Recent Developments in Isogeometric Analysis

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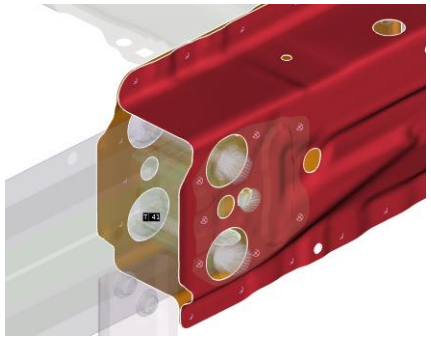
Ansys

The Benefits of Isogeometric Analysis

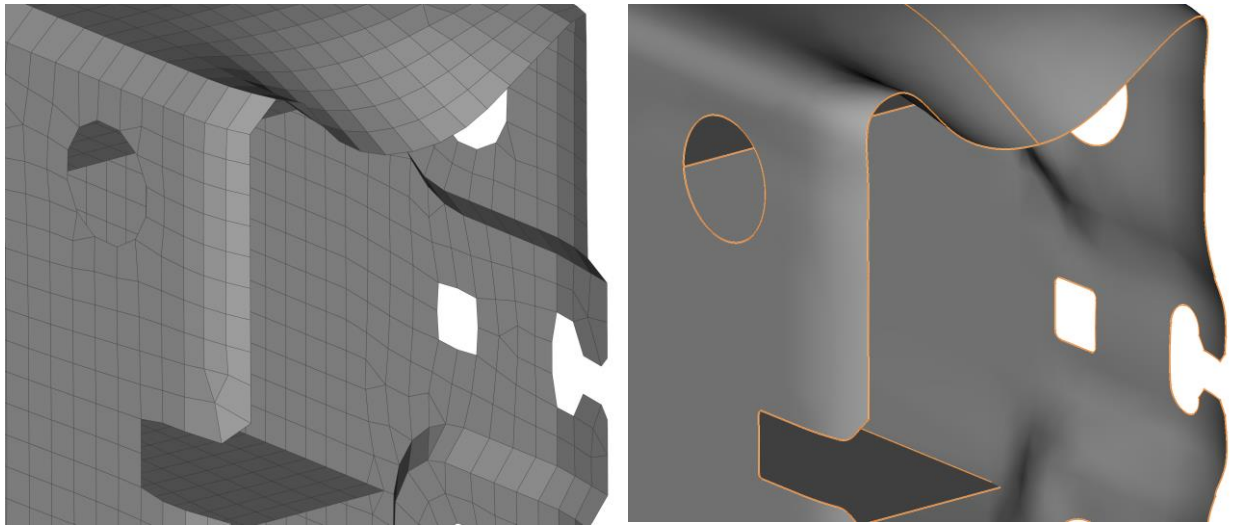
- **Faster development process by integrating design and analysis**
  - Same NURBS-based geometry description, consistent data structure
  - Mesh-independent modeling (spotwelds, connections, etc.)
- **Higher predictive accuracy** (for similar element size)
  - More accurate geometry description: Consider details neglected with standard FEA
  - Higher-order AND higher-continuity basis
    - Smooth solution field
    - Capture deformation modes correctly
- **Increased efficiency**
  - Larger element size and fewer DOFs (for similar accuracy)
  - Larger time step size in explicit dynamics (for similar element size, C^{p-1} continuity and interior elements)



Courtesy of BMW Group

Linear FEA

IGA



Courtesy of BMW Group

Trimmed NURBS-based CAD

courtesy of B URICK, nvariate

trimmed

untrimmed

De facto standard in industrial scale CAD kernels e.g., ACIS, Parasolid, PTC.

Trimming remedies the topological restrictions of NURBS in theory.

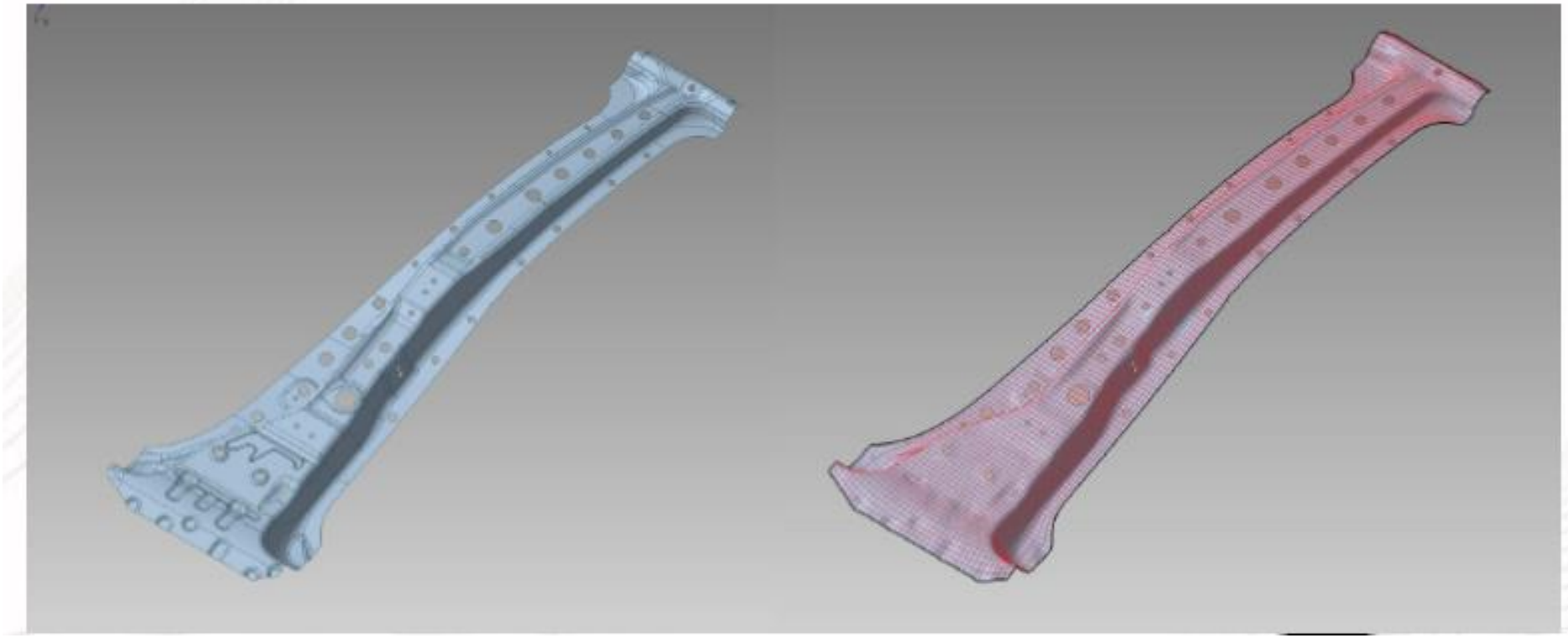
CAD is not analysis aware which induces problems for downstream analysis and design.

4. NURBS Generator Tool

モデル作成時間 (1)

Working hours between FEM model and IGA optimization tool

- Quadrangulation regardless of face segmentation
- Only 1 patch (with holes) was generated!



Conventional FEM model

2 hours

IGA model

20 minutes (1/6)

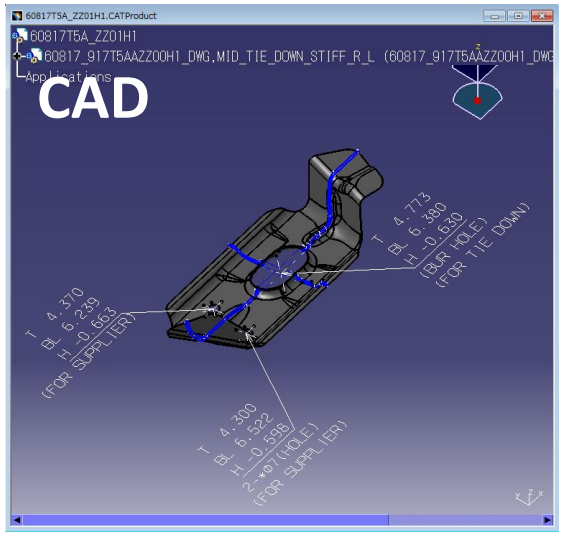
(2019)
Courtesy of
Kenji Takada
Honda R&D

4. NURBS Generator Tool

モデル作成時間 (2)

