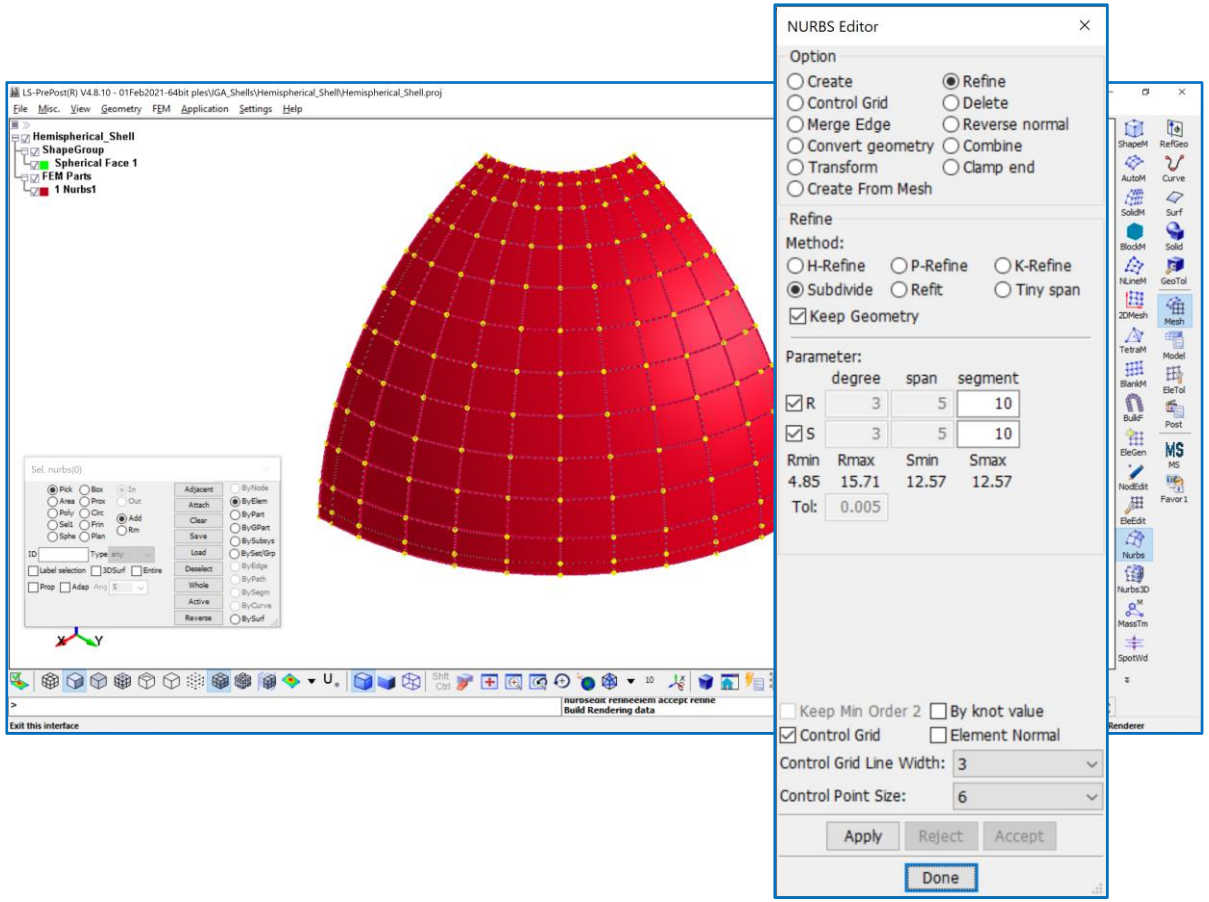
- Model generation for NURBS shells
  - Multiple trimmed NURBS shells



# IGA in LS-DYNA and LS-PrePost

## IGA in LS-PrePost

- Model generation for NURBS shells
  - Multiple trimmed NURBS shells
  - Refinements ($h$, $p$, $k$)
  - Define model properties, boundary conditions
  - In development: Topology btw. multiple shells
  - Not yet possible: Rebuild or merge patches



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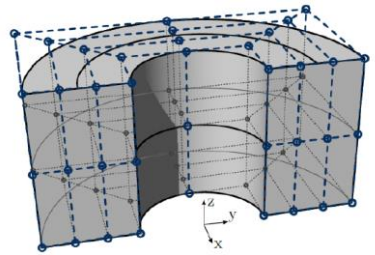
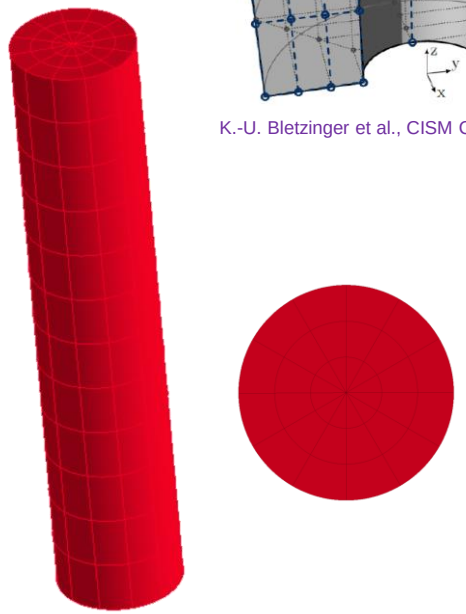
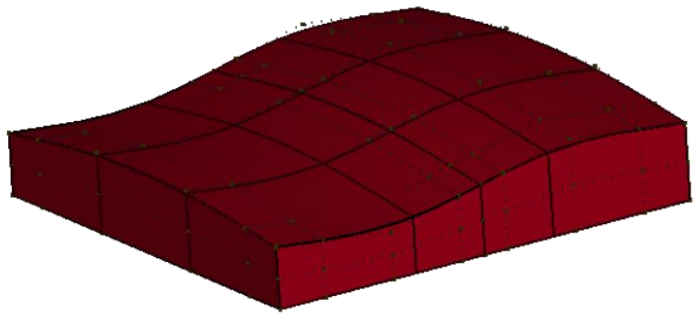
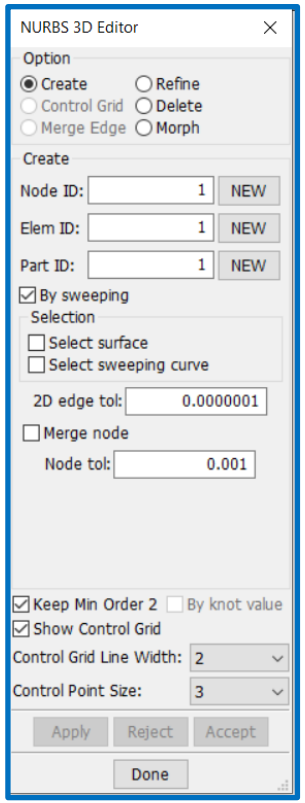
  - Cuboid-type shapes
  - Refinements ($h$, $p$, $k$)
- Write and read original and new *IGA keywords



K.-U. Bletzinger et al., CISM Course notes, 2017





# IGA in LS-DYNA and LS-PrePost

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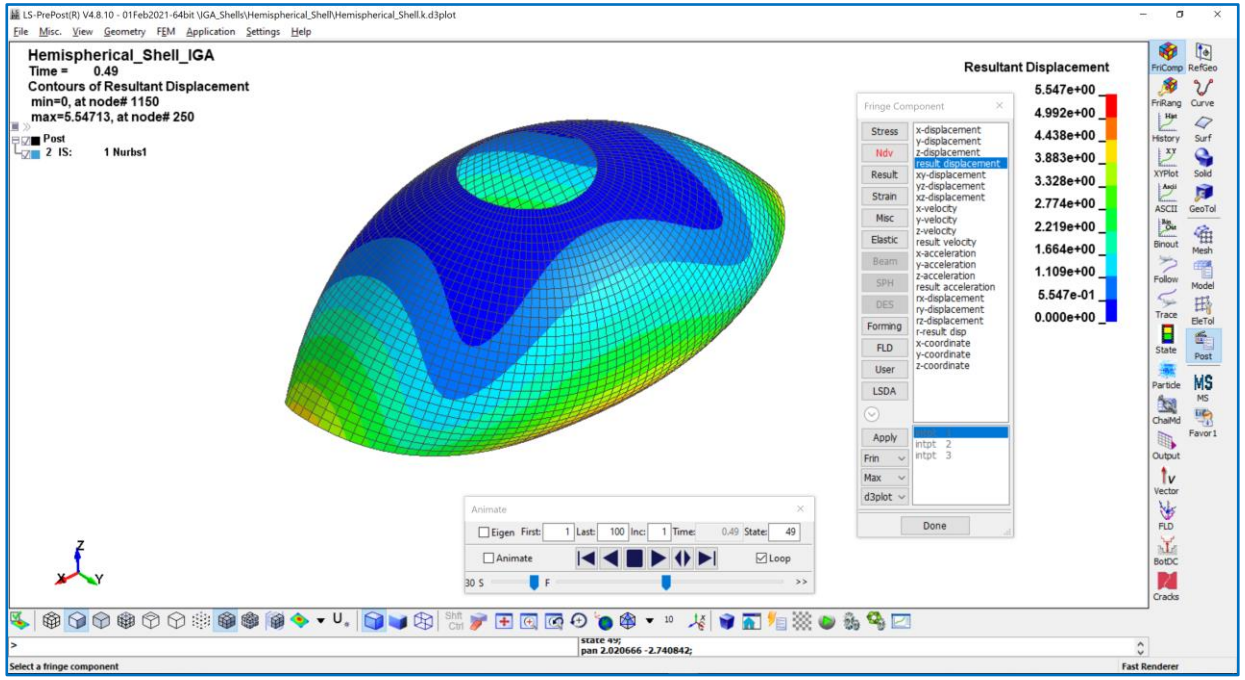
  - Cuboid-type shapes
  - Refinements ($h$, $p$, $k$)
- Write and read original and new *IGA keywords
- Postprocessing
  - Visualization of FE interpolation mesh
  - Open *.d3plot as for standard FEA
  - Fringe plots of displacements, stresses, strains, etc.



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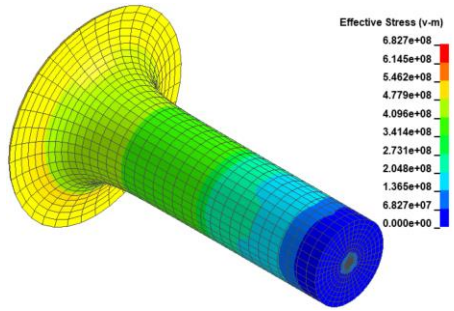


