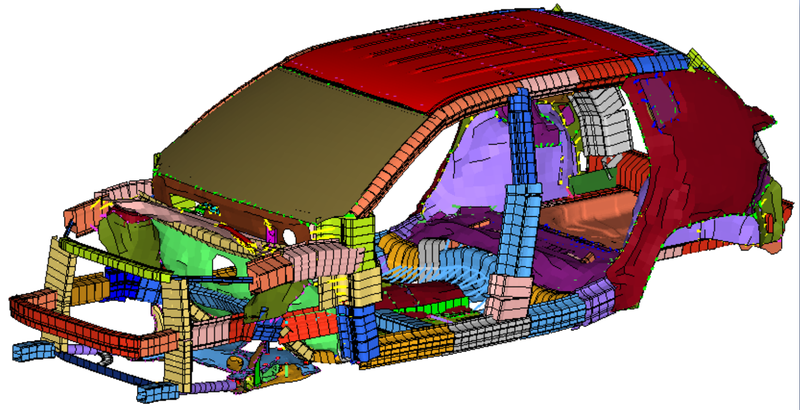
Evolution of Simplified Loadpath Models for Advanced Body Structure Development

James Truskin

Body S&CE | BIW

FCA US LLC



Altair Technology Conference | Detroit, MI USA

October 10, 2019

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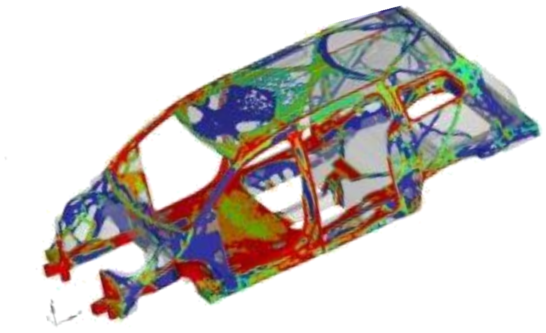
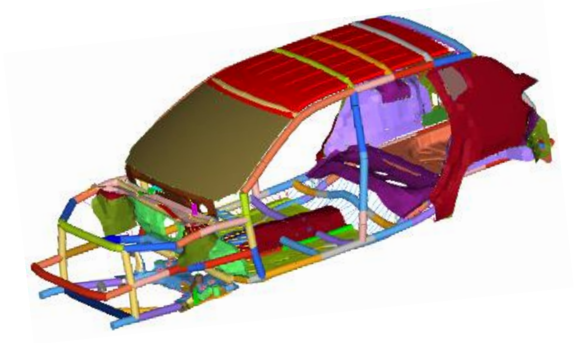
Key Topics

- **Concept Phase Objectives & Challenges**
- **Body System Design Process**
  - Loadpath, Section & Joint design tools
- **"New" Concept-Phase Structure Design Tools**
  - Simplified Loadpath Models (SLM)

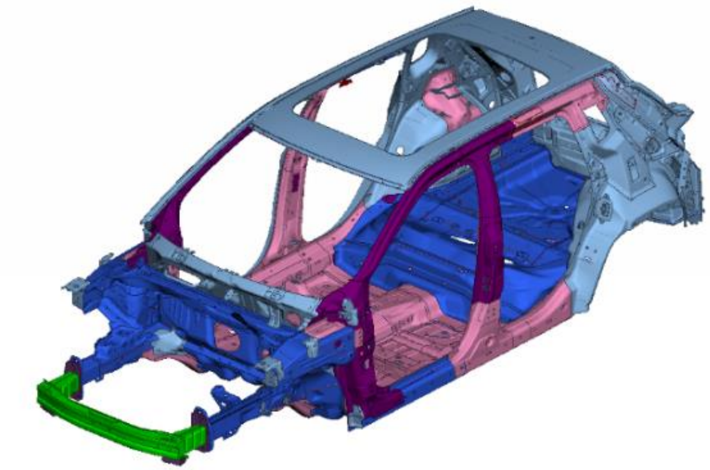




Body Structure Challenges – Concept Phase

1. What do we need to know about the body structure in the concept phase?
   - Targets (weight, performance)
   - Structural requirements
   - Constraints: Packaging & section sizes, assembly sequence, joining processes, material availability