Working hours between FEM model and IGA optimization tool

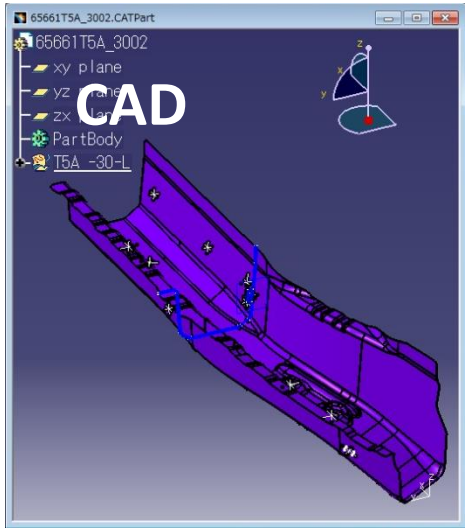
Small parts



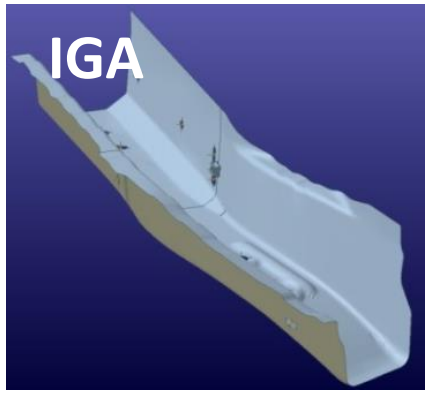
IGA model ⇩ **2 min**

FEM model : **3 min**

Medium-sized parts

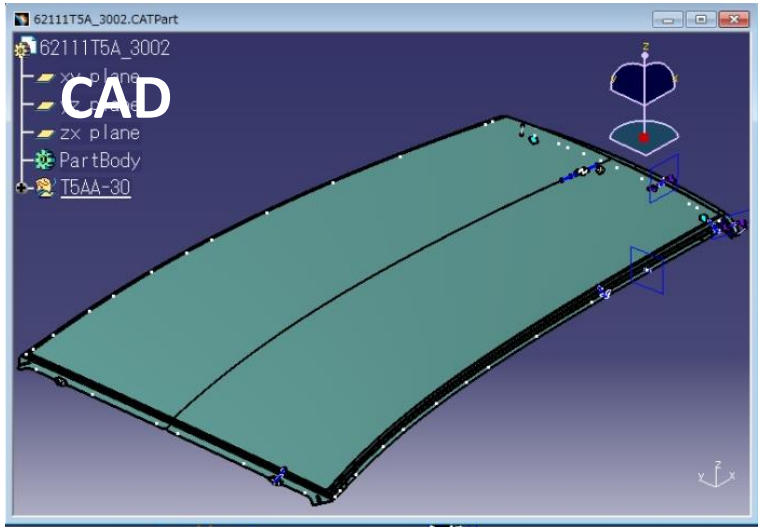


IGA model ⇩ **2 min**

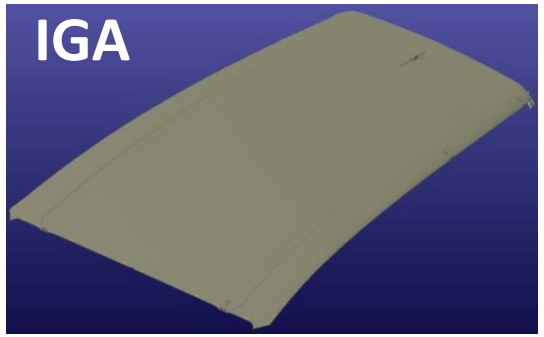


FEM model : **1h 30 min**

Large parts



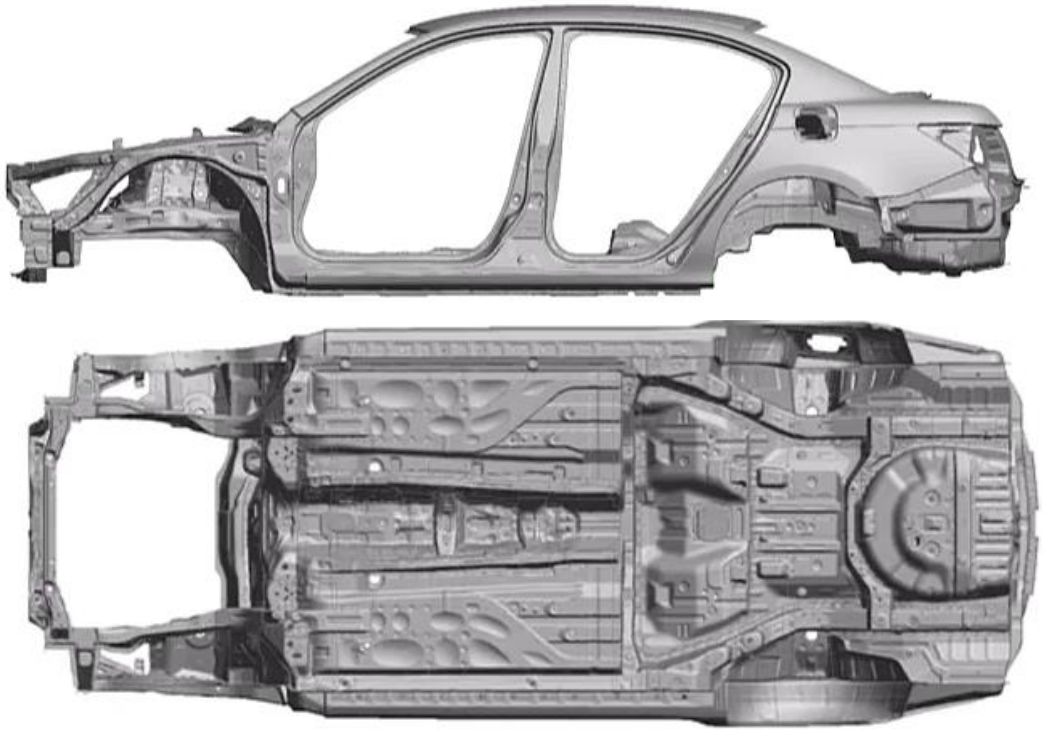
IGA model ⇩ **4 min**



FEM model : **30 min**

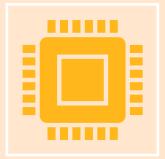
(2019)
Courtesy of
Kenji Takada
Honda R&D

First IGA Body in White in 2019



Courtesy of K. Takada,
HONDA

Design and Analysis Integration: A Vision for the Future



Feature-based modeling: Analysis using the conventions of CAD for describing the boundary value problem for a common language in design and analysis.

Parametric descriptions of the geometry for design, analysis, and optimization.

Single solver with exact geometry for both preliminary and final analysis:

Preliminary design: fast, coarse meshing with trimmed NURBS.

Final analysis: higher order, unstructured splines with local refinement.

Our Current Goal: Moving IGA into Production Analysis

Basic capabilities for production analysis:

- **Preprocessing:** Compatible workflow with easy IGA and hybrid IGA/FEA modeling. Hybrid is useful for V&V studies.
- **Analysis:** Elements and materials are essentially complete. Currently implementing additional options for boundary conditions, contact, welds, etc as beta testers request.
- **Postprocessing:** Display and contour the exact deformed spline geometry.

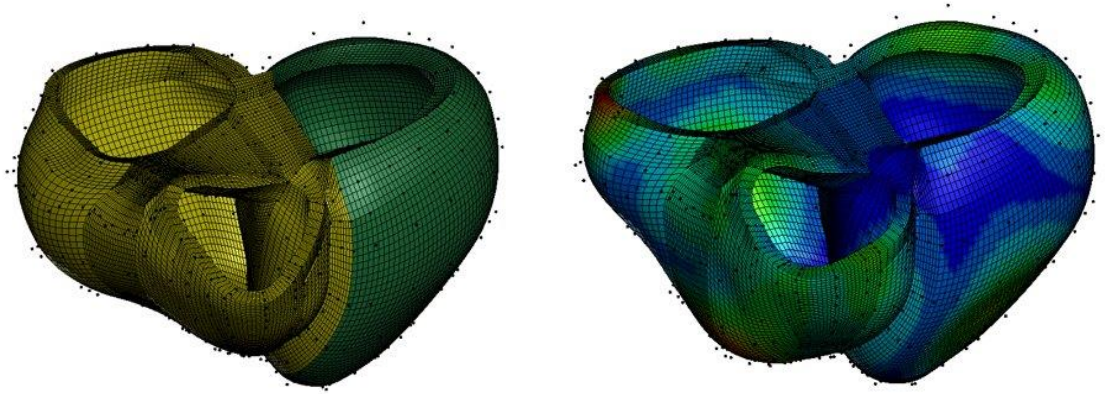
Preprocessing & Mesh Generation

Ansys

Prime is a Meshing Research Platform

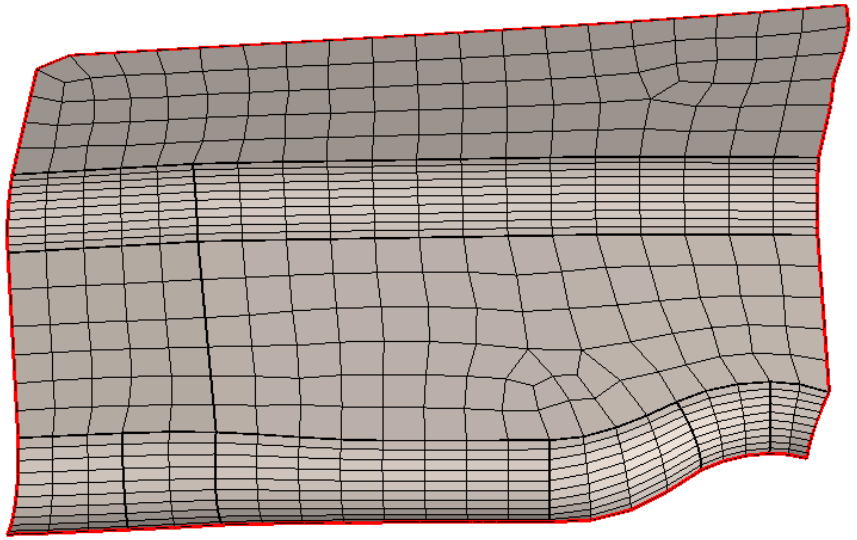
- Prime is for developing different meshing technologies. For IGA:
  - Unstructured splines for shells.
  - Trimmed NURBS for solids.
- Complements current ANSA capabilities:
  - Trimmed NURBS for shells.
  - NURBS for solids.
- Some customers have copies to test with their proprietary data and give us feedback.
  - We will continue to make it available to customers for their work with LS-DYNA until a commercial solution is available.

Aerospace Working Group fan blade, hub and shaft assembly courtesy of G Blankenhorn (2021)

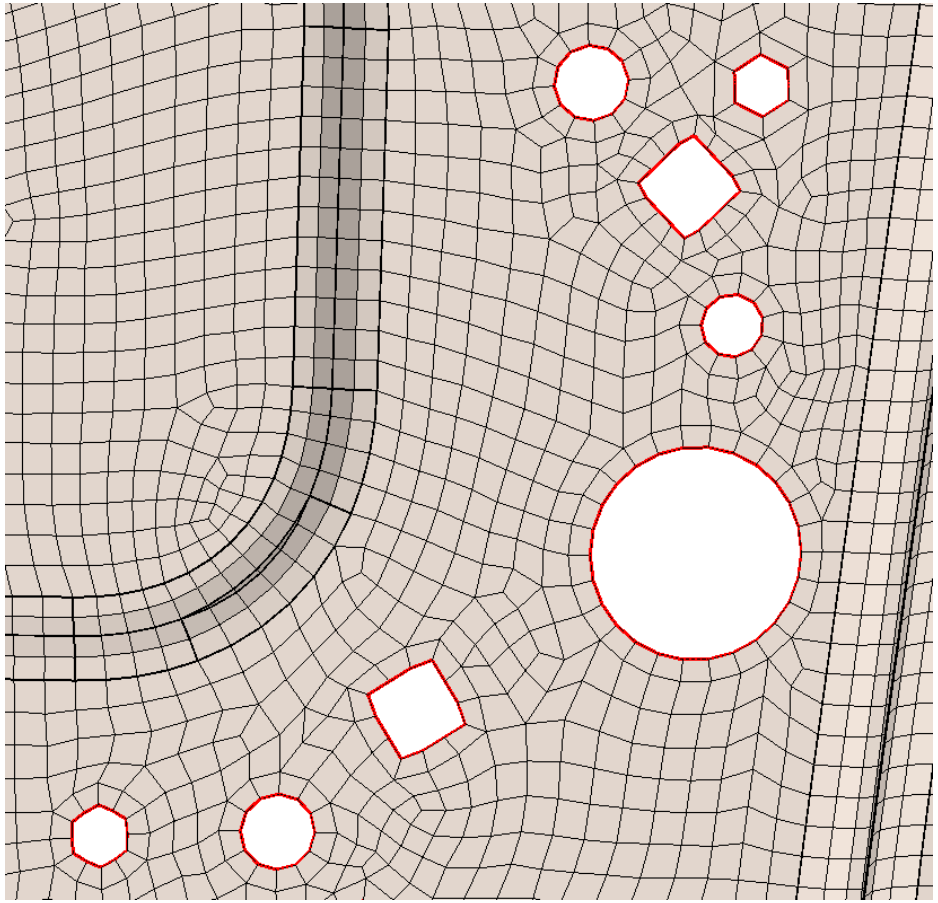


Biventrical heart model courtesy of C Maurath (2022)