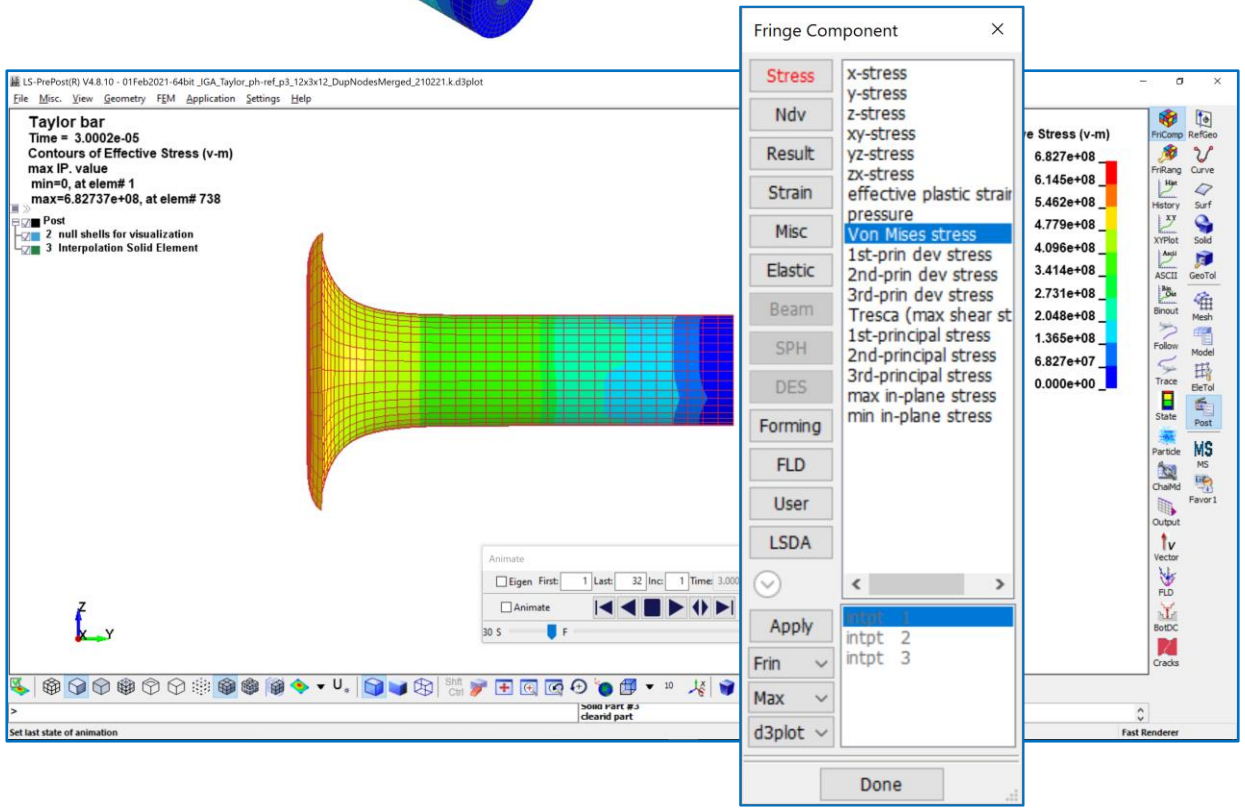

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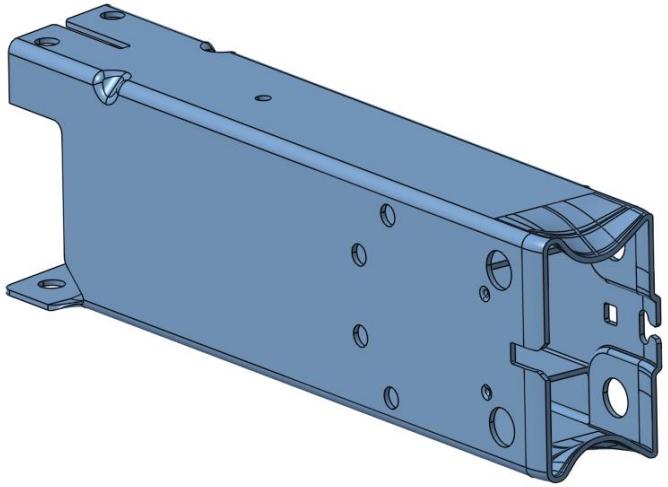
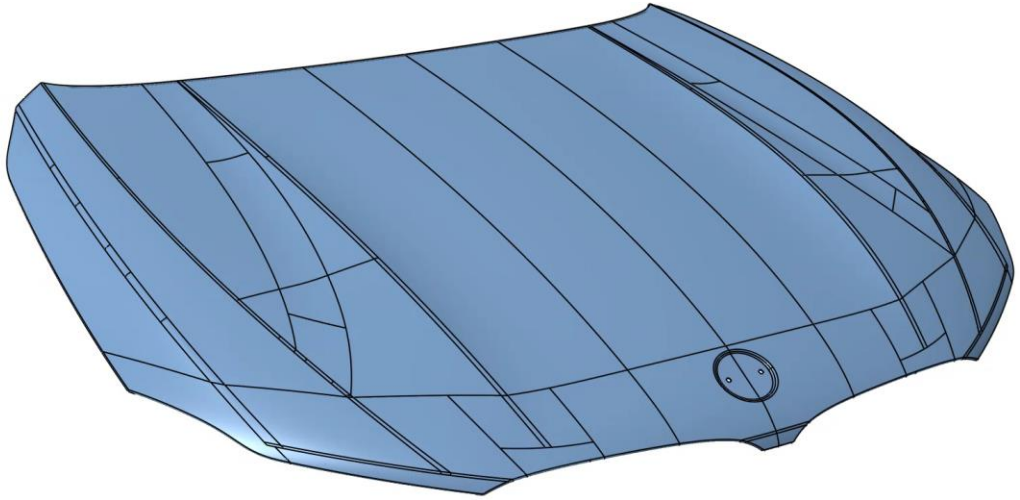
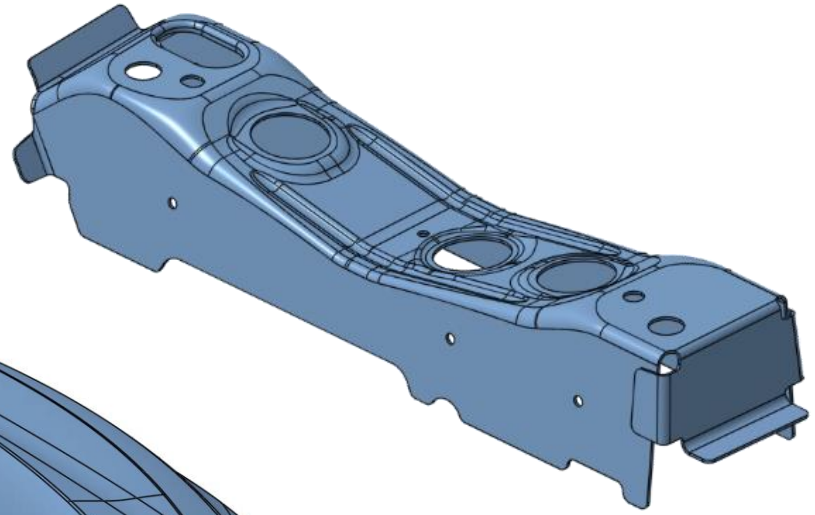
# The New CAD-Inspired *IGA Keywords – Motivation

- Motivation: Isogeometric analysis on industrial CAD models (B-Rep models)

  → Develop keywords that capture B-Rep data structure: Geometry + topology information



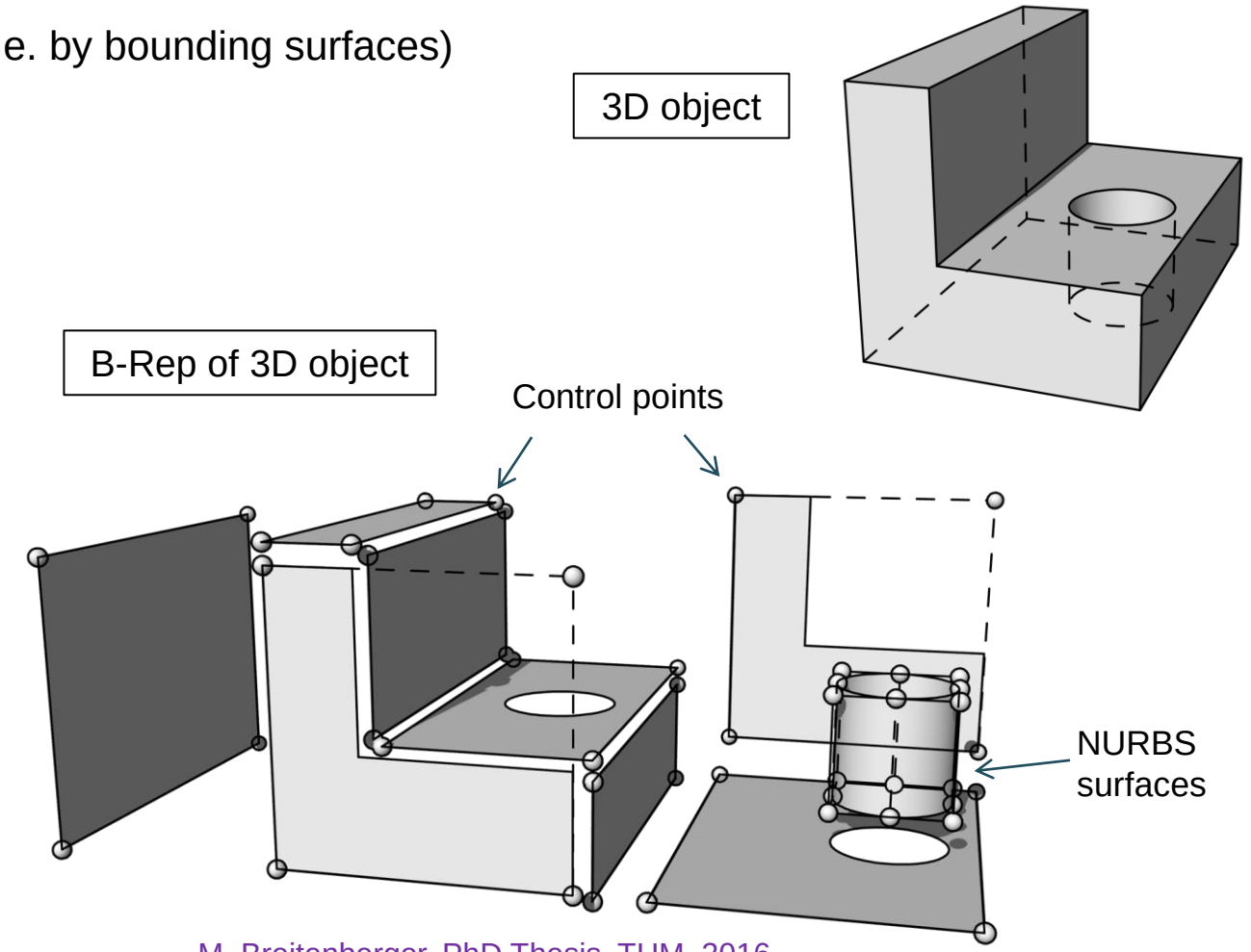




Courtesy of BMW Group

# The New CAD-Inspired *IGA Keywords – Motivation: B-Rep data structure

- Most common modeling approach in industry: Boundary Representation (B-Rep)
  - 3D object only represented by its outer skin (i.e. by bounding surfaces)
  - Based on multiple trimmed NURBS surfaces
    1. NURBS-based geometry description




M. Breitenberger, PhD Thesis, TUM, 2016

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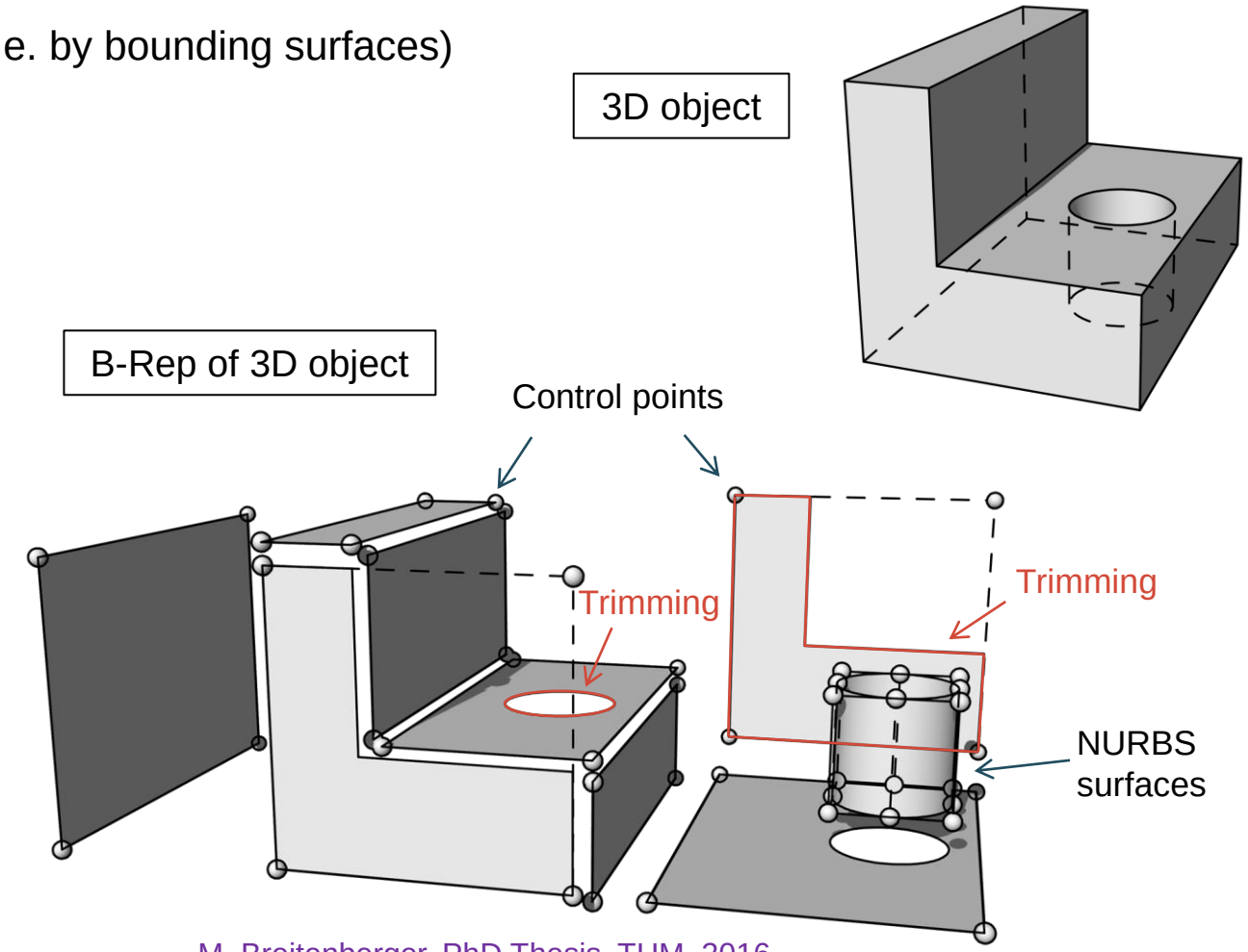
    1. NURBS-based geometry description
    2. Concept of Trimming




M. Breitenberger, PhD Thesis, TUM, 2016

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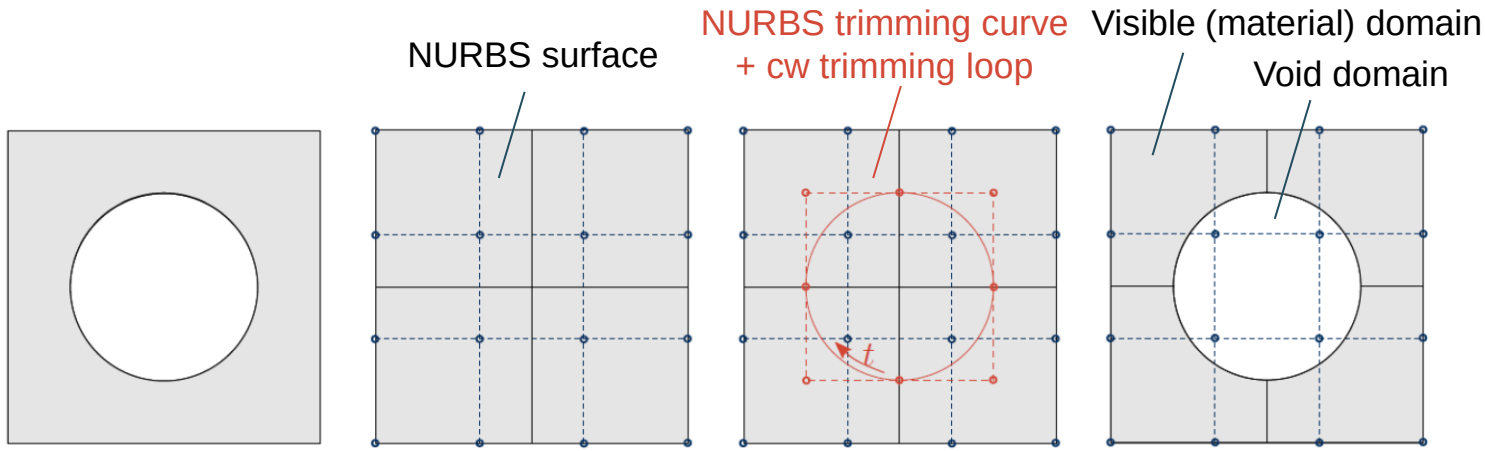
- NURBS surfaces have tensor product structure
  → Topology limited to quadrangular surfaces
  → Trimming to overcome this limitation
- Trimming curves divide NURBS surface into visible and void domain(s)