2. How do we develop the body structure to assess against these targets?
   - Create a conceptual model that is fast to build and iterate loadpath sections and their properties



BIW Structure – Development Principals

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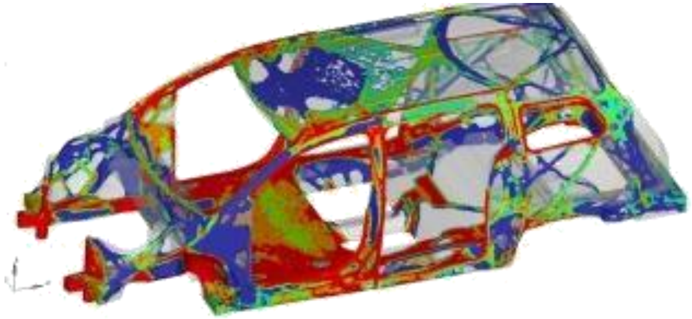

Loadpaths

- Evolutionary or revolutionary needs as vehicles evolve
- Loadpaths manage and transfer energy input through the body system
- Critical in determining the performance and weight

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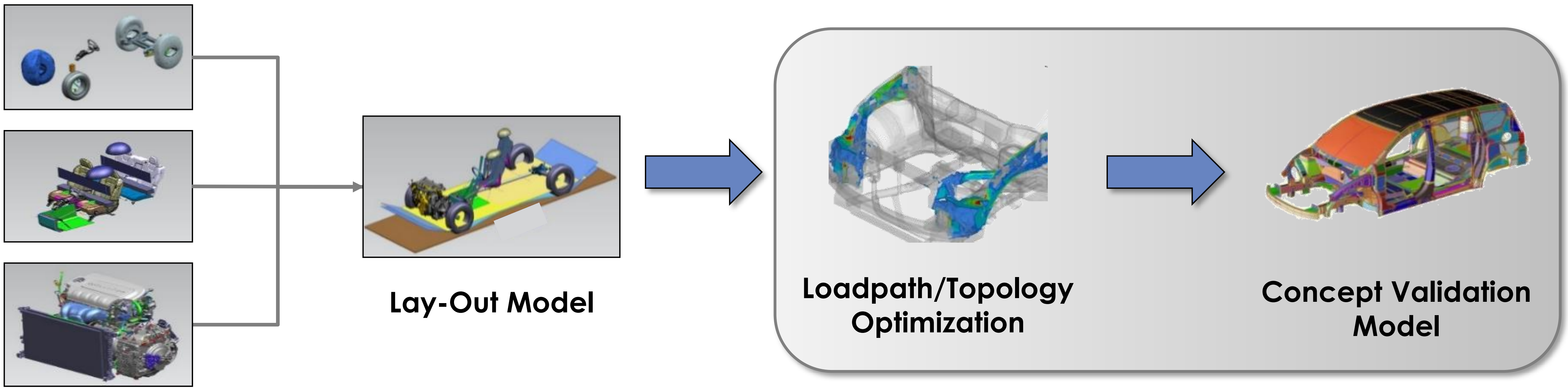
BIW Structure – Loadpath Concept Development



- **Loadpath Generation Process**
  - Develop vehicle lay out: hard points, critical monuments
  - Identify and quantify energy input points to body (load points)
  - Develop efficient reaction structure
  - Optimize body joints and structural section sizing

- **Concept Validation Model**
  - Mass/Performance
  - Vehicle package integration
  - Process and assembly validation

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BIW Structure – Development Principles

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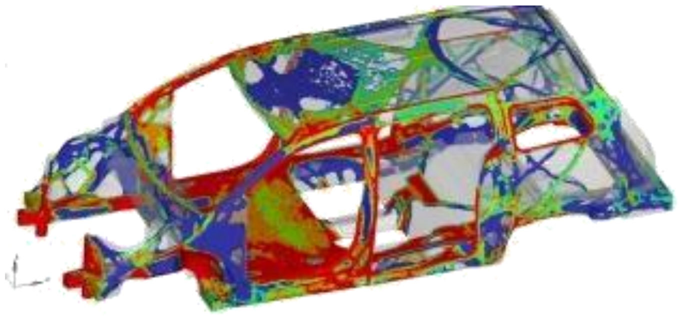