Unstructured Splines Using Prime

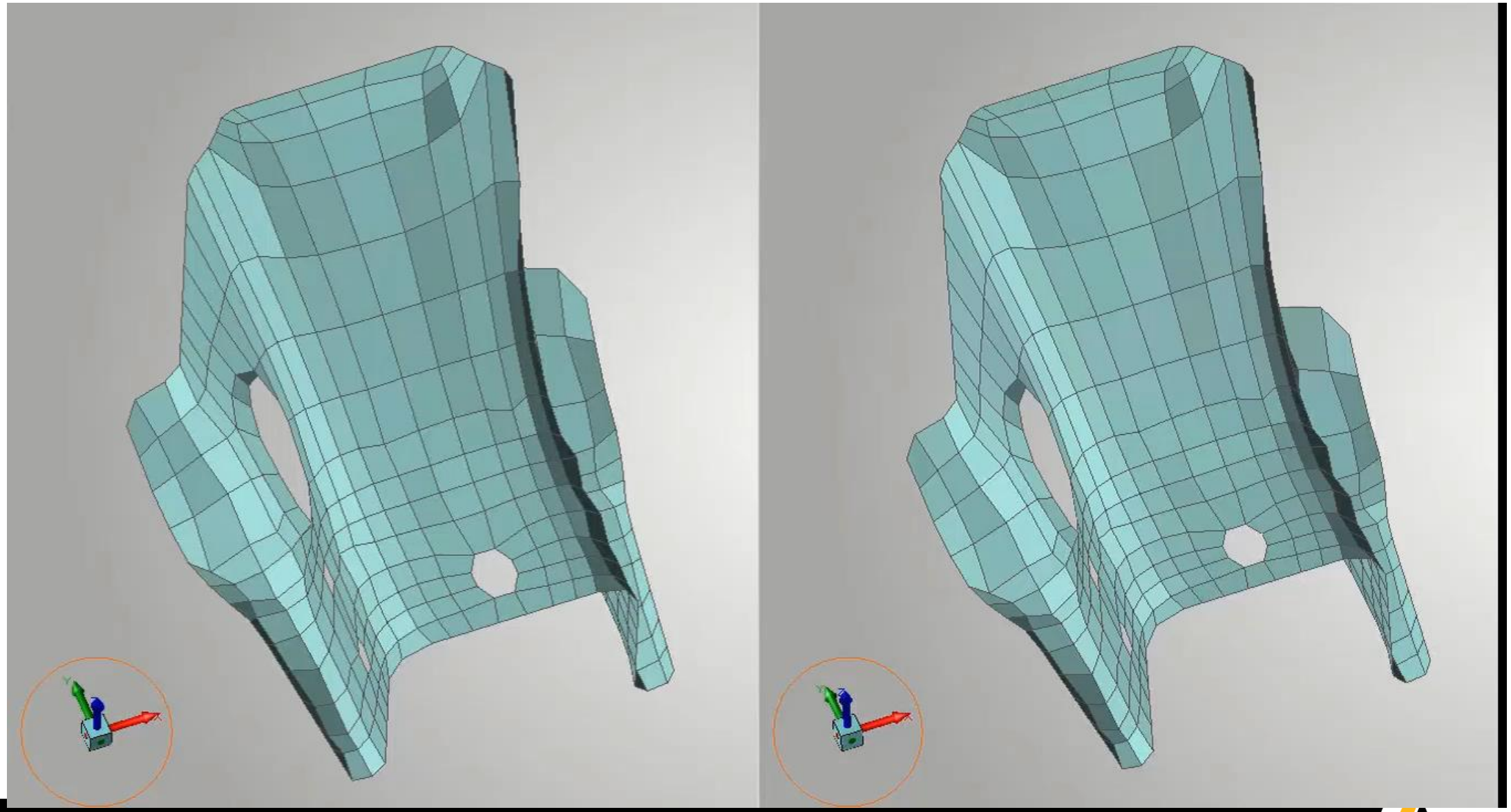


Map mesh treatment on Fillets

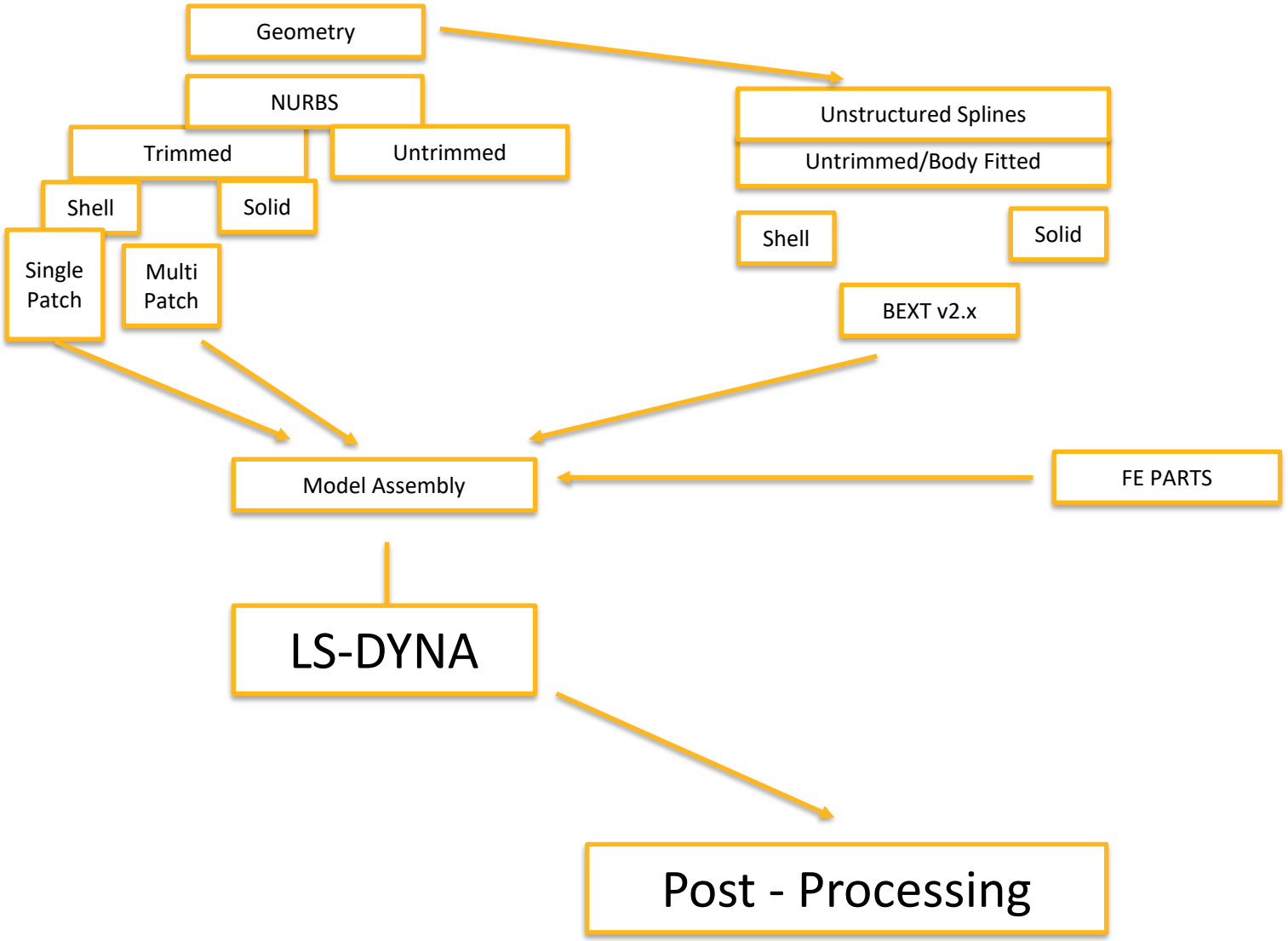


Quad Boundary Layer around Holes

Video: Alteration of Shell Splines with Prime



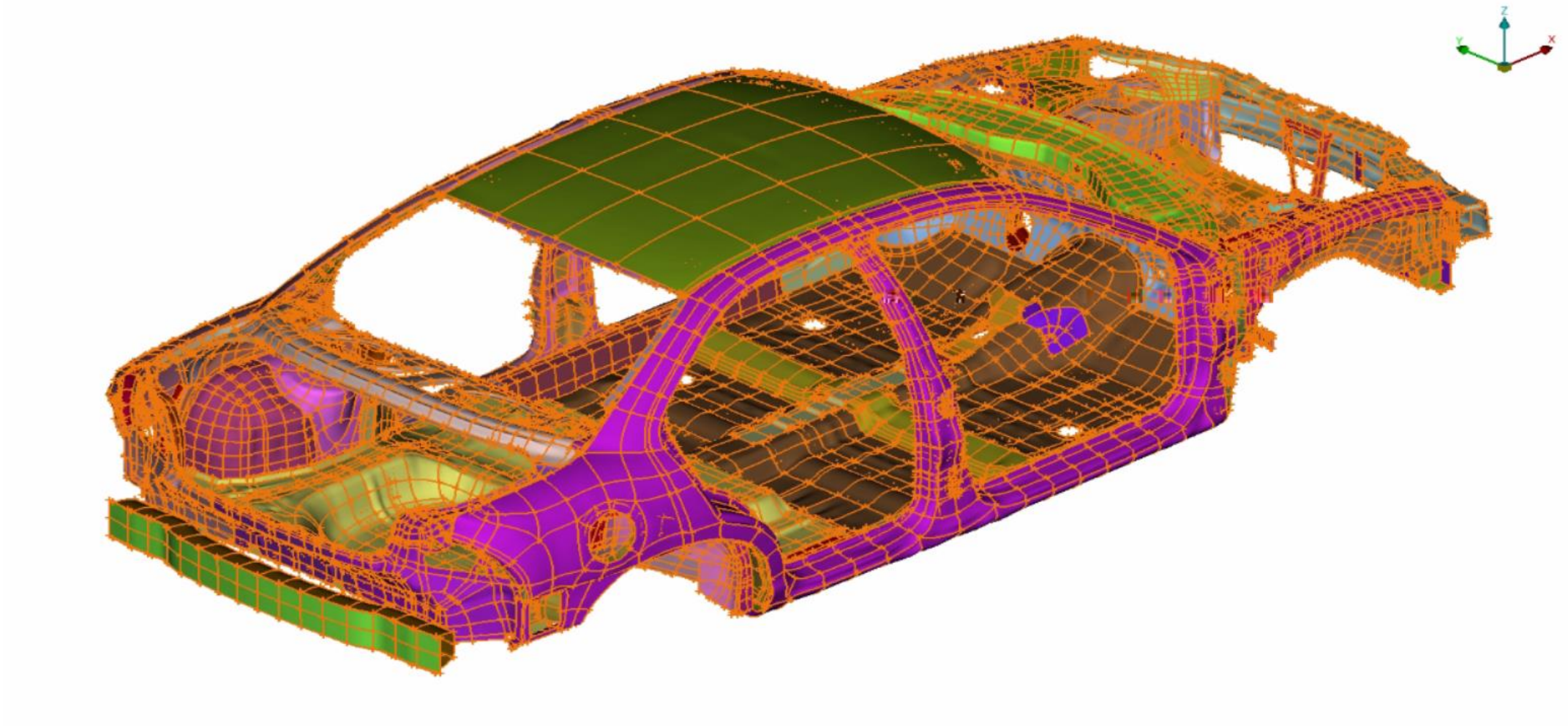
Next Developments in ANSA



This development plan was provided courtesy of Lambros Rorris, BETA CAE.

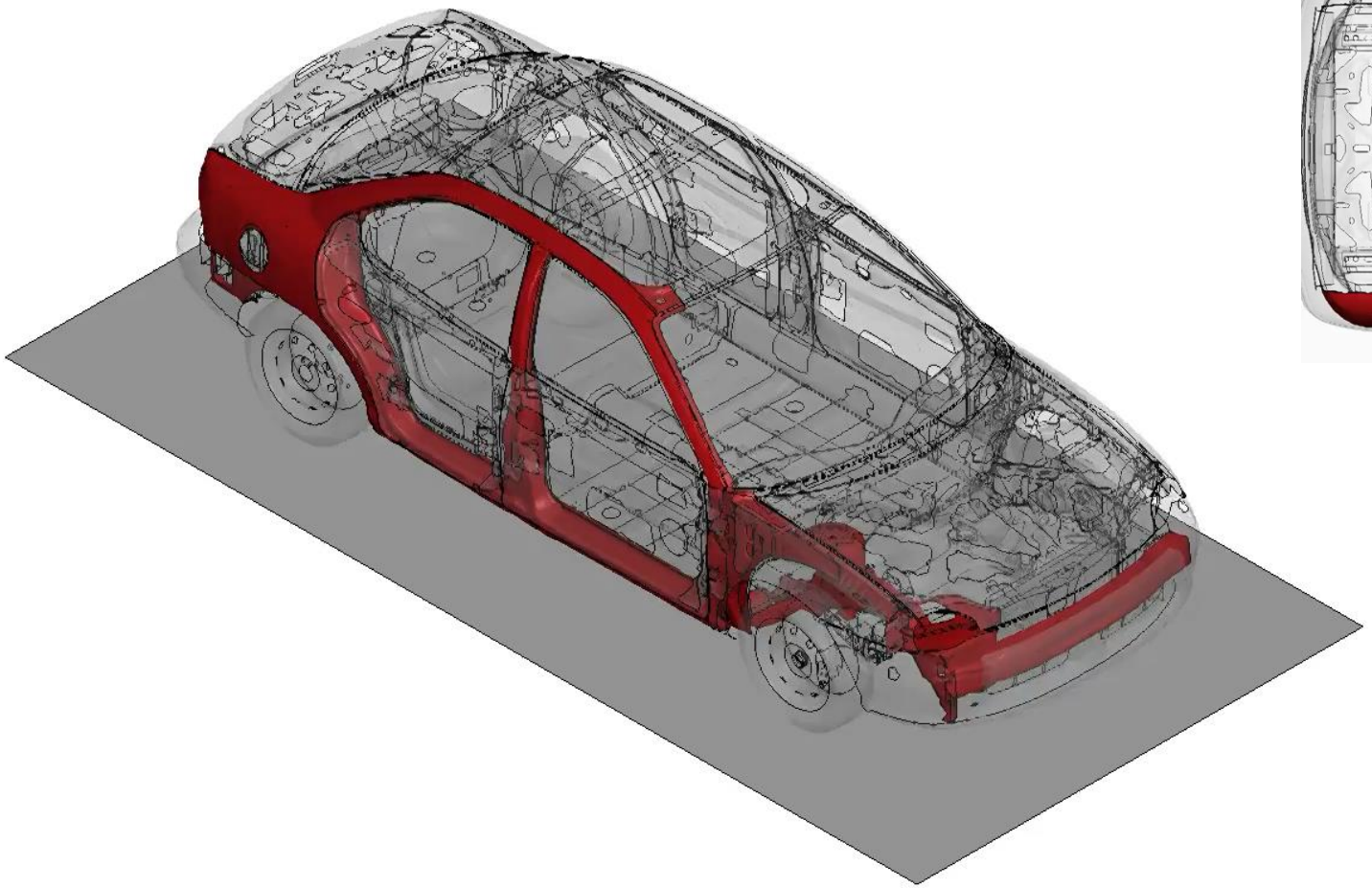
BEXT v2.x is the Bezier extraction format we are using for unstructured splines.