Target structure: Rectangular plate with circular hole

Design Step 1: Plate without hole

Design Step 2: Define trimming curve by a circle

Design Step 3: Trimming operation by CAD

K.-U. Bletzinger et al., CISM Course notes, 2017

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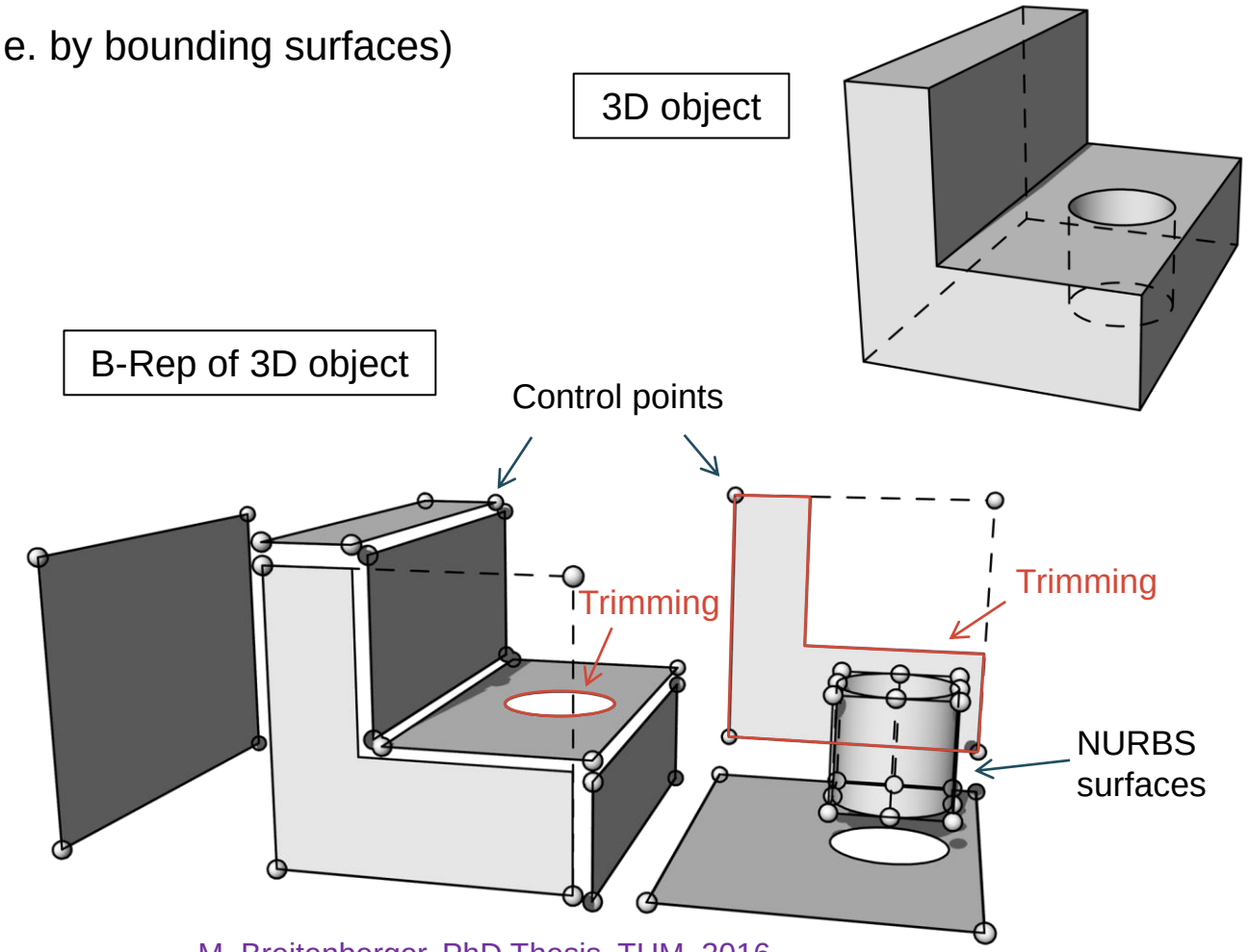


M. Breitenberger, PhD Thesis, TUM, 2016

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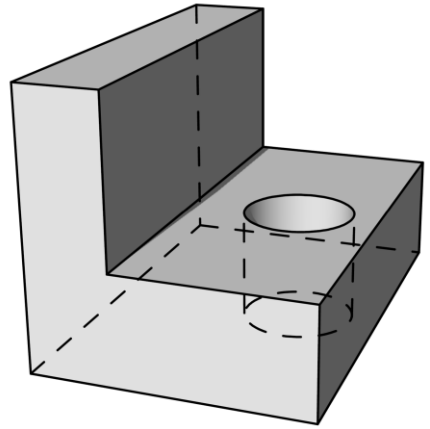
    1. NURBS-based geometry description
    2. Concept of Trimming
    3. Data structure: Geometry + Topology

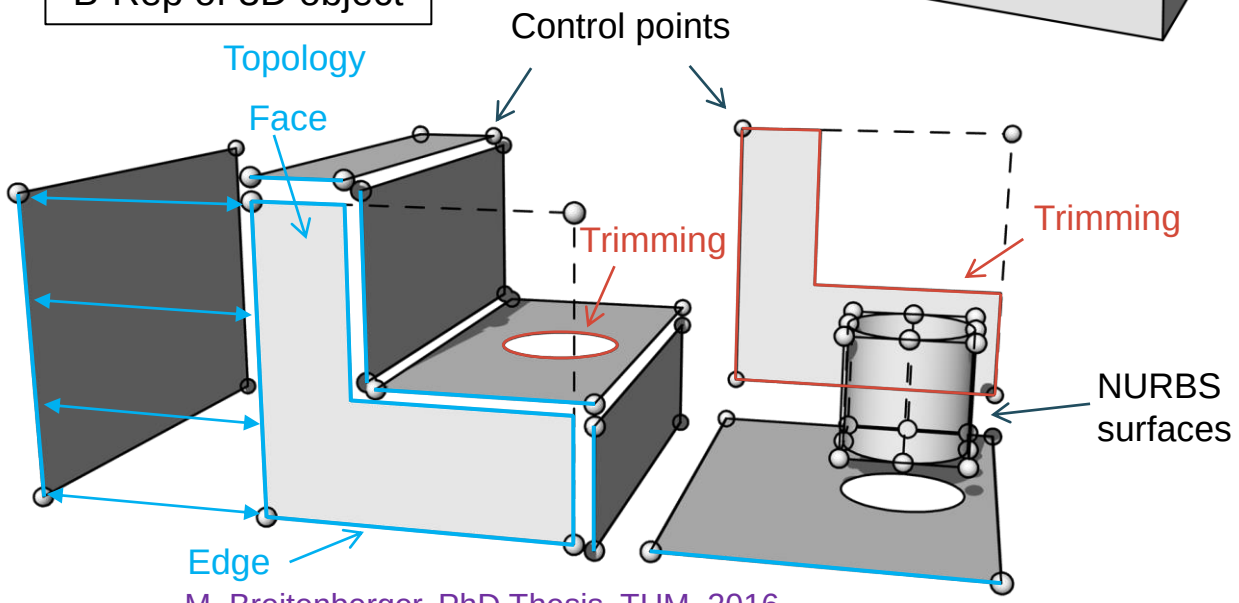
→ Capture B-Rep data structure with *IGA keywords

- **Geometry:**
  Defines position and shape of geometric entities
- **Topology:**
  Defines how entities are arranged and connected

3D object



B-Rep of 3D object

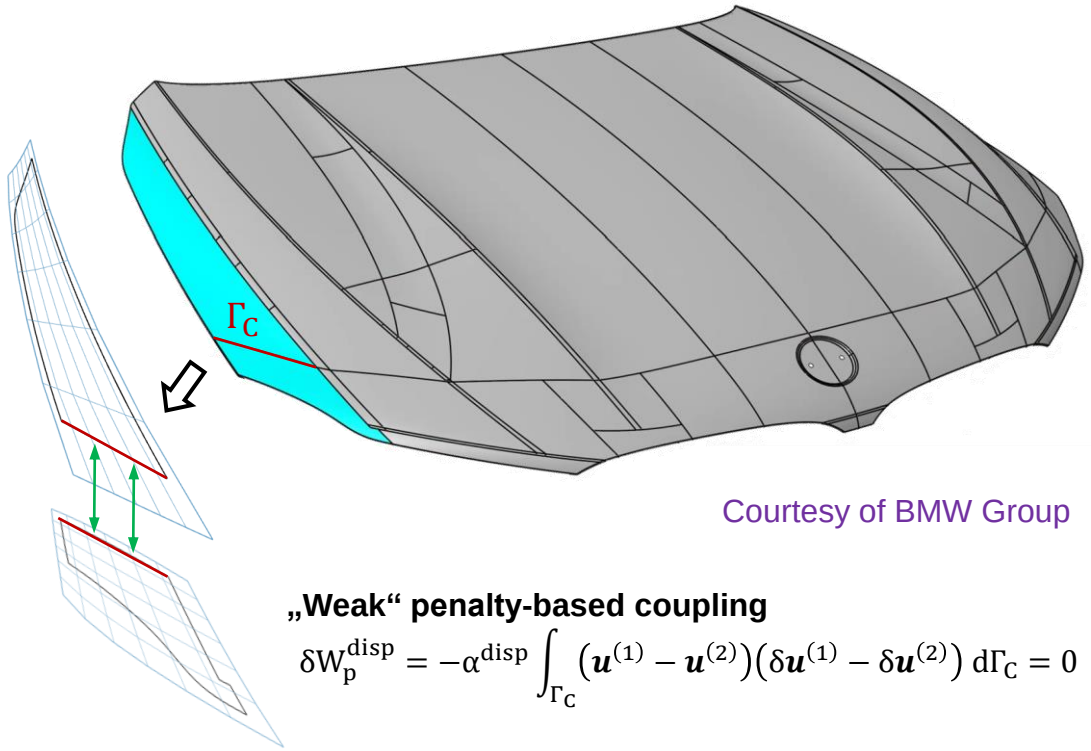



M. Breitenberger, PhD Thesis, TUM, 2016

# The New CAD-Inspired *IGA Keywords – Motivation: Trimming and coupling

- IGA on trimmed multi-patch NURBS shells requires specific analysis capabilities
  1. Processing of B-Rep data including geometry, trimming and topology information
  2. Numerical integration of trimmed NURBS elements
  3. Application of coupling and boundary conditions
  4. Stabilization of small trimmed elements

- First approach covering all capabilities for implicit statics
  - Isogeometric B-Rep Analysis (IBRA) by Breitenberger et al. 2015 [1]
- Extension to explicit dynamics in LS-DYNA
  - Explicit IBRA by Leidinger et al. 2019 [2]
- **Current *IGA implementation in LS-DYNA**




Courtesy of BMW Group

**„Weak“ penalty-based coupling**

$$\delta W_p^{disp} = -\alpha^{disp} \int_{\Gamma_C} \left(\boldsymbol{u}^{(1)} - \boldsymbol{u}^{(2)}\right)\left(\delta\boldsymbol{u}^{(1)} - \delta\boldsymbol{u}^{(2)}\right) d\Gamma_C = 0$$


[1] M. Breitenberger, A. Apostolatos, B. Philipp, R. Wüchner, K.-U. Bletzinger, Analysis in computer aided design: Nonlinear isogeometric B-Rep analysis of shell structures, Comput. Methods Appl. Mech. Eng. 284 (2015) 401–457.

[2] L.F. Leidinger, M. Breitenberger, A.M. Bauer, S. Hartmann, R. Wüchner, K.-U. Bletzinger, F. Duddeck, L. Song, Explicit dynamic isogeometric B-Rep analysis of penalty-coupled trimmed NURBS shells, Comput. Methods Appl. Mech. Eng. 351 (2019) 891–927.

# Outline

1. What is Isogeometric Analysis (IGA)?
2. IGA in LS-DYNA and LS-PrePost
3. **The New CAD-Inspired *IGA Keywords**
   - Motivation
   - **Trimmed Multi-Patch Shells**
   - Novel Spline Technologies
4. IGA for Industrial Applications
5. Summary and Outlook

# The New CAD-Inspired *IGA Keywords – Original Keywords for Shells

- Input structure for original “NURBS-based FEA”: Comparison with standard FEA

Input structure for standard FEA (shells)

```
*NODE                       NID X Y Z
*ELEMENT_SHELL              EID PID N1 N2 N3 N4
*PART                       PID SECID MID
*SECTION_SHELL              SECID ELFORM SHRF NIP
*MAT_ELASTIC                MID RO E PR
```

Input structure for NURBS-based FEA (shells)

```
*NODE                       NID X Y Z
*ELEMENT_SHELL_NURBS_PATCH  NPID PID ... N1 N2 N3 N4 N5 N6 N7 N8 ...
*PART                       PID SECID MID
*SECTION_SHELL              SECID ELFORM SHRF NIP
*MAT_ELASTIC                MID RO E PR
```

Patch-wise element definition

ELFORM=201 indicates NURBS shells

# The New CAD-Inspired *IGA Keywords – The *IGA Keyword Structure for Shells

- Input structure for new *IGA keywords: Comparison with standard FEA

```
*NODE                   NID X Y Z
*ELEMENT_SHELL          EID PID N1 N2 N3 N4
*PART                   PID SECID MID
*SECTION_SHELL          SECID ELFORM SHRF NIP
*MAT_ELASTIC            MID RO E PR
```

Input structure for standard FEA (shells)

```
*IGA Keywords for Geometry and Topology
*IGA_SHELL              SID PID NISR NISS
*PART                   PID SECID MID
*SECTION_IGA_SHELL      SECID ELFORM SHRF NIP IRL
*MAT_ELASTIC            MID RO E PR
```

Input structure for new *IGA keywords (shells)

# The New CAD-Inspired *IGA Keywords – The *IGA Keyword Structure for Shells

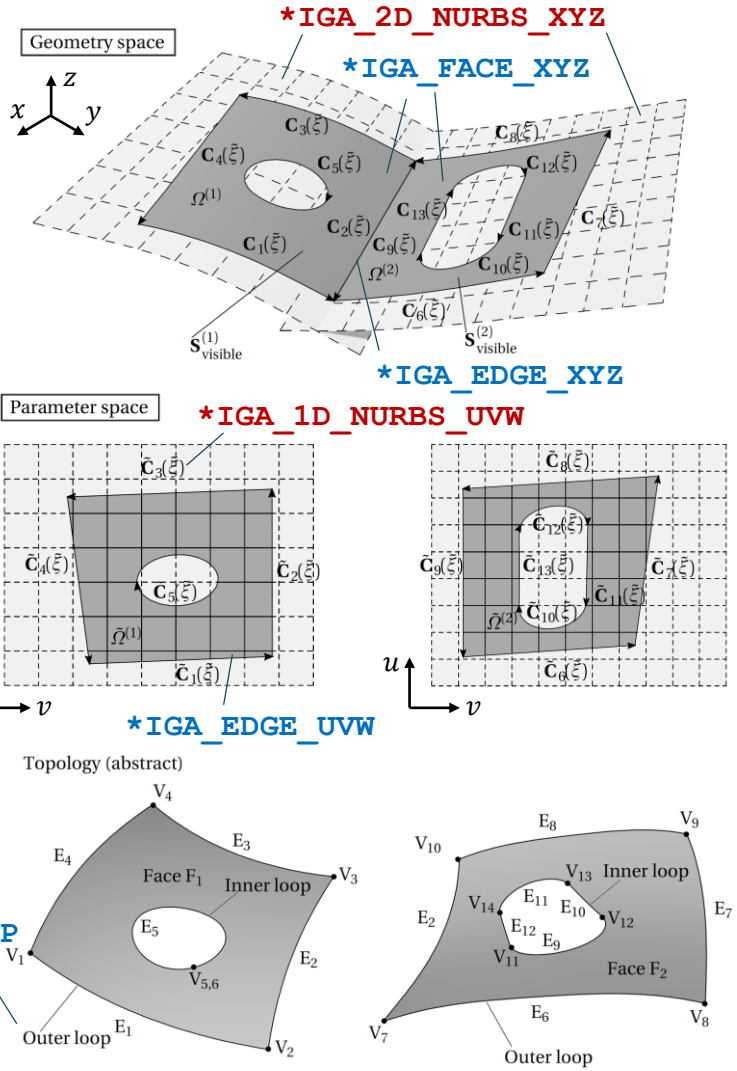
- Input structure for new *IGA keywords in LS-DYNA

```
*IGA Keywords for Geometry and Topology
*IGA_1D_NURBS_UVW      NID NR PR RKi U V W WGT
*IGA_EDGE_UVW          EID EXYZID NID
*IGA_EDGE_XYZ          EID NID PSID
*IGA_1D_BREP           BRID EIDi
*IGA_2D_NURBS_XYZ      NID NR NS PR PS RKi SKi X Y Z WGT
*IGA_FACE_XYZ          FID NID ORI PSID ESID BRIDi
*IGA_SHELL             SID PID NISR NISS
*PART                  PID SECID MID
*SECTION_IGA_SHELL     SECID ELFORM SHRF NIP IRL
*MAT_ELASTIC           MID RO E PR
```

Input modification not recommended

Geometry
Topology
Analysis

Analysis settings to be modified by the user




L. Leidinger, PhD Thesis, TUM, 2020

# The New CAD-Inspired *IGA Keywords – Preview: Trimmed Solids

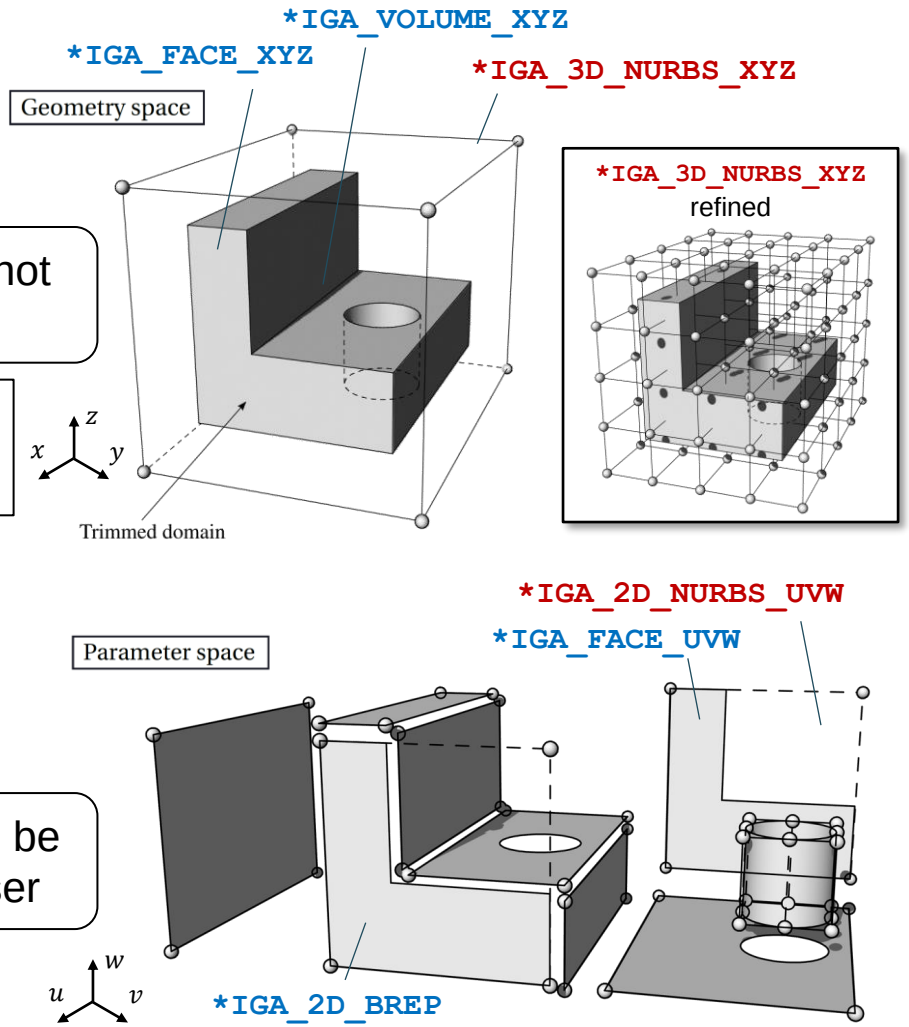
- Input structure for new *IGA keywords in LS-DYNA

| *IGA-KWs for Geometry and Topology | |
|---|---|
| *IGA_2D_NURBS_UVW | NID NR NS PR PS RKi SKi U V W WGT |
| *IGA_FACE_UVW | FID FXYZID NID |
| *IGA_FACE_XYZ | FID NID PSID ESID BRIDi |
| *IGA_2D_BREP | BRID FIDi |
| *IGA_3D_NURBS_XYZ | NID NR/S/T PR/S/T R/S/TKi X Y Z WGT |
| *IGA_VOLUME_XYZ | FID NID PSID ESID FSID BRIDi |
| *IGA_SOLID | SID PID NISR NISS NIST |
| *PART | PID SECID MID |
| *SECTION_IGA_SOLID | SECID ELFORM IR |
| *MAT_ELASTIC | MID RO E PR |

Input modification not recommended

Geometry
Topology
Analysis

Analysis settings to be modified by the user




M. Breitenberger, PhD Thesis, TUM, 2016

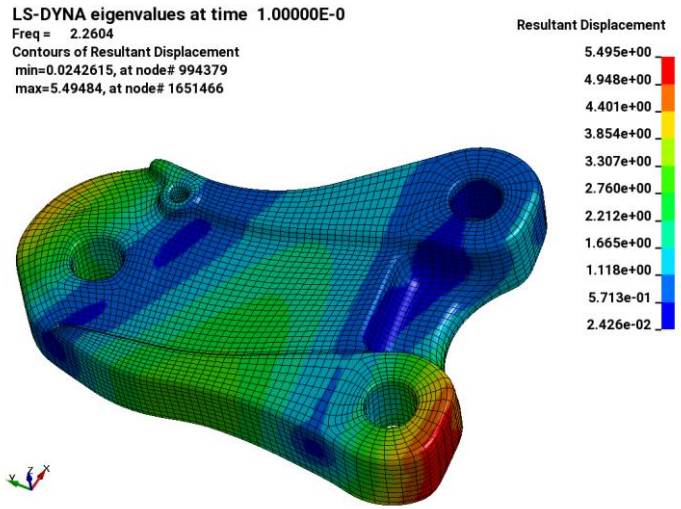
# Outline

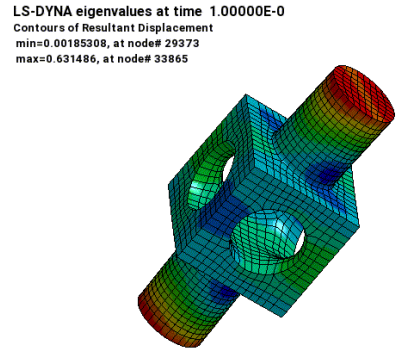
1. What is Isogeometric Analysis (IGA)?
2. IGA in LS-DYNA and LS-PrePost
3. **The New CAD-Inspired *IGA Keywords**
   - Motivation
   - Trimmed Multi-Patch Shells
   - **Novel Spline Technologies**
4. IGA for Industrial Applications
5. Summary and Outlook

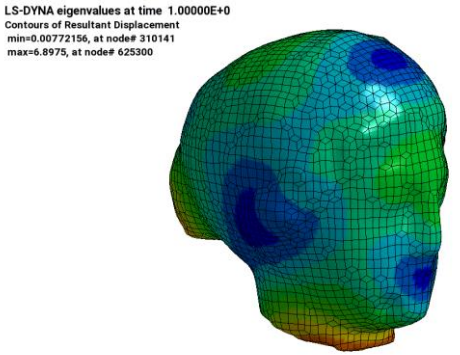
# The New CAD-Inspired *IGA Keywords – Novel Spline Technologies

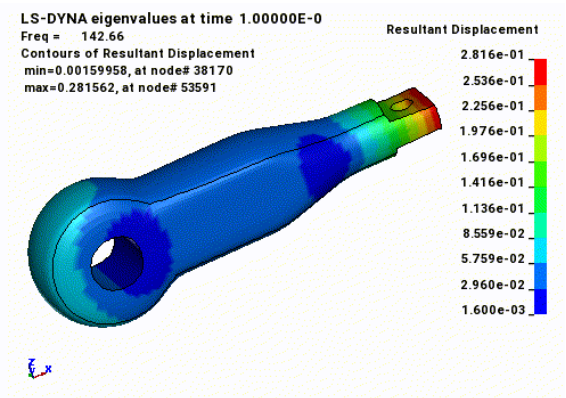
Please contact us if interested

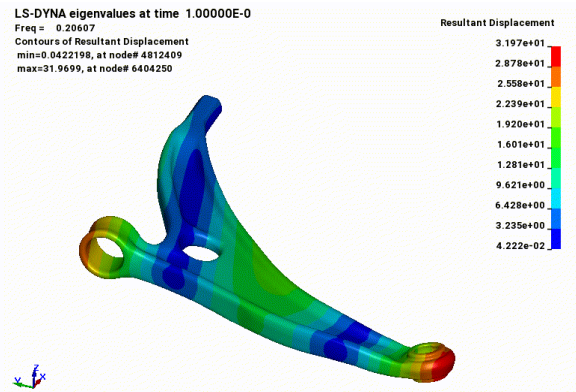
- Include Bézier extraction format: **`*IGA_INCLUDE_BEZIER`**
  - Input any kind of spline technology via Bézier extraction format
  - Bézier extraction allows representing a spline basis (higher continuity) as a Bézier basis ($C^0$ as in standard FEA)
  - Mainly non-standard, boundary-fitted descriptions
    - T-Splines, U-Splines, LR-Splines,
    - Subdivision Surfaces,
    - and others…




Carnegie Mellon University, Jessica Zhang's group; Honda Motor Co., Ltd.

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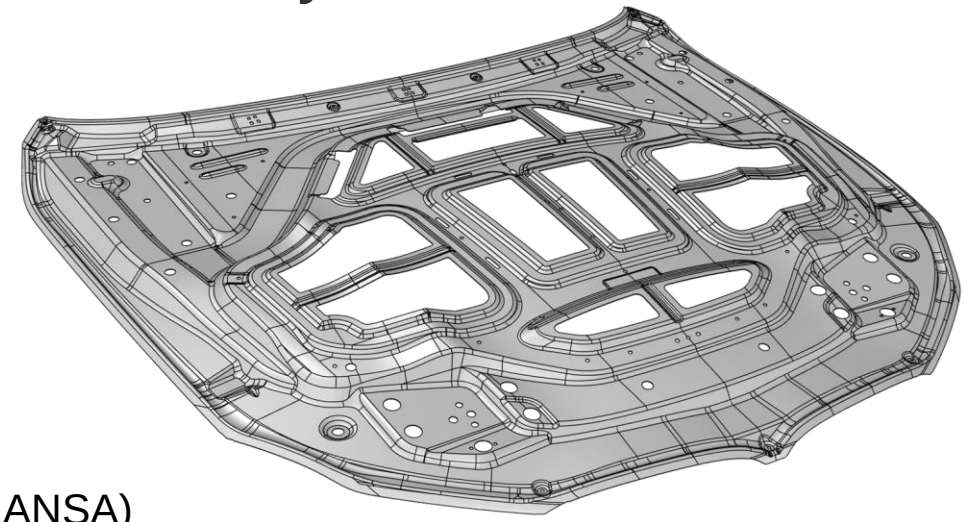
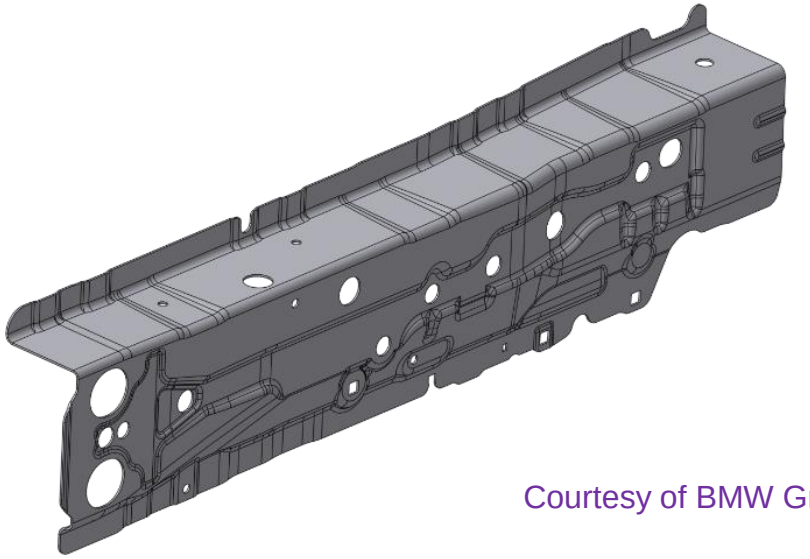
# IGA for Industrial Applications – Analysis-Suitability

- Current CAD models
  - Not designed with analysis-suitability in mind
  - Small narrow faces → small NURBS elements
  - Surfaces with high polynomial degree (up to ~13)



- Two ways to use NURBS models for shell analysis
  1. Current CAD models: Make suitable for analysis (preprocessor ANSA)
     - Generate midsurface (mostly automatic)
     - Reduce degree, join patches
     - Min./max. element size, uniform “mesh”
  2. Future CAD models: Build according to certain guidelines
     - Min. element size, min. patch size, max. degree, etc.
     - Provide midsurface description in CAD
     - Still limited “preprocessing” capabilities of CAD systems