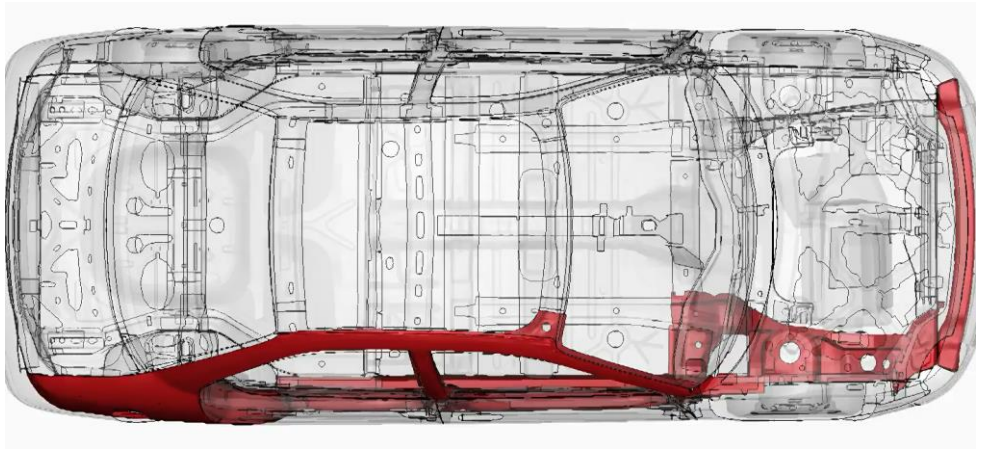
Adapting a legacy model: FEA to IGA with ANSA

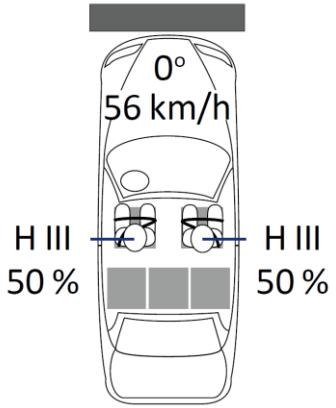


Kendrick Shepherd, Brigham Young University

Frontal Crash Using Boundary Fitted Splines

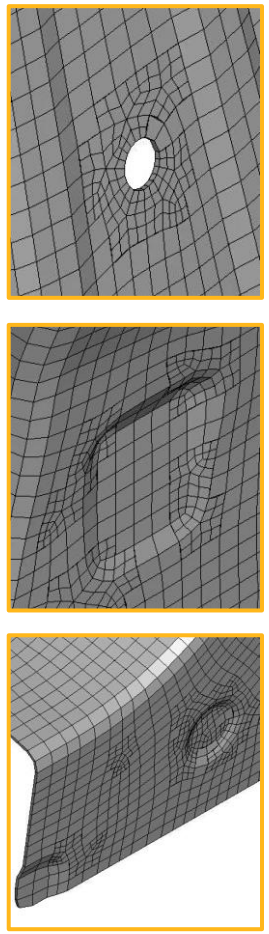


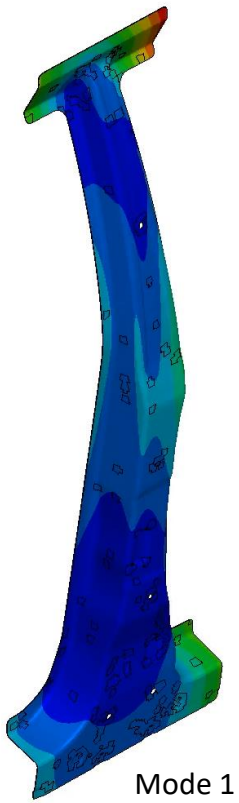




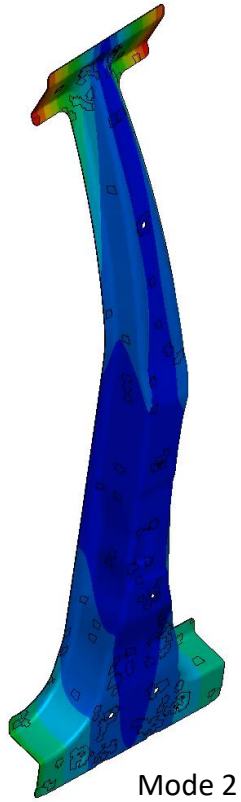
courtesy of K SHEPHERD (in collaboration with BETA CAE and LST)

Unstructured Solids Via Extrusion

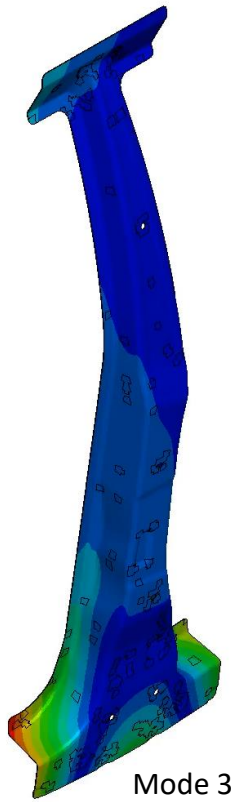




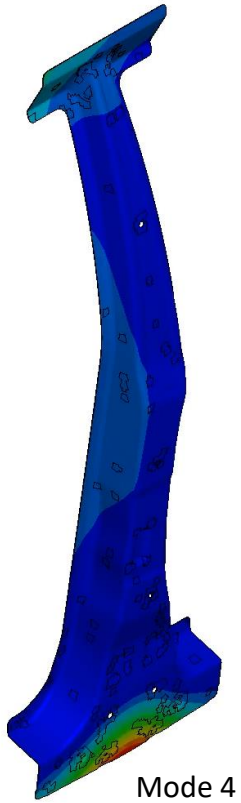
Mode 1



Mode 2



Mode 3



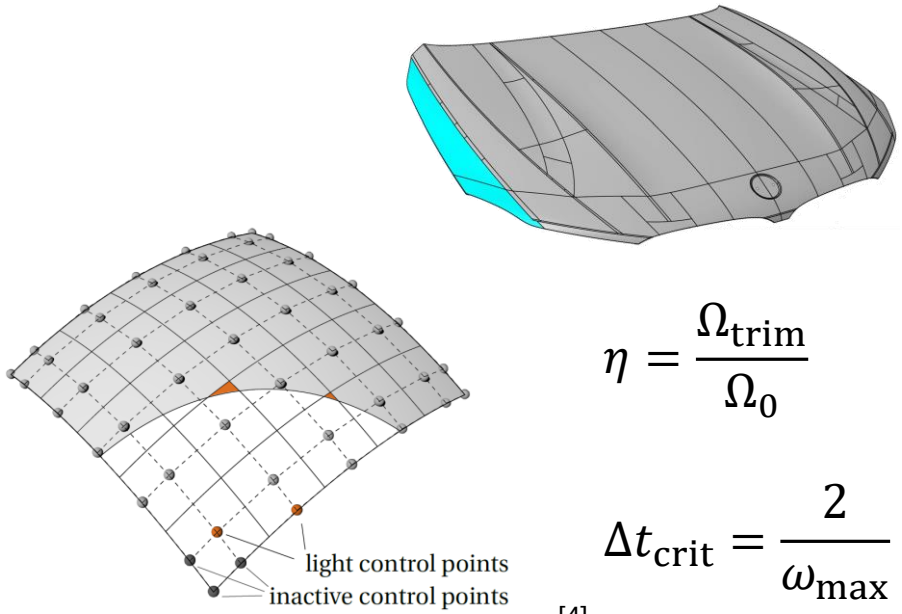
Mode 4

Analysis with LS-DYNA

Ansys

Analysis Capabilities for Explicit Dynamic Crash

Effect of trimmed element size on time step size?
Practically no effect for IGA with C^{p-1} and $p > 1$

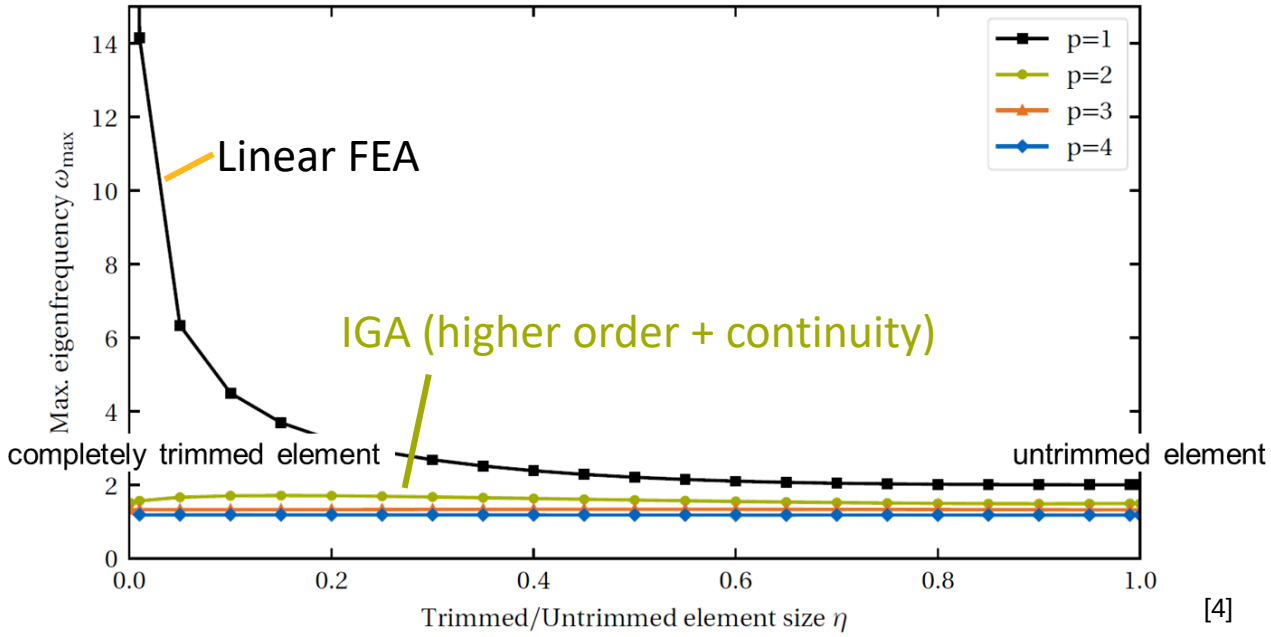


[4]

$$\eta = \frac{\Omega_{\text{trim}}}{\Omega_0}$$

$$\Delta t_{\text{crit}} = \frac{2}{\omega_{\max}}$$

Ratio of trimmed/untrimmed time step size



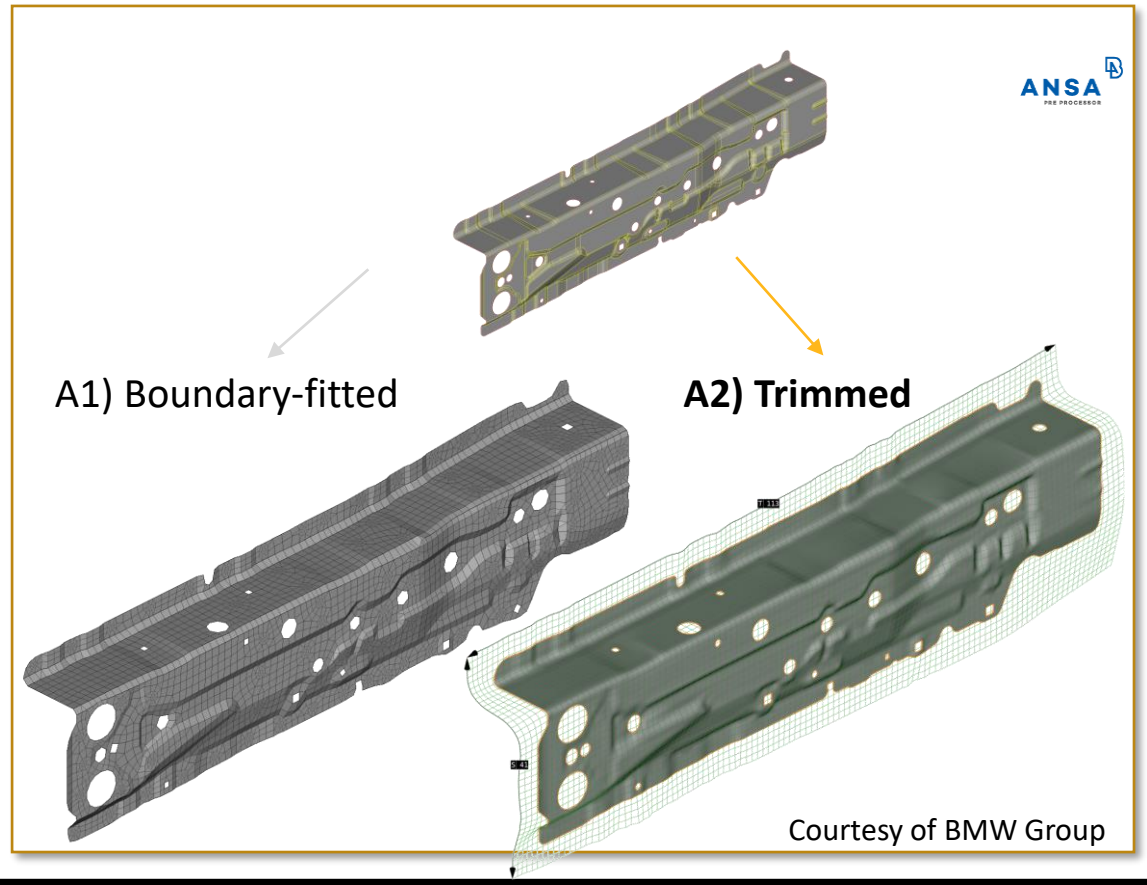
[4]

L. F. Leidinger, Explicit Isogeometric B-Rep Analysis for Nonlinear Dynamic Crash Simulations: Integrating Design and Analysis by Means of Trimmed Multi-Patch Shell Structures, PhD thesis, Technical University of Munich, Germany (2020).