ANSA PRE PROCESSOR



Courtesy of BMW Group

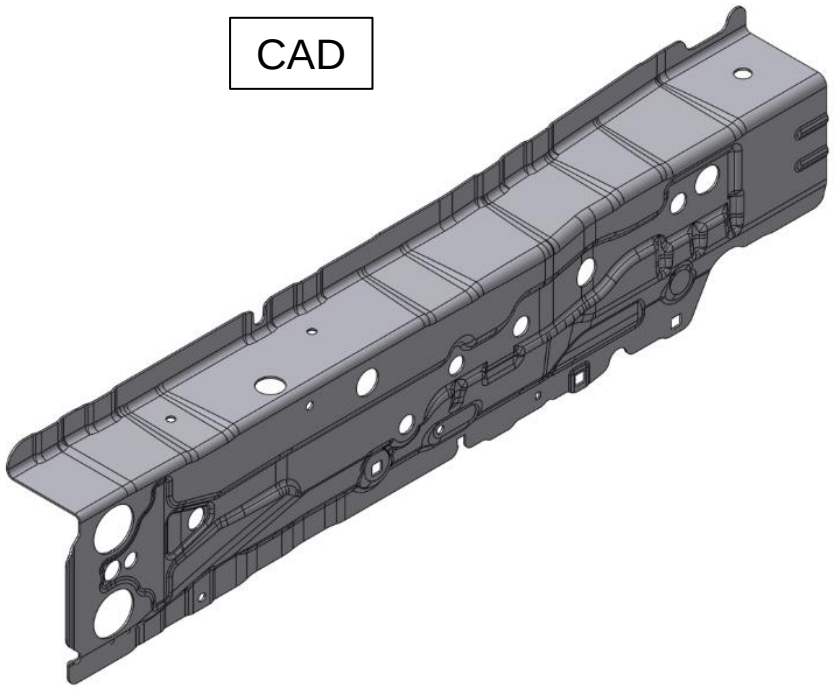
# IGA for Industrial Applications – Model Generation with ANSA

- Analysis-suitable model generation with ANSA
  1. Import B-Rep model
  2. Generate midsurface
  3. Generate single-patch model (min/max span, distortion, uniform mesh, join patches)

| Mode | Create |
|---|---|
| Distortion di... | 0.05 |
| Subinterval par... | |
| Min span | 6. |
| Max span | 20. |
| Uniform | ✓ |
| Extend | ✓ |
| Join | ✓ |

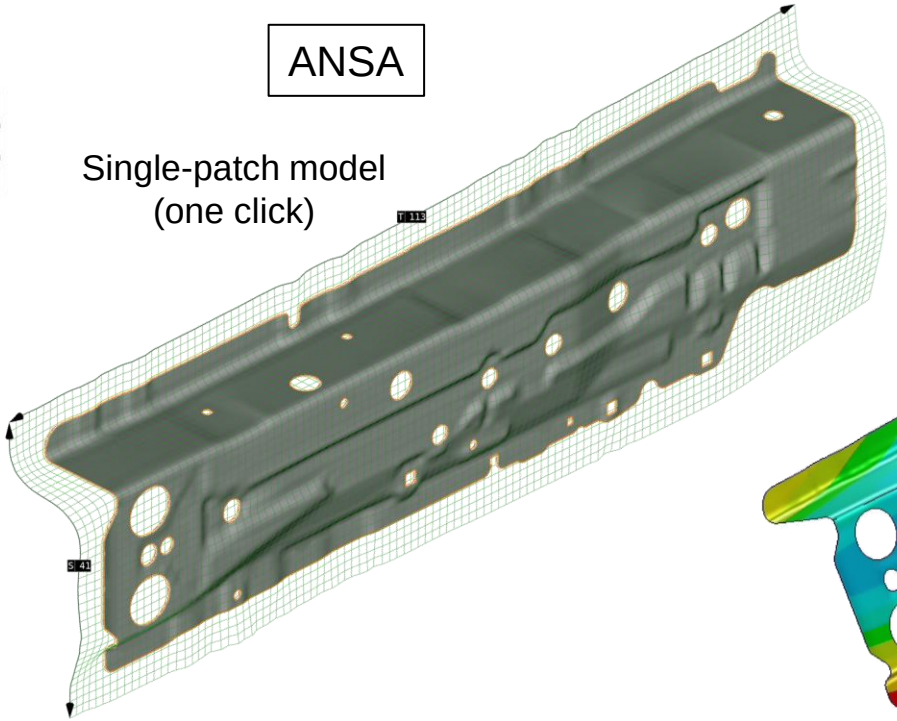
ANSA PRE PROCESSOR

CAD



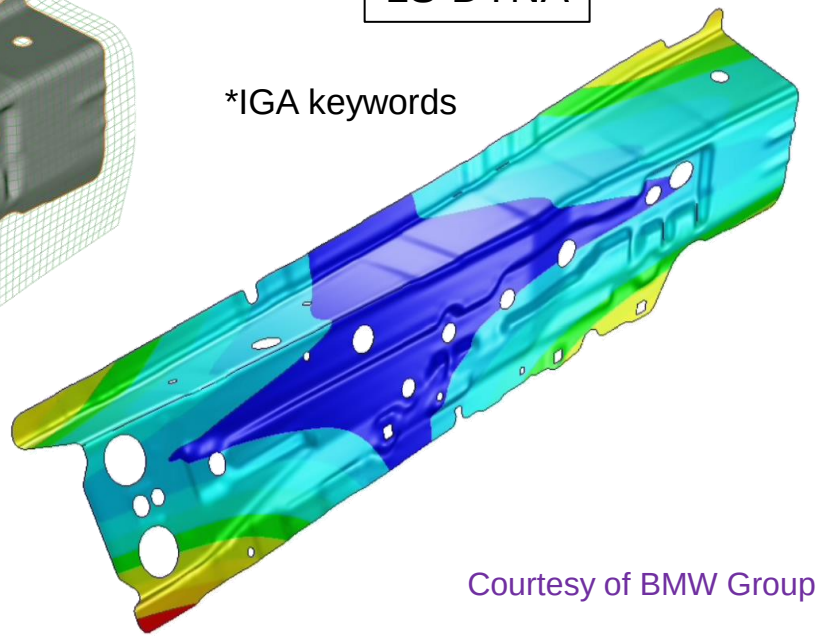
ANSA

Single-patch model
(one click)



LS-DYNA

*IGA keywords

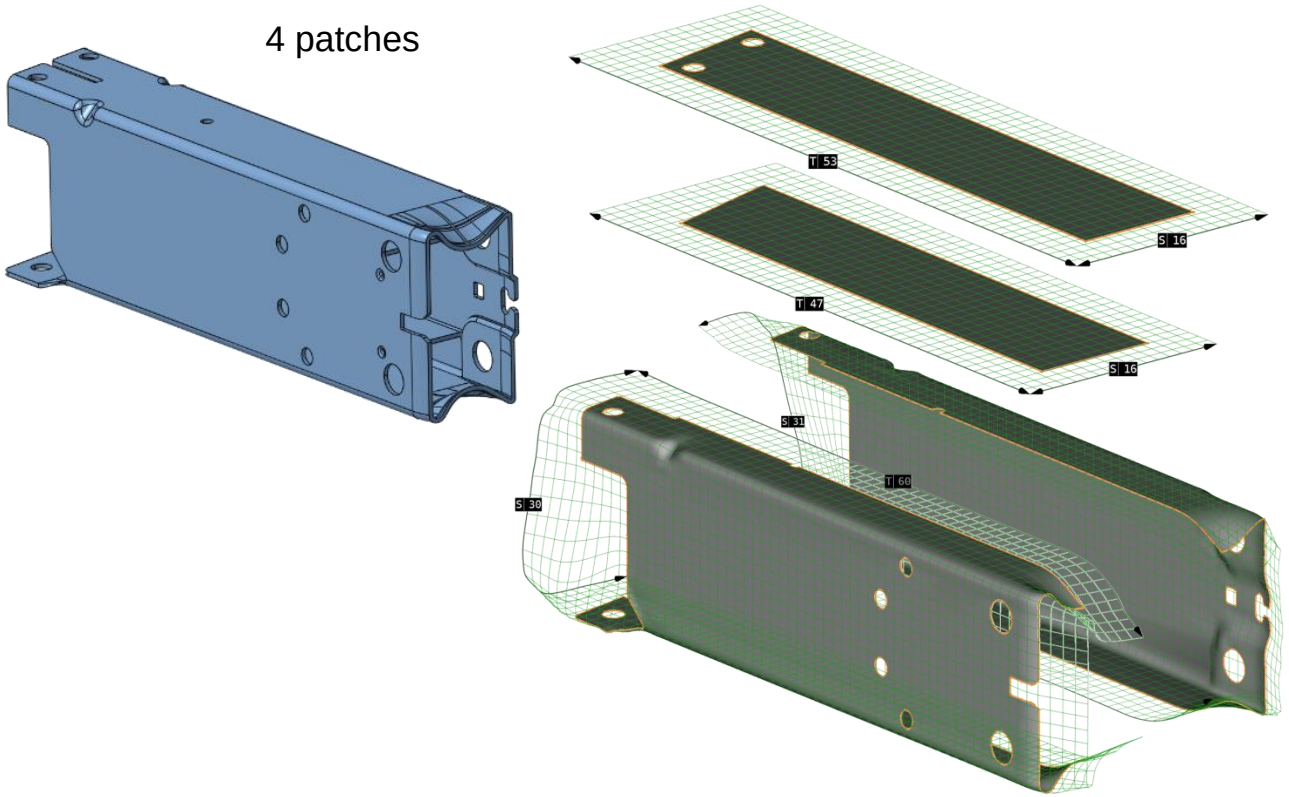


Courtesy of BMW Group

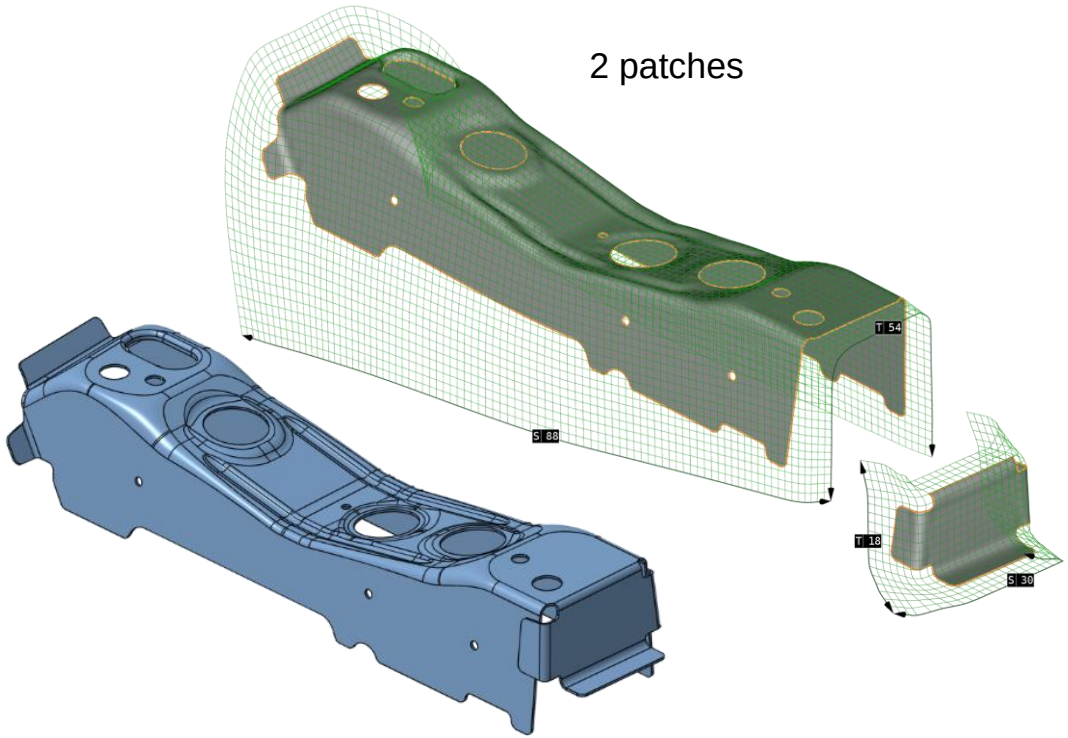
# IGA for Industrial Applications – Model Generation with ANSA

- Analysis-suitable model generation with ANSA
  - Single-patch models not always possible: Closed cross-sections, T-joints, undercuts, overlaps, etc.
  - → Multi-patch models with penalty-based patch coupling in LS-DYNA

4 patches



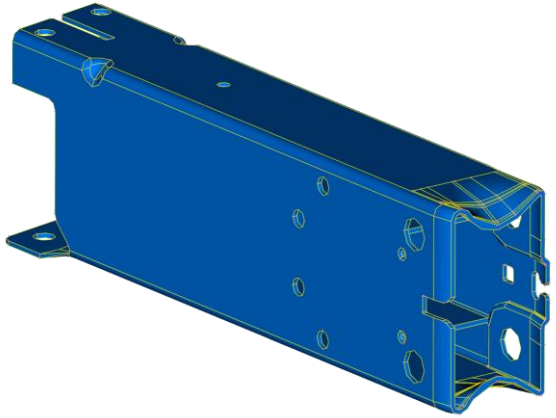
2 patches

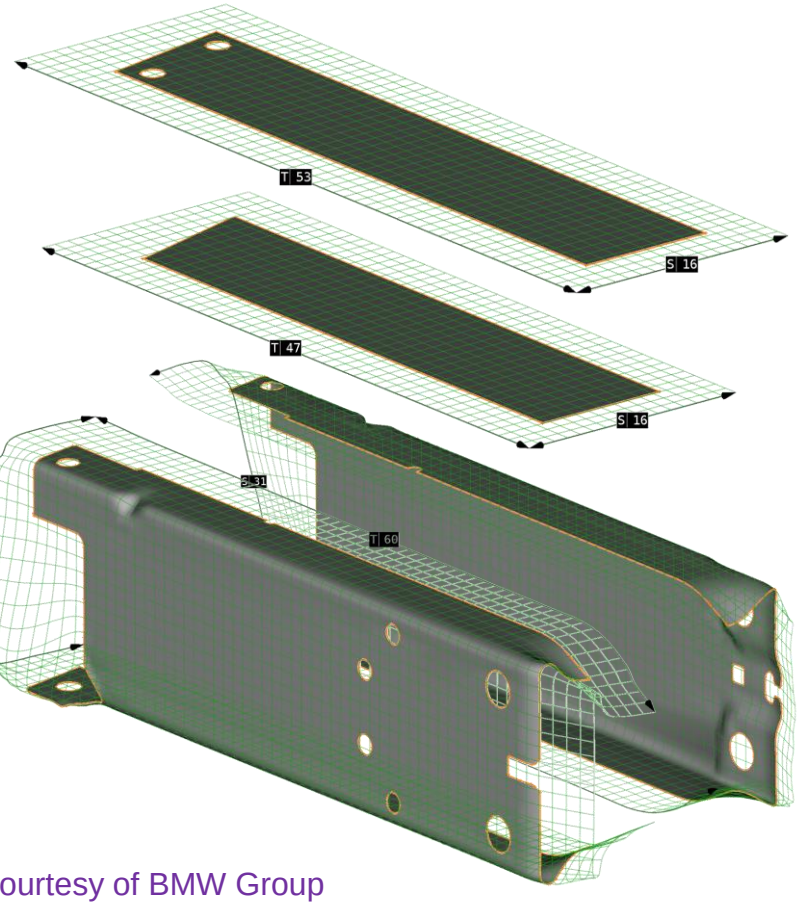


Courtesy of BMW Group

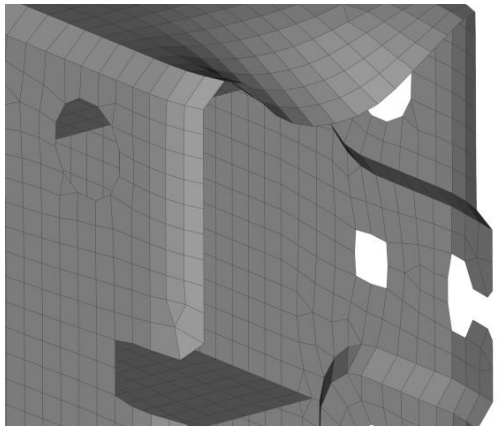
# IGA for Industrial Applications – Example 1

- Dynamic buckling of an energy-absorbing component
  - Component modeled with 4 patches
  - Model generation with ANSA
  - Goal
    - Extruded component with IGA shells
    - Coupling of trimmed NURBS patches (penalty-based, smooth + T-joints)
    - Large deformations, energy absorption

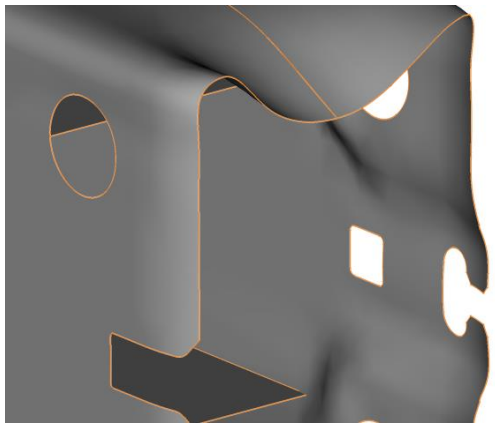





FEA model



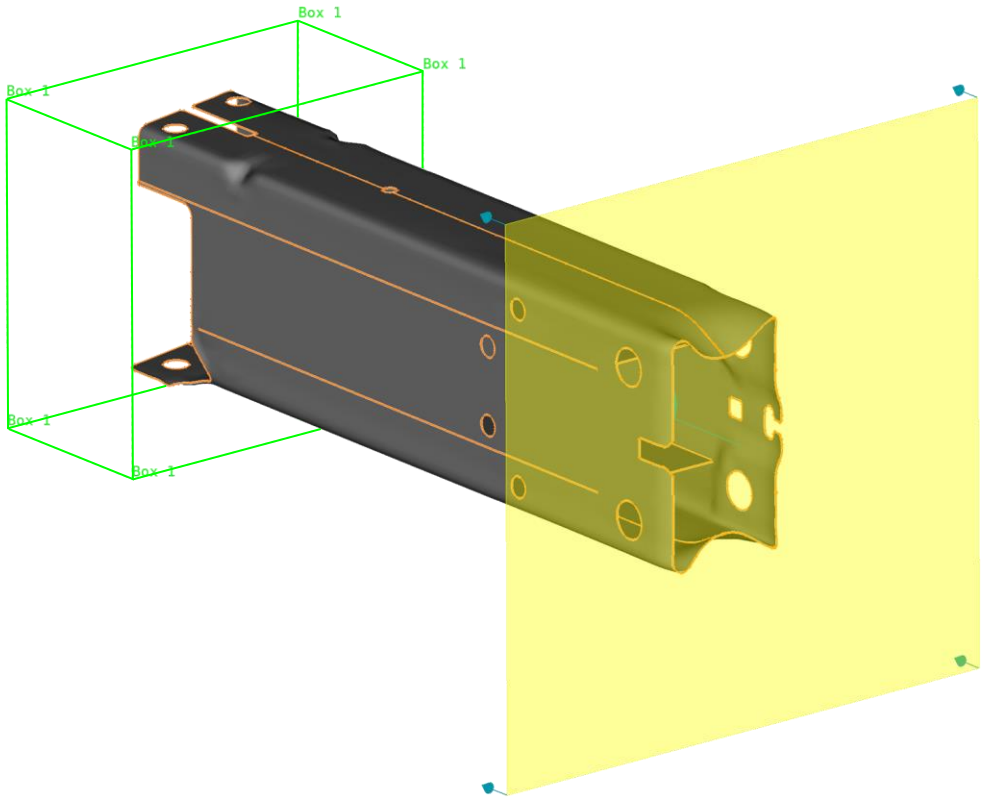
IGA model



Courtesy of BMW Group

# IGA for Industrial Applications – Example 1

- Dynamic buckling of an energy-absorbing component
  - Problem definition
    - MAT_024 (piecewise linear plasticity)
    - Fixed DOFs within Box
    - Rigid Wall $m = 150\text{kg}, v = 50\text{km/h}$




**IGA settings**

- Cubic NURBS-based RM shell ELFORM=3
- # Out-of-plane IPs NIP=5
- # In-plane IPs IRL=0 ($p \times p$)
- Average element length ~6/4mm

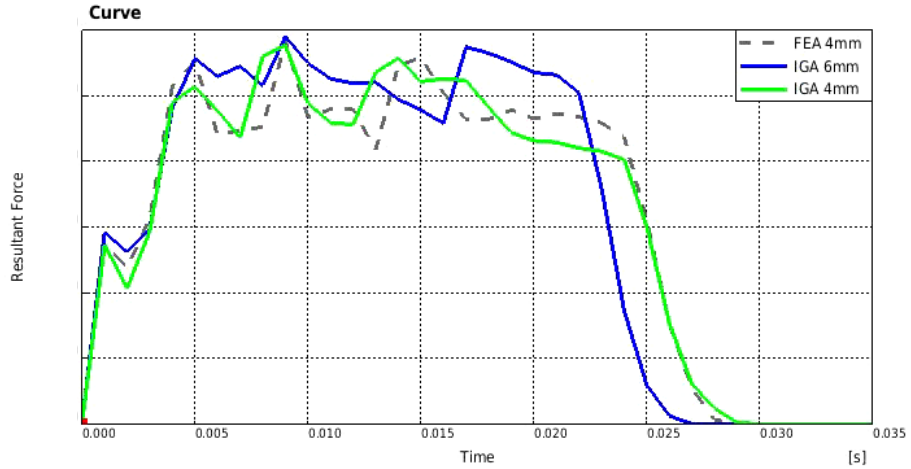
**FEA settings**

- Linear Belytschko-Tsay elements ELFORM=2
- # Out-of-plane IPs NIP=5
- Average element length ~4mm

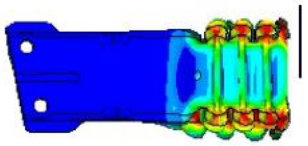
Courtesy of BMW Group

# IGA for Industrial Applications – Example 1

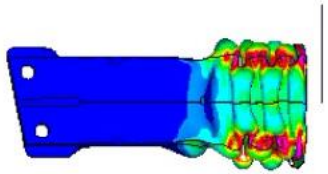
- Dynamic buckling of an energy-absorbing component
  - Explicit dynamic crash analysis
    - Good agreement with FEA results
    - Numerical effort per time step still higher
    - Larger time step possible (same mesh size): >2.5
    - Large potential to increase efficiency



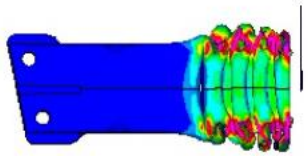

FEA 4mm



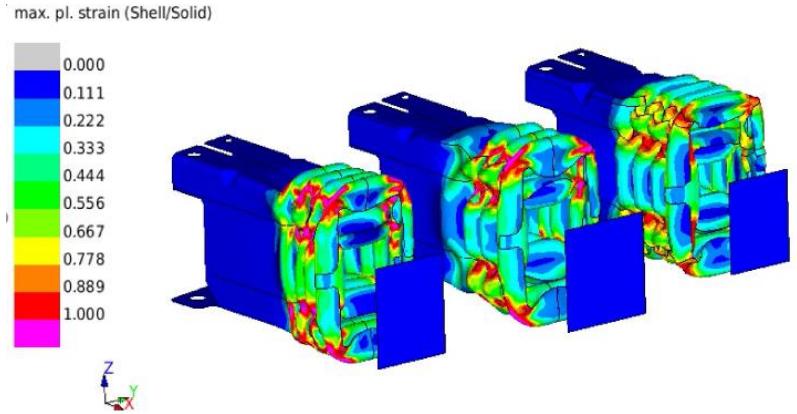
IGA 6mm



IGA 4mm



Courtesy of BMW Group

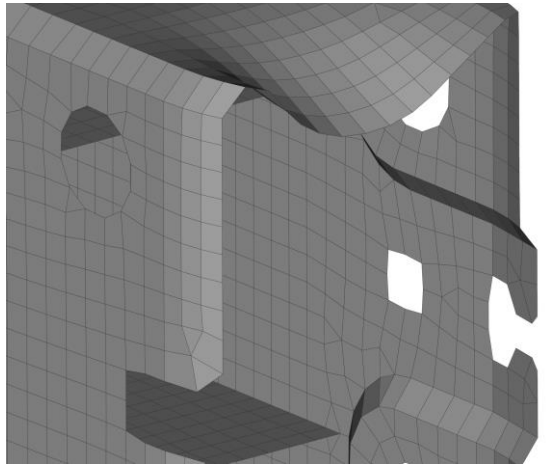



IGA 4mm IGA 6mm FEA 4mm

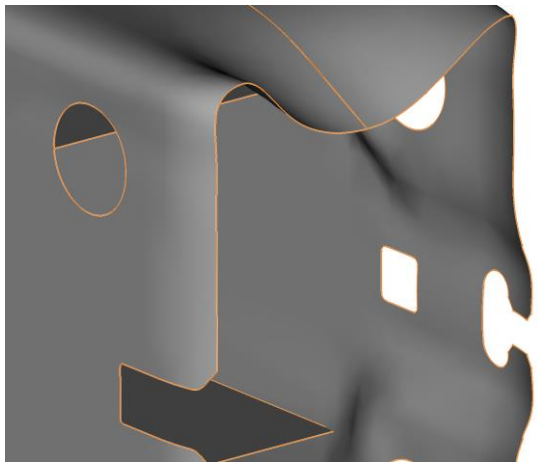
# IGA for Industrial Applications – Example 1

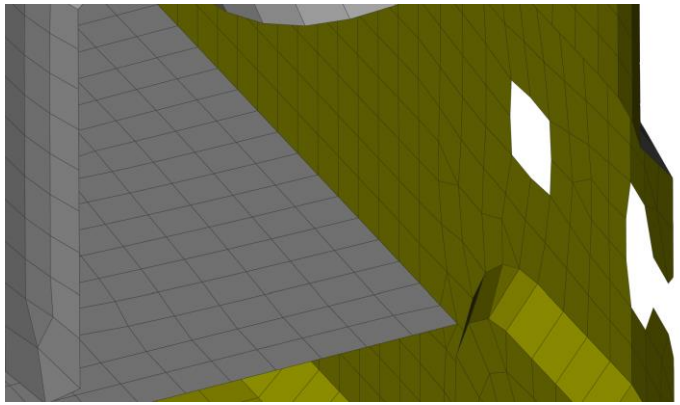
- Dynamic buckling of an energy-absorbing component
  - Explicit dynamic crash analysis
    - Good agreement with FEA results
    - Numerical effort per time step still higher
    - Larger time step possible (same mesh size): >2.5
    - Large potential to increase efficiency
  - Immediate benefits
    - More accurate geometry for same element size OR
    - Use larger elements → fewer DOFs
    - Larger time step OR no/less mass scaling
    - T-joint modeling independent of mesh

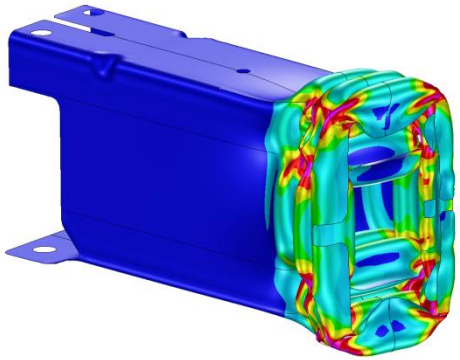
FEA model



IGA model



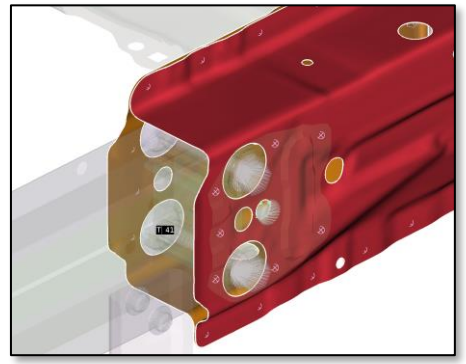




Courtesy of BMW Group

# IGA for Industrial Applications – Example 2

- Hybrid IGA/FEA vehicle front end structure
  - Conventional FEA model, but longitudinal members replaced by NURBS-based IGA shells
  - Model generation with ANSA
  - Goal
    - Hybrid crash simulations possible?
    - Simple 1:1 include exchange FEA ⇔ IGA
    - No change in connection modeling (spotwelds, bolts, rigid bodies)
    - No time step reduction



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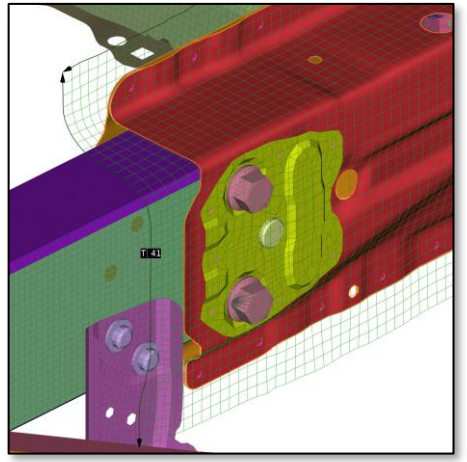
  - Goal
    - Hybrid crash simulations possible?
    - Simple 1:1 include exchange FEA ⇔ IGA
    - No change in connection modeling (spotwelds, bolts, rigid bodies)
    - No time step reduction
  - Required IGA functionality
    - Elasto-plastic material (MAT_024), Contact
    - Time step estimation + mass scaling
    - Spotwelds via SPR3 (IGA/IGA + IGA/FEA)
    - Bolts: Tied contact btw. FEA beams and IGA shells
    - Attach rigid bodies to IGA shells
    - Full availability for MPP