Geometry and *IGA keywords

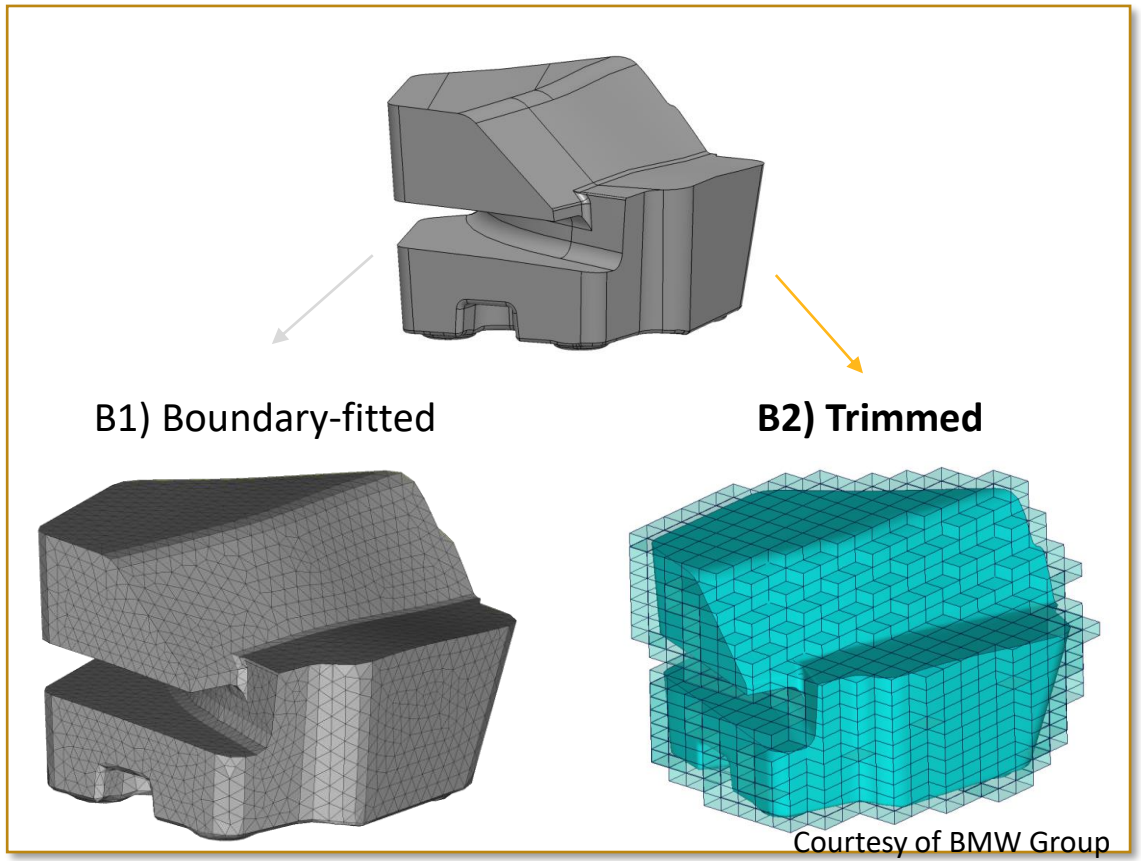
A) Thin-walled components → Shell model

- Generate midsurface



B) Bulky components → Solid model

- Generate solid discretization



Committed to Hybrid IGA/FEA Models

- **Long-established and optimized development processes for FEA**
- **All-encompassing IGA process: Requires fundamental changes and mind shift**

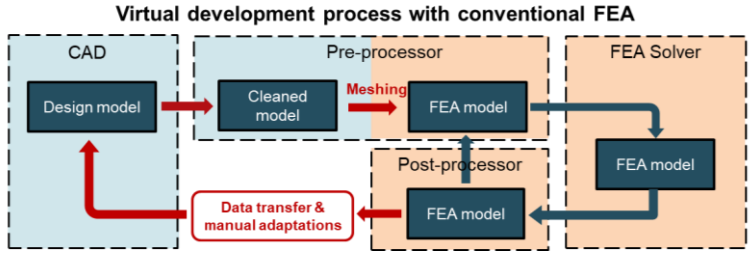
1. Impossible to change entire process at once.
2. Pure isogeometric vehicle model not yet possible (but close).

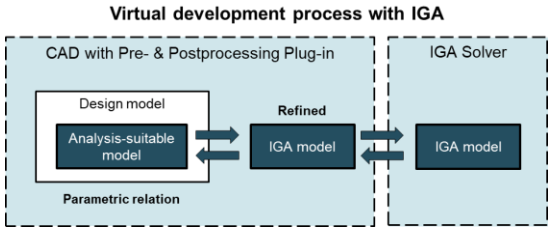
→ Start with small changes: Replace certain components

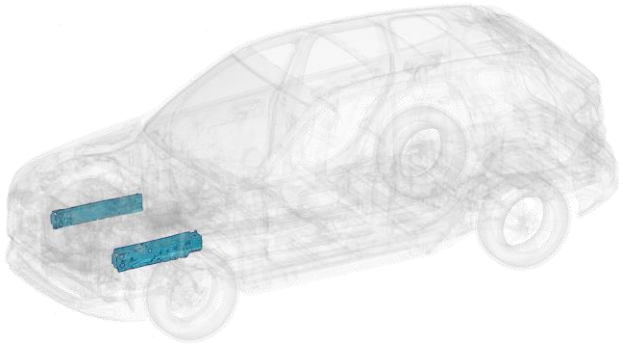
→ Build trust in the technology

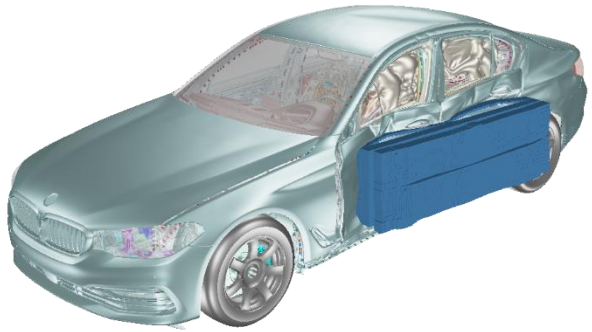
→ Make changing to IGA as simple as changing the element formulation

→ Demonstrate specific benefits









Courtesy of BMW Group

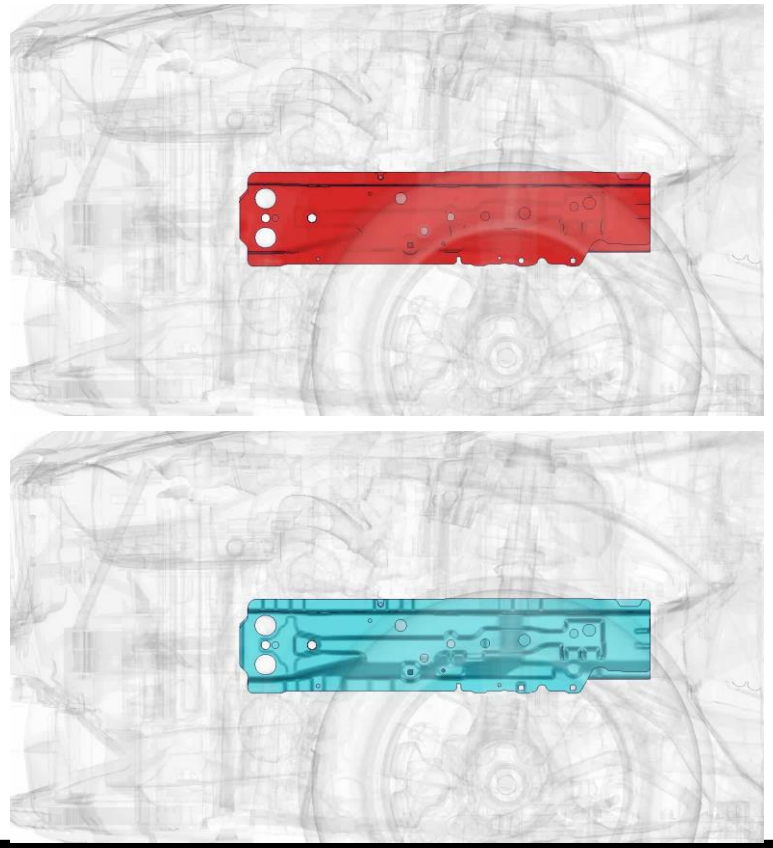
Example of Hybrid of FEA and IGA in Models