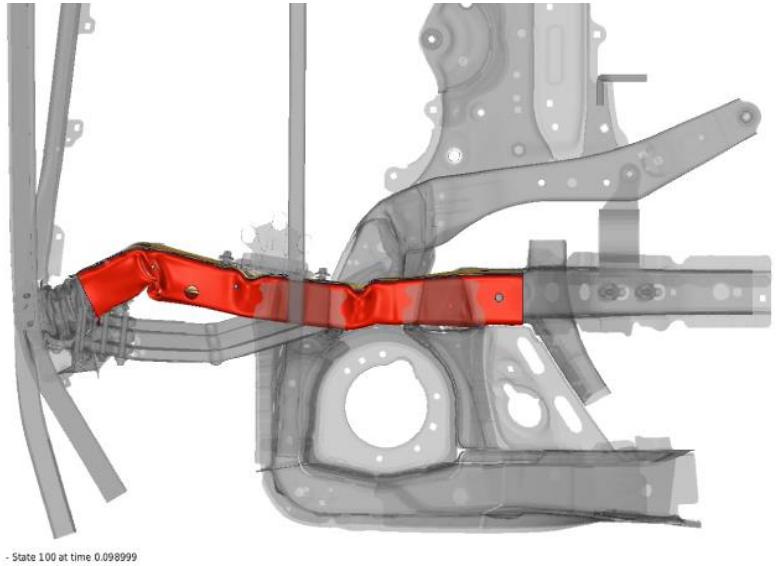


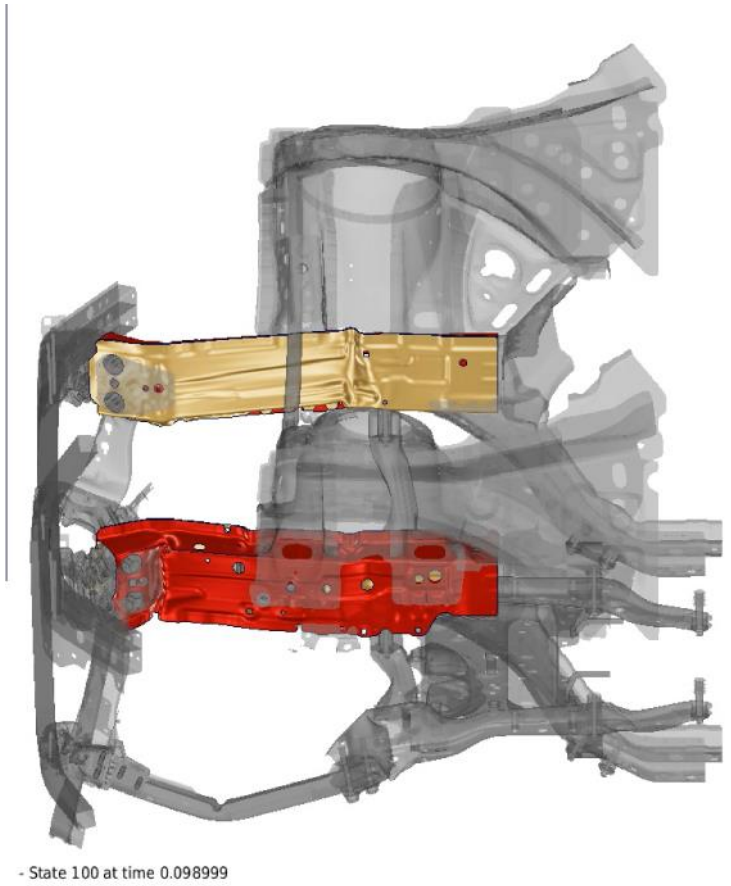



Courtesy of BMW Group

# IGA for Industrial Applications – Example 2

- Hybrid IGA/FEA vehicle front end structure
  - Explicit dynamic crash analysis
    - Standard postprocessing via FE interpolation mesh
    - Similar behavior as conventional FEA model
    - All connections considered
      - → Next step: IGA components in full vehicle simulation

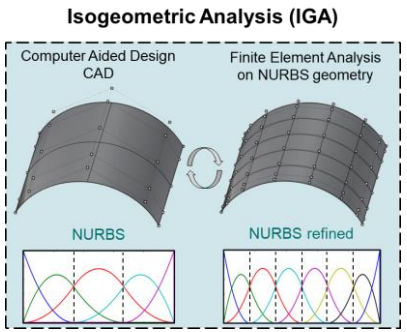


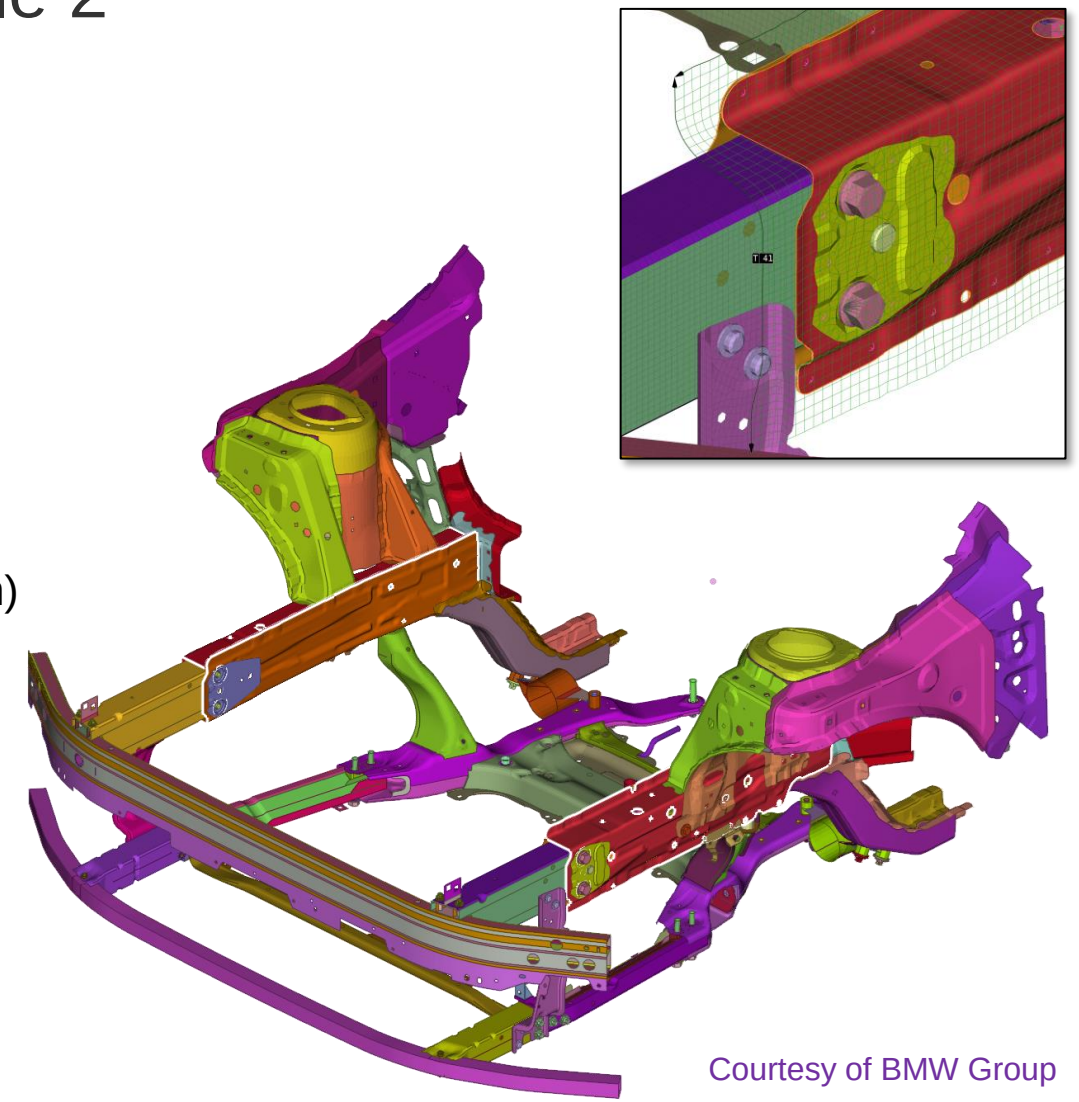




Courtesy of BMW Group

# IGA for Industrial Applications – Example 2

- Hybrid IGA/FEA vehicle front end structure
  - Immediate benefits
    - Fast and robust model generation with ANSA
    - Mesh-independent modeling of spotwelds
    - Mesh-independent connections btw. shell and bolts
    - Larger time step / No mass scaling
  - Long-term goal: CAD/CAE integration
    - Consistent data structure for design and analysis (ID system)
    - Associative model structure as in CAD (automatic updates)

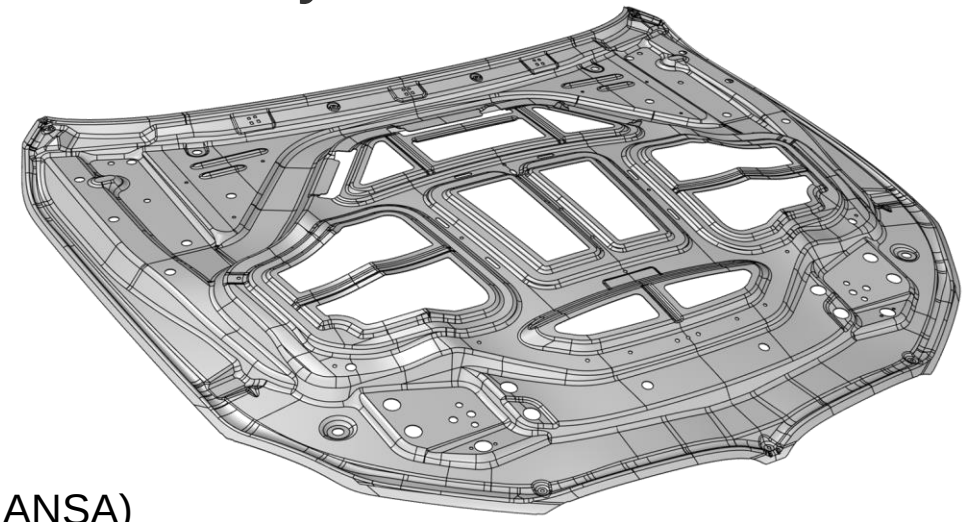


Courtesy of BMW Group

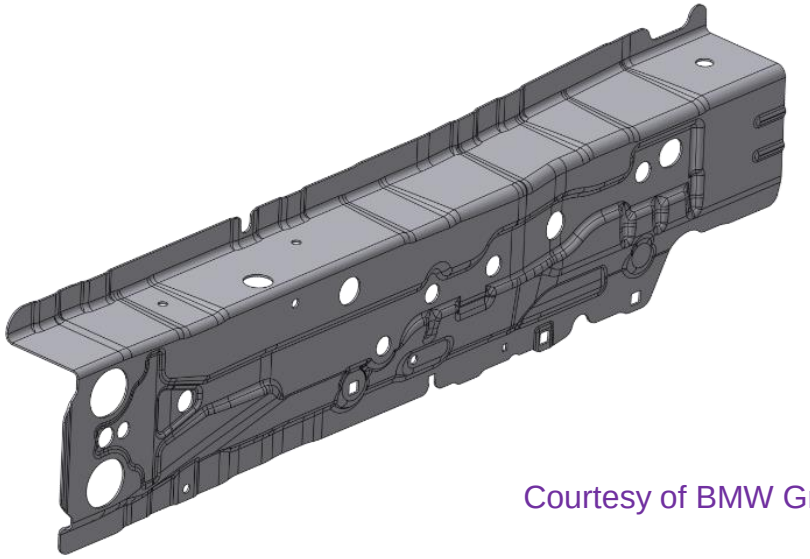
# IGA for Industrial Applications – Analysis-Suitability

- Current CAD models
  - Not designed with analysis-suitability in mind
  - Small narrow faces → small NURBS elements
  - Surfaces with high polynomial degree (up to ~13)



- Two ways to use NURBS models for shell analysis
  1. Current CAD models: Make suitable for analysis (preprocessor ANSA)
     - Generate midsurface (mostly automatic)
     - Rebuild as cubic patches, join patches
     - Min./max. element size, uniform “mesh”
  2. **Future CAD models: Build according to certain guidelines**
     - Min. element size, min. patch size, max. degree, etc.
     - Provide midsurface description in CAD
     - Still limited “preprocessing” capabilities of CAD systems

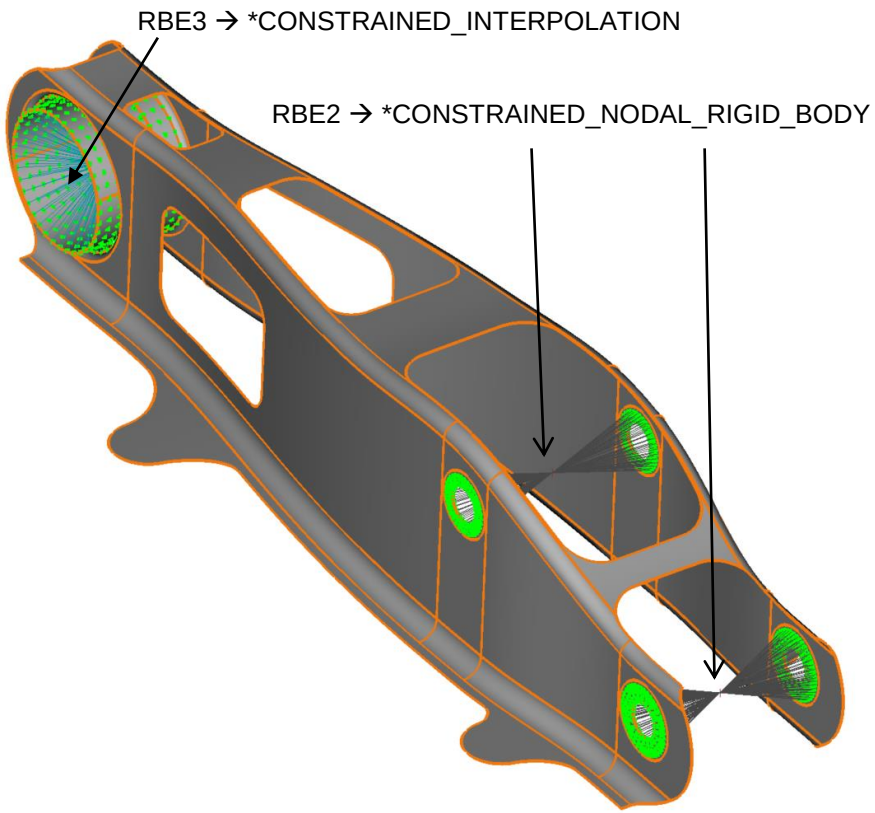
ANSA PRE PROCESSOR



Courtesy of BMW Group

# IGA for Industrial Applications – Example 3

- Stiffness and strength evaluation of a suspension component
  - Analysis-suitable CAD model
    - No small, narrow faces
    - Associated midsurface as output of design process
  - Model generation in ANSA
    - No merging of patches required
    - Fully automatic: Reduce degree, create uniform “mesh” size
    - Generate *IGA keywords + apply boundary conditions
  - Rigid bodies attached to IGA shells (to model bearings)