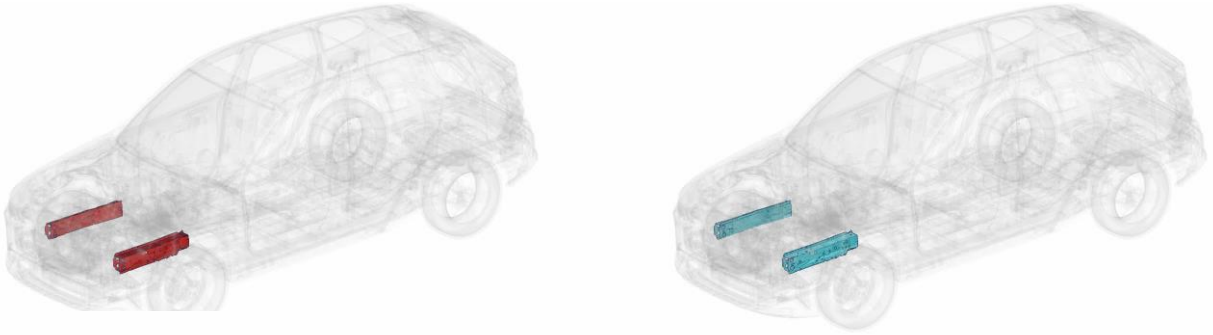
Pure FEA vs. Hybrid IGA/FEA model

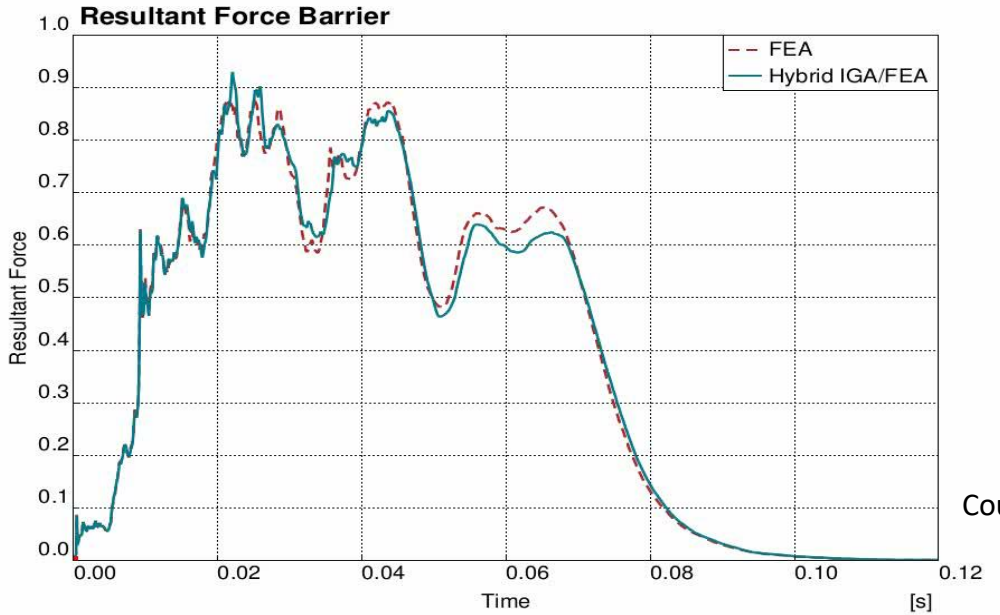
Side view

FEA

Hybrid IGA/FEA







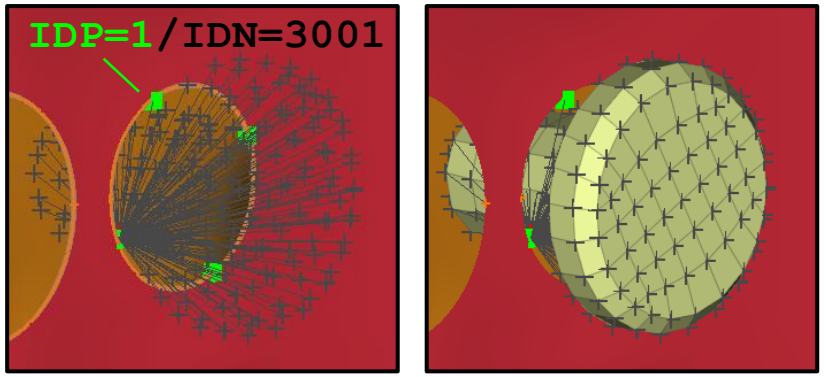
Courtesy of BMW Group

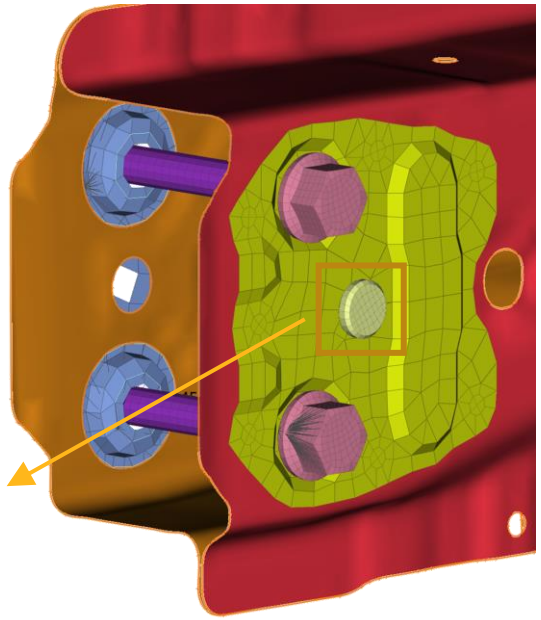
Connection Modeling: A Prerequisite for Production

- For One-To-One Component Exchange (FEA→IGA)
- Spotwelds: PID-based and mesh-independent
  - ***CONSTRAINED_INTERPOLATION_SPOTWELD**
- Tied contact between bolts and IGA shells (PID-based)
  - ***CONTACT_TIED_SHELL_EDGE_TO_SURFACE_BEAM_OFFSET**
- Attach existing rigid bodies (pins and bolts)
  - "Glue" FE nodes of ***CNRB** to IGA shells using
  - ***IGA_POINT_UVW**

```
*CONSTRAINED_INTERPOLATION_SPOTWELD
$       MID       SID      NSID     THICK         R
        101       102       200       3.0         7
$        RN        RS     BETA1       LCF     LCUPF
       xxx       xxx       xxx       xxx       xxx
$        ES        EB        ET    LCDEXP     GAMMA
       xxx       xxx       xxx       xxx       xxx
```

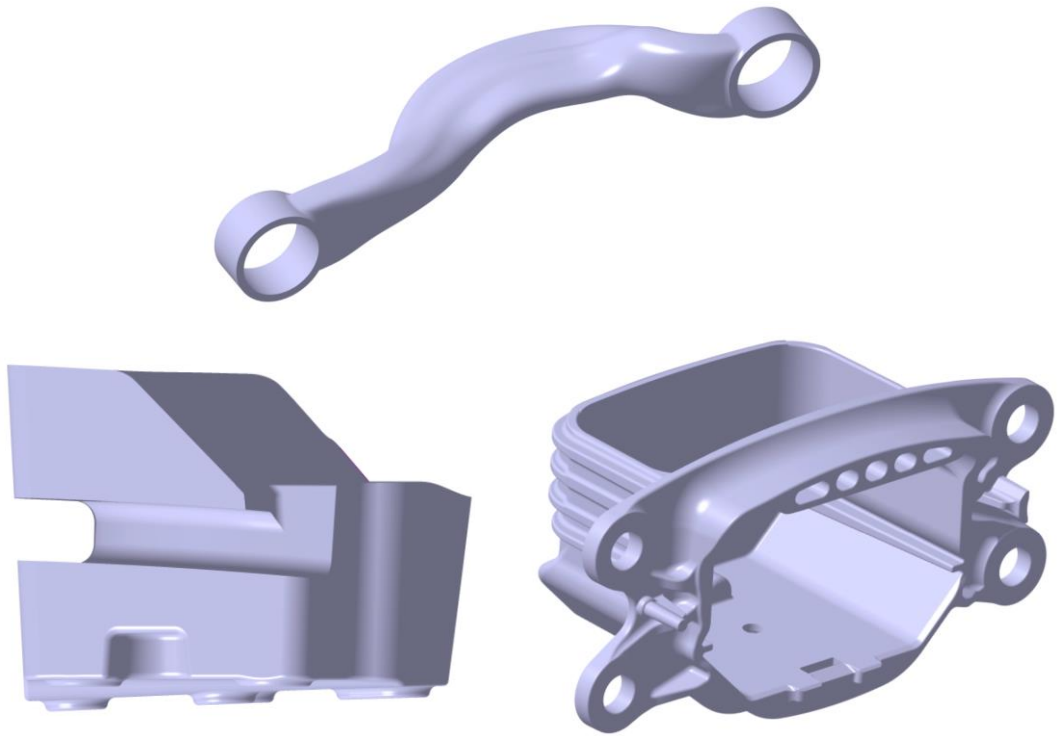
```
*IGA_POINT_UVW
$       IDP|       IDN|         U|         V|
          1       3001      0.78      0.15
```





Courtesy of BMW Group

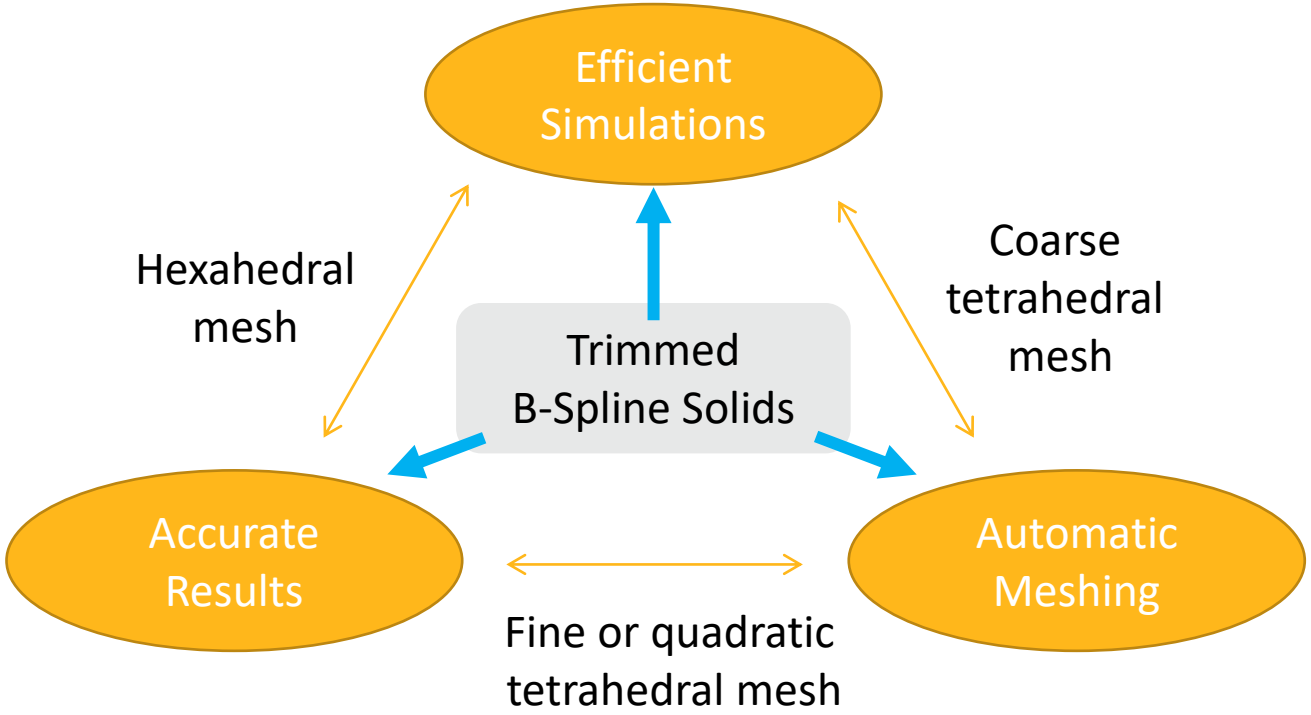
Trimmed IGA Solids for Crash



Courtesy of BMW Group

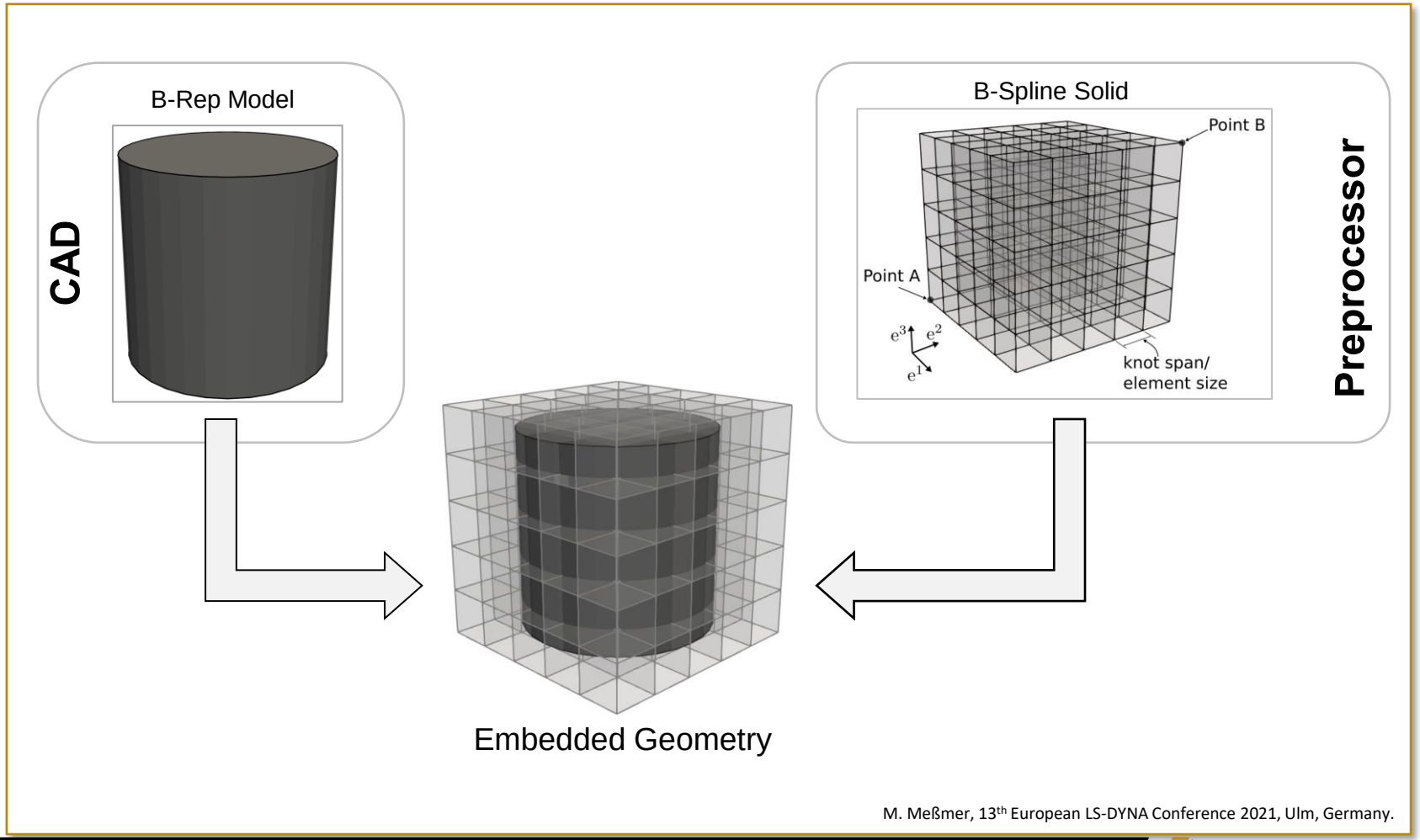
Conflicting goals:

Each FEA option satisfies 2 out of 3.



Trimmed B-Spline solids

- **General Idea**
  - B-Spline background grid
  - Embed geometry
  - Generate integration rule

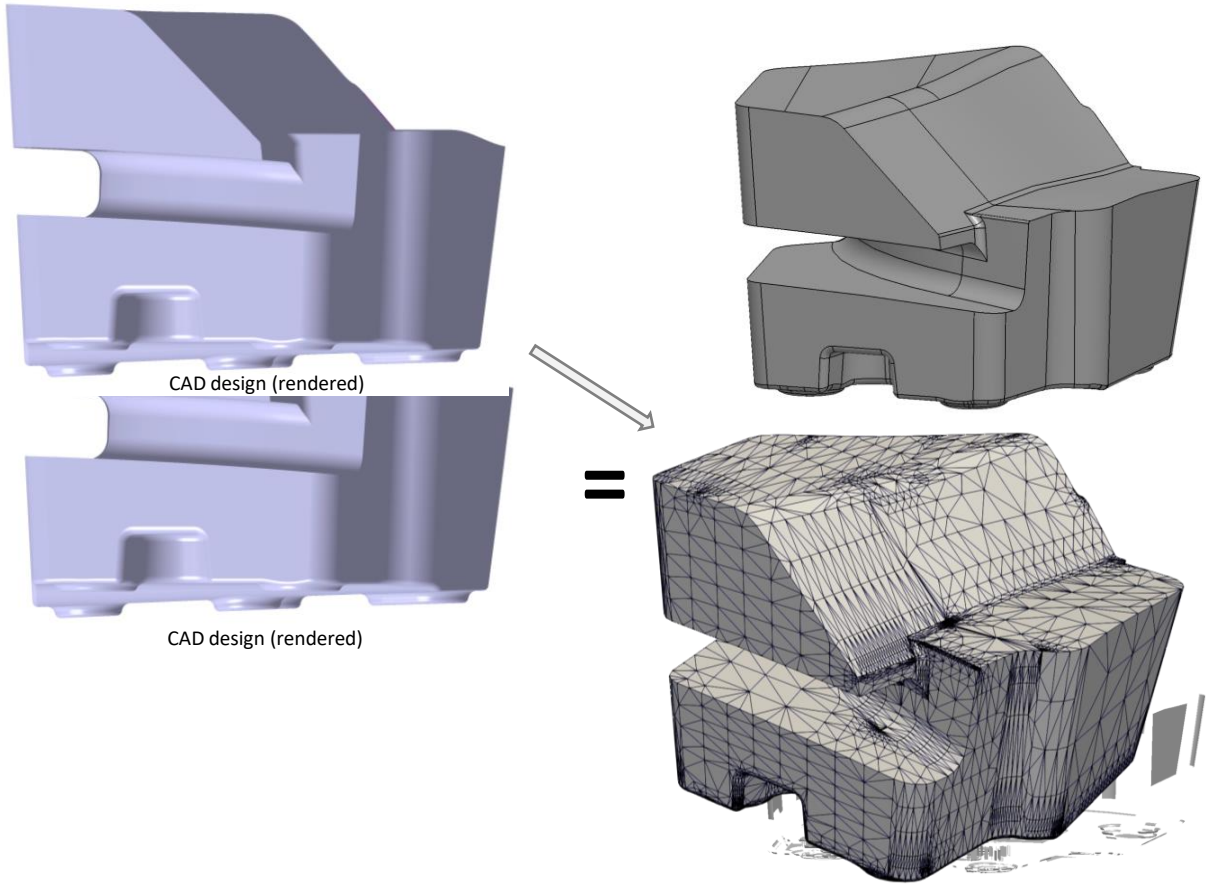


M. Meßmer, 13th European LS-DYNA Conference 2021, Ulm, Germany.

Current workflow - I

External Preprocessing (M. Meßmer, TUM)

- **Generate STL Boundary Representation**

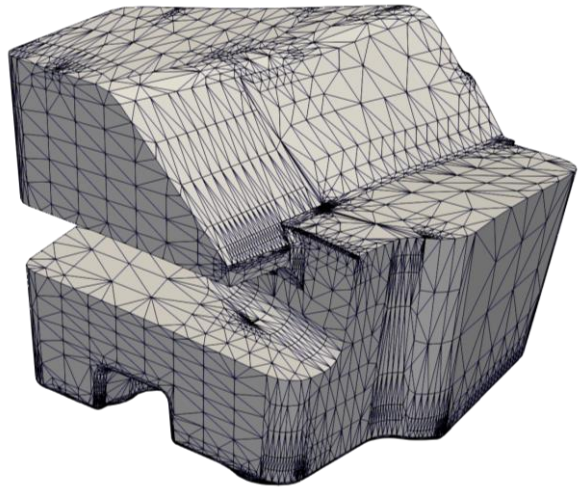


M. Meßmer, 13th European LS-DYNA Conference 2021, Ulm, Germany.

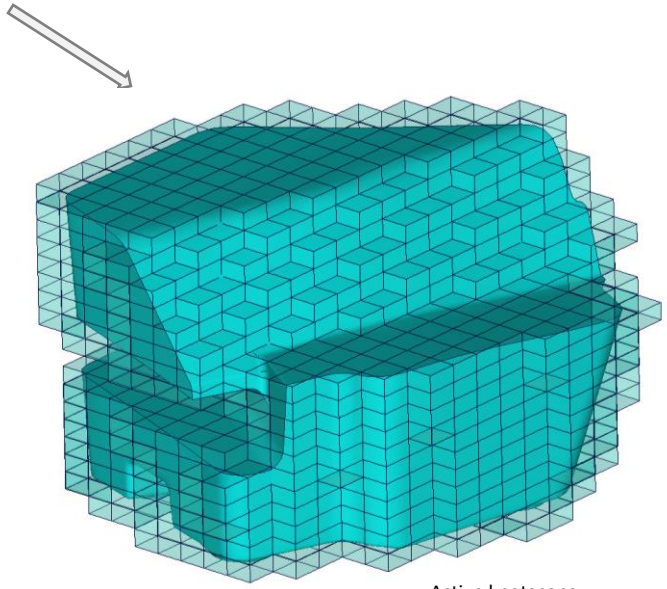
Current workflow - I

External Preprocessing (M. Meßmer, TUM)

- Generate STL Boundary Representation
- **Identify active knot spans (elements)**
  - Boolean operation
  - Inside/outside test (ray tracing)



STL Boundary representation



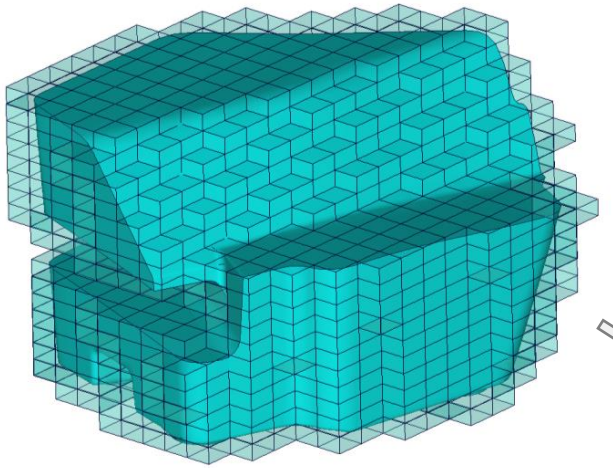
Active knotspans

M. Meßmer, 13th European LS-DYNA Conference 2021, Ulm, Germany.

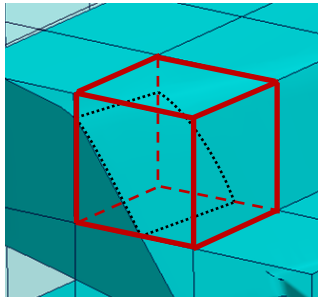
Current workflow - I

External Preprocessing (M. Meßmer, TUM)

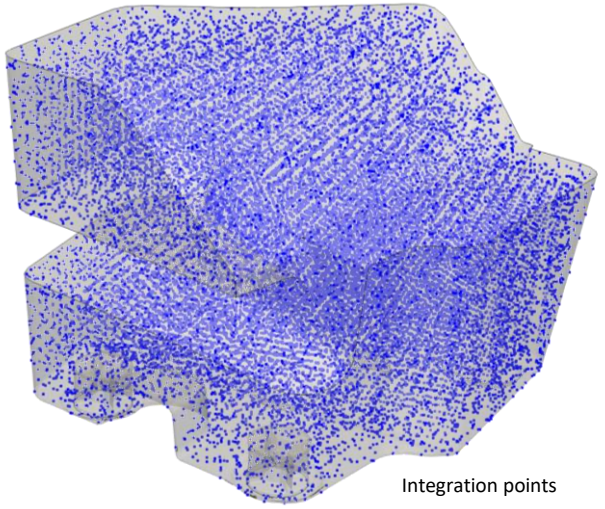
- Generate STL Boundary Representation
- Identify active knot spans (elements)
  - Boolean operation
  - Inside/outside test (ray tracing)
- **Generate integration rule for each knot span**
  - Untrimmed knot span/element
    - Full/reduced Gauss
    - GGQ (Generalized Gaussian Quadrature)
  - Trimmed knot span/element
    - Moment fitting algorithm



Active knotspans



trimmed knotspan/element



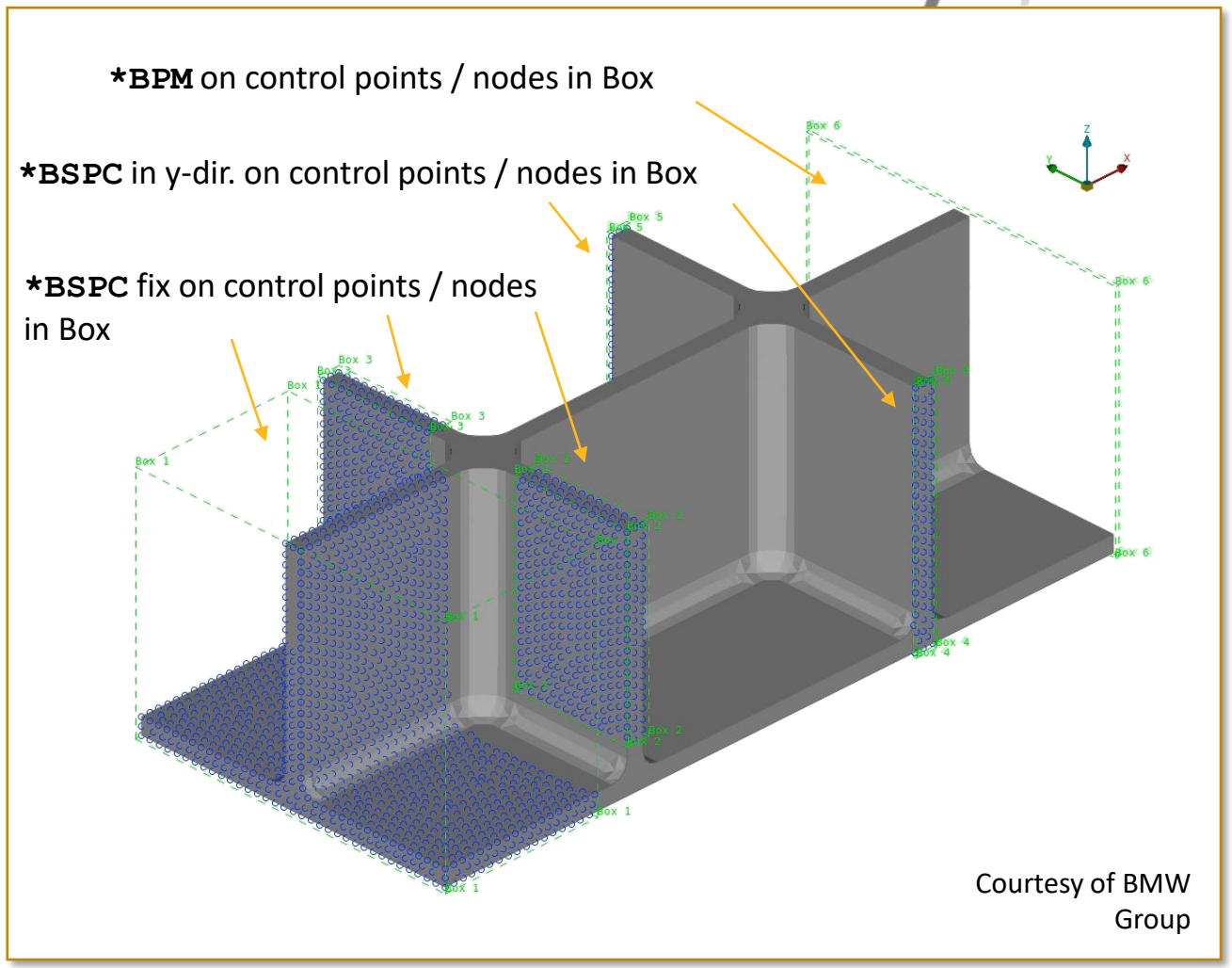
Integration points

M. Meßmer, 13th European LS-DYNA Conference 2021, Ulm, Germany.

Examples

Academic Cast Component: Problem Definition

- Cast Component
  - FE solid: ELFORM=13 (1-point tet)
  - Trimmed tri-quadratic B-spline solid
- Boundary conditions via Box-definition
  - Fixed on left side
  - Prescribed vertical motion on right side
- Settings FE
  - Mesh: 0.5mm / 1mm / 2mm
- Settings trimmed IGA
  - B-Spline mesh: 2mm / 4mm / 8mm