Courtesy of BMW Group

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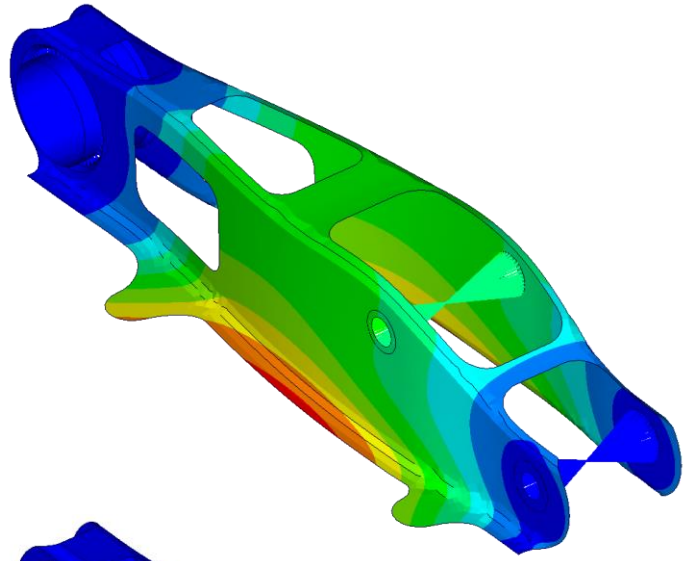
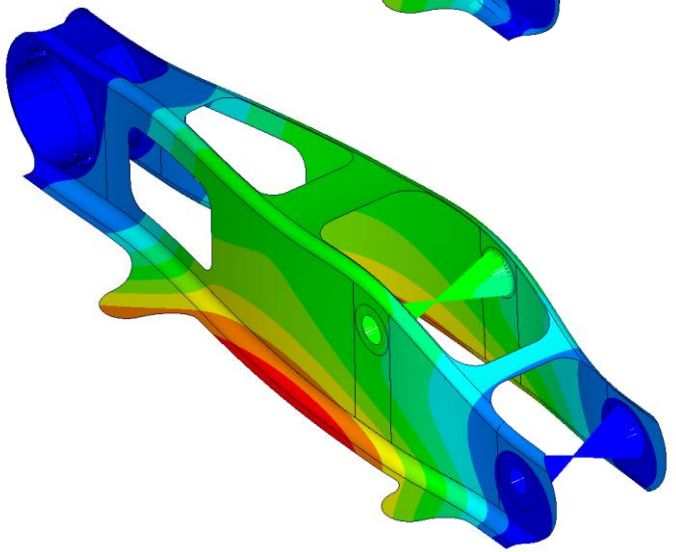
  - Analysis-suitable CAD model:
    - No small, narrow faces
    - Associated midsurface as output of design process
  - Model generation in ANSA:
    - No merging of patches required
    - Fully automatic: Reduce degree, create uniform “mesh” size
    - Generate *IGA keywords + apply boundary conditions
  - Rigid bodies attached to IGA shells (to model bearings)
  - Implicit static analysis
  - Trimmed multi-patch shell model (47 patches)
  - Good agreement btw. FEA and IGA results

→ Possible to design CAD model with analysis in mind!

FEA



IGA

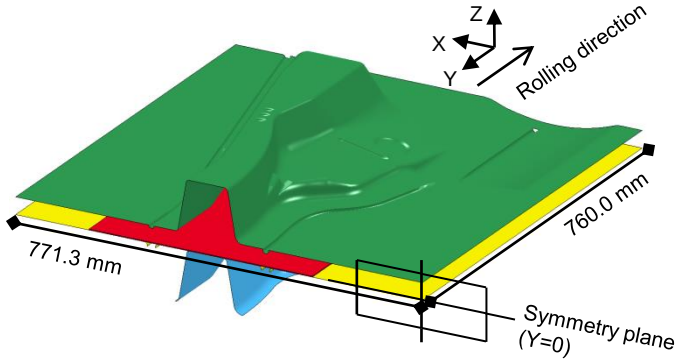


Courtesy of BMW Group

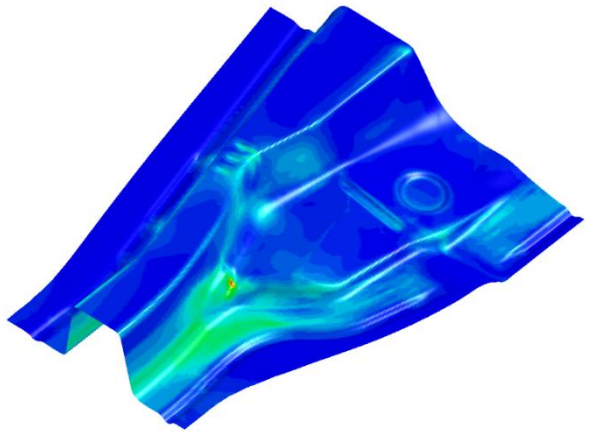
# IGA for Industrial Applications – Forming applications

## Sheet metal forming

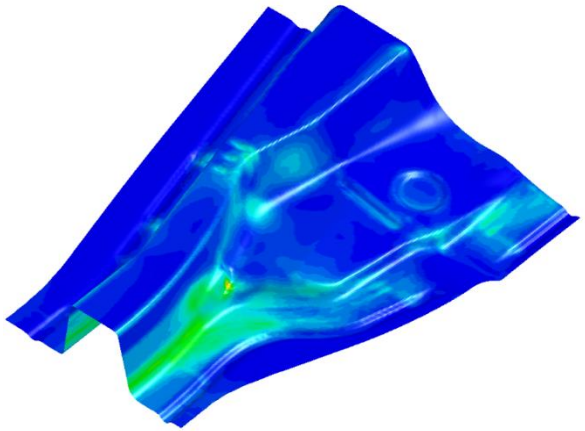
- Accurate tool geometry
- Solution field of higher order and higher continuity
- Potentially larger elements and time steps, lower number of DOFs
- Multi-stage analysis: Reinitialization of stresses, strains and thicknesses
  - **`*INTERFACE_SPRINGBACK`**
  - **`*INITIAL_STRESS_SHELL_NURBS_PATCH`**
  - **`*INITIAL_STRAIN_SHELL_NURBS_PATCH`**

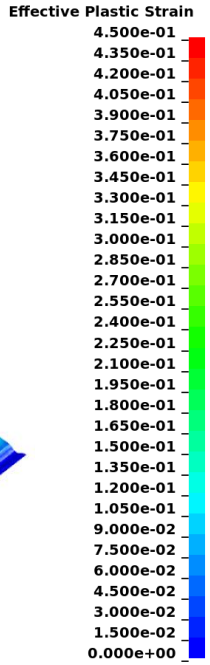



FEA (Elform=16) 2mm
max value: 0.445336



IGA (Form=0) 4mm (INT=2)
max value: 0.380803

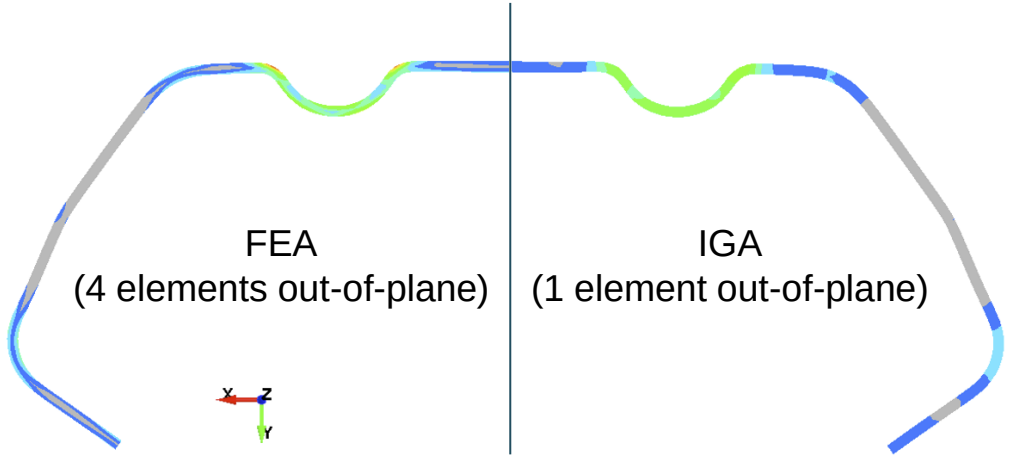




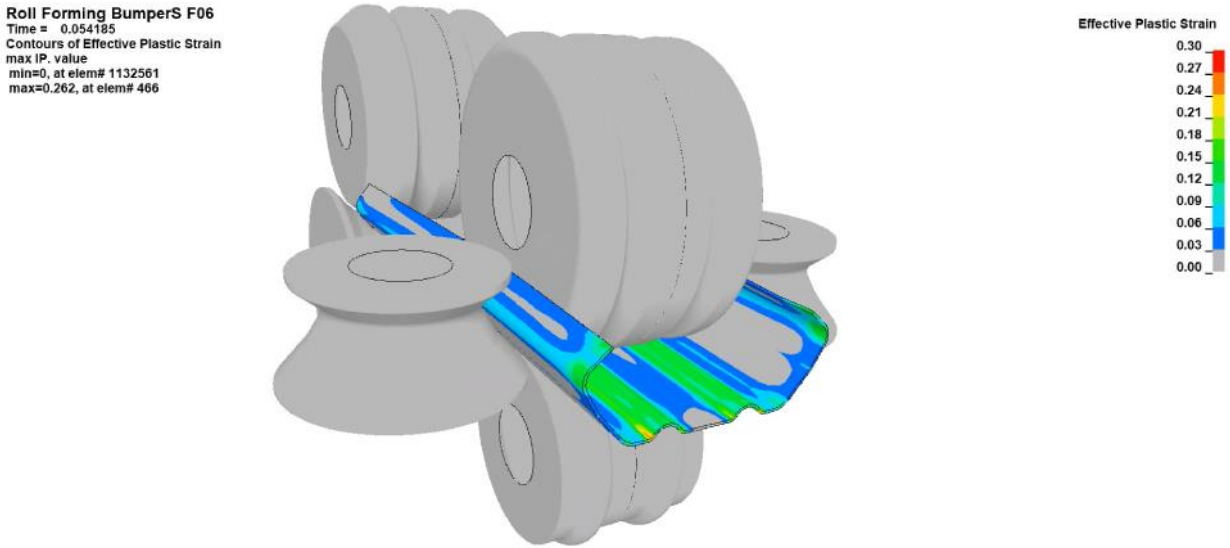
# IGA for Industrial Applications – Forming applications

## Roll forming (work in progress)

- NURBS solids with different polynomial degrees
- In-plane: Quadratic
  - → Low degree sufficient
  - → Keep number of in-plane integration points low
- Out-of-plane: Quartic
  - → Lower number of elements across thickness
  - → Lower number of DOFs + larger time step




Roll forming with Isogeometric Analysis




Simulations and support by Pierre Glay and Stefan Hartmann

# Outline

1. What is Isogeometric Analysis (IGA)?
2. IGA in LS-DYNA and LS-PrePost
3. The New CAD-Inspired *IGA Keywords
   - Motivation
   - Trimmed Multi-Patch Shells
   - Novel Spline Technologies
4. IGA for Industrial Applications
5. **Summary and Outlook**

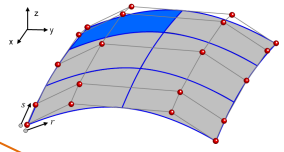
# Summary and Outlook

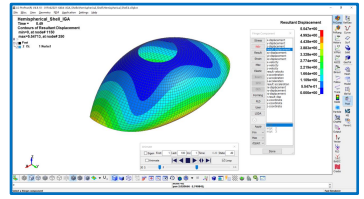
- IGA capabilities in LS-DYNA and LS-PrePost

- The new CAD-inspired *IGA keywords in LS-DYNA
  - Capture CAD data structure: geometry and topology
  - Trimmed multi-patch NURBS shells
  - Preview to trimmed solids and novel spline technologies

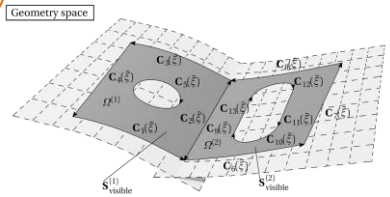
- IGA for industrial applications
  - Fast and robust model generation with ANSA
  - Hybrid IGA/FEA vehicle models for crash
  - Immediate benefits and long-term goal CAD/CAE integration

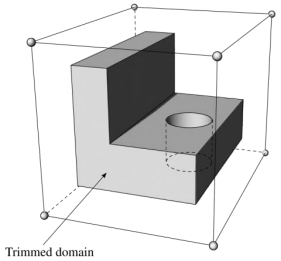
- Outlook
  - Make IGA ready for productive usage
    → we need your applications / your models!
  - In-depth IGA webinar incl. tutorials

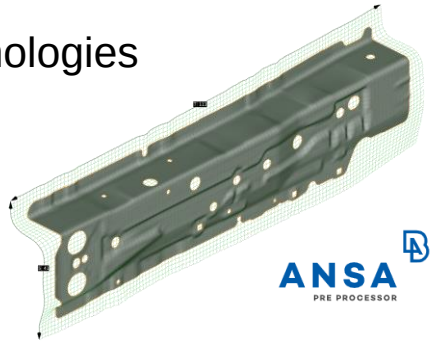




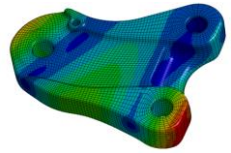
Available from R13 or in DEV versions

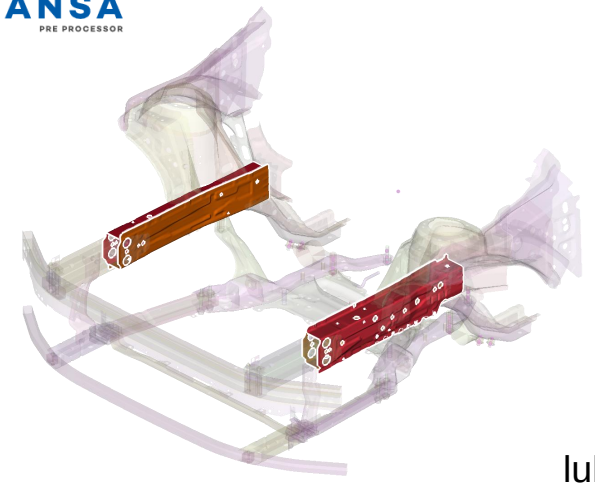



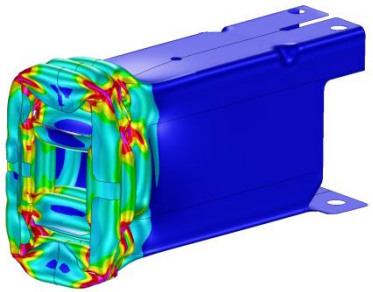



ANSA PRE PROCESSOR







Courtesy of BMW Group

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