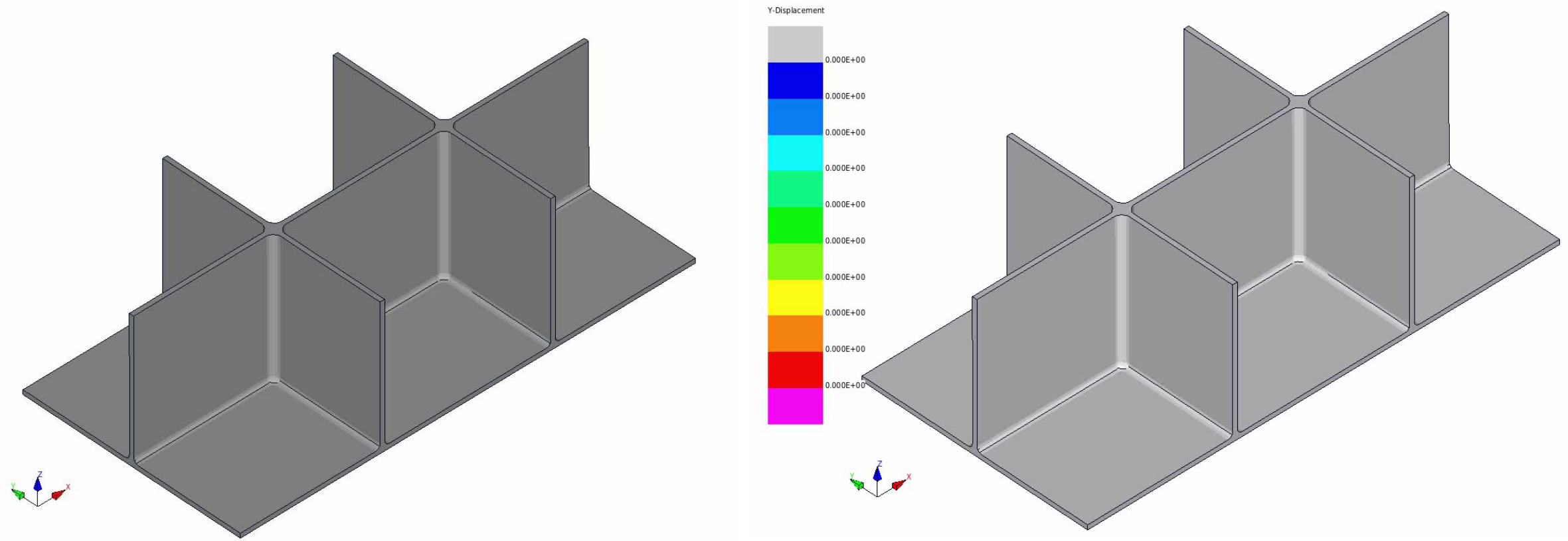


Courtesy of BMW Group

Examples

Academic Cast Component: Deformation

IGA 2mm

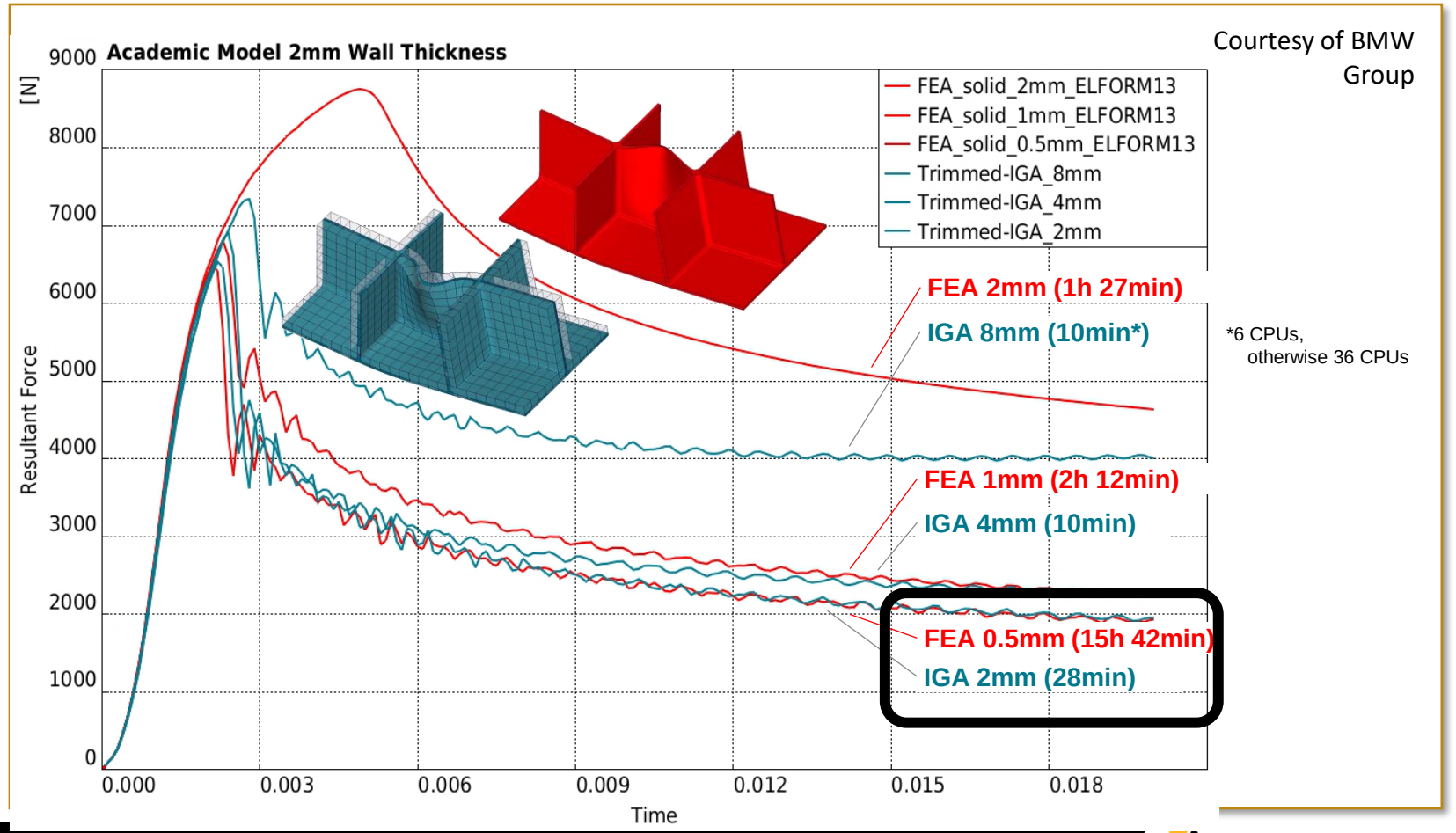


Courtesy of BMW Group

Examples

Academic Cast Component: FEA vs. IGA

- Resultant Force and computational time
- Comparable accuracy:
  - FEA_1mm – IGA_4mm
  - FEA_0.5mm – IGA_2mm
- Larger time step for trimmed IGA (at least 4x higher here)
  - Feasible time step for full vehicle simulations could be achieved with 4mm trimmed IGA solids
- **Finest trimmed IGA model is 3x faster than coarsest FE model!**



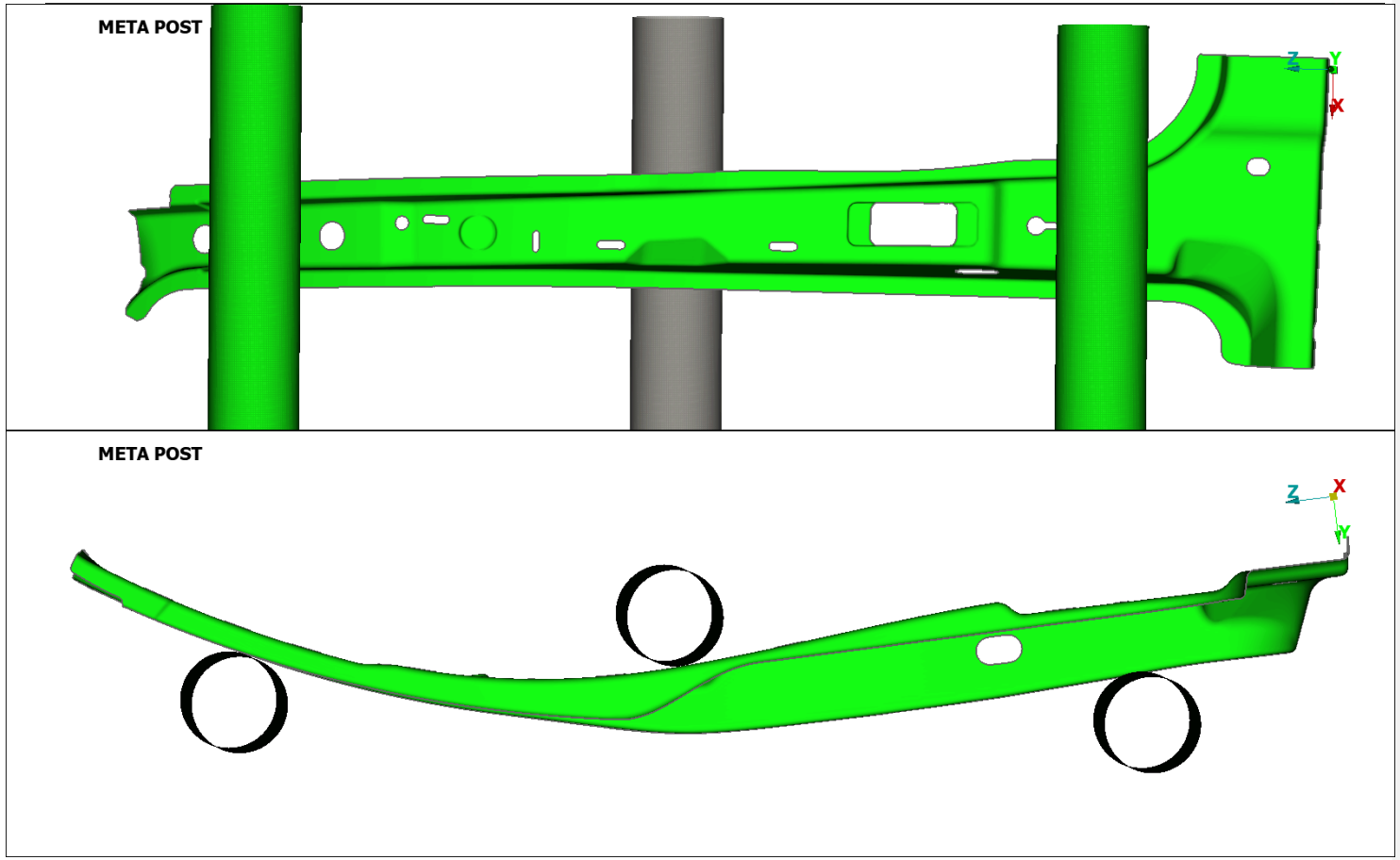
Courtesy of BMW Group

*6 CPUs, otherwise 36 CPUs

Future Postprocessing Plans

- Visualization of the deformed IGA geometry with contouring. Proof of concept with ANSA.
- Lifting of the solution data from the integration points to the control points.
- Writing out selected integration point solution variables for time histories.

META IGA Support



Native Support for IGA results
Directly on IGA Surface
Fast
Precise

The file format has not been finalized and currently doesn’t include stress, strain, or other solution variables. We are working with them to generalize it for production use.

Commitment to New Technology

- We have ongoing contact and collaborations with the leaders in IGA technology including:
  - Thomas J. R. Hughes, inventor of IGA.
  - Yuri Bazilevs, co-author on the first IGA paper.
  - Jessica Zhang, first post-doc of T. J. R. Hughes devoted to meshing.
  - Hugo Casquero, U. of Mich. Assistant Professor, meshing and element technology. Post-doc of Jessica Zhang.
- Our element implementations permit immediate use of any basis functions that can be expressed through Bezier extraction operators and NURBS.

Summary:

- Trimmed splines are fast to mesh and fast to run.
- Unstructured splines are optimized for accuracy but are still very efficient.
- Production ready IGA is available in LS-DYNA now.
- Post-processing improvements are on the way.

Ansys