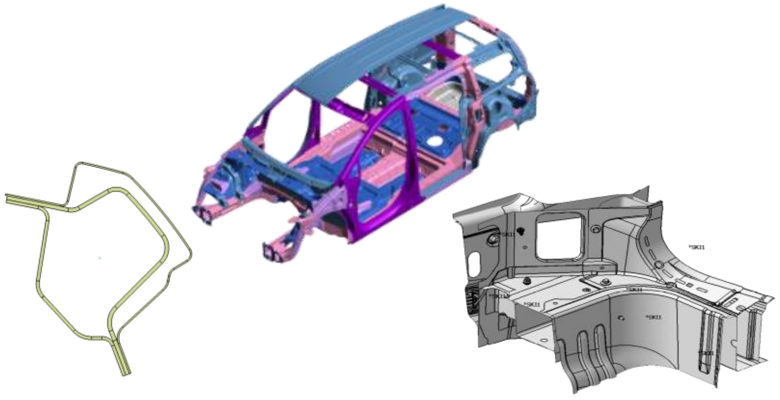

Loadpaths

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Sections, Materials and Joints/Build Process

- Realization of loadpaths
- Sections transfer loads
- Joints connect sections
- Materials selection to balance section and joint stiffness and strength

BIW Structure – Development Principals

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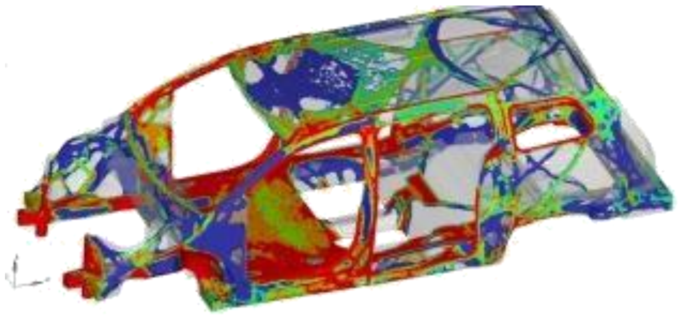

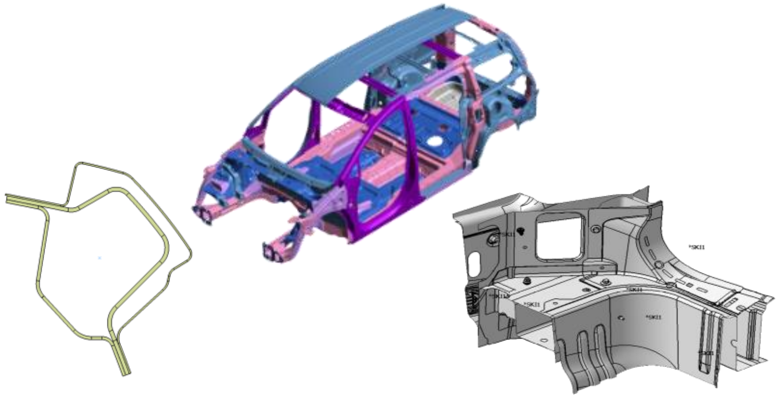

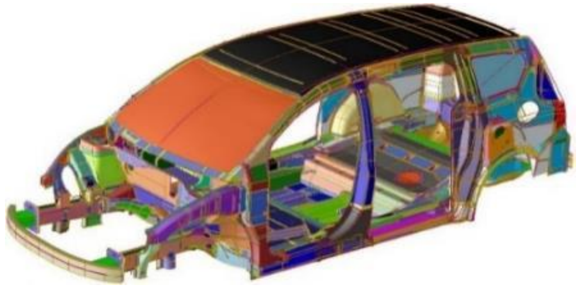

Loadpaths

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Sections, Materials and Joints/Build Process

- Realization of loadpaths
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- Materials selection to balance section and joint stiffness and strength

Virtual Concept Validation

- Loadpath, Section and Joint validation
- Vehicle package integration and trade-offs
- Process and assembly validation

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Body Structure Challenges – Concept Phase

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    - Targets (weight, performance)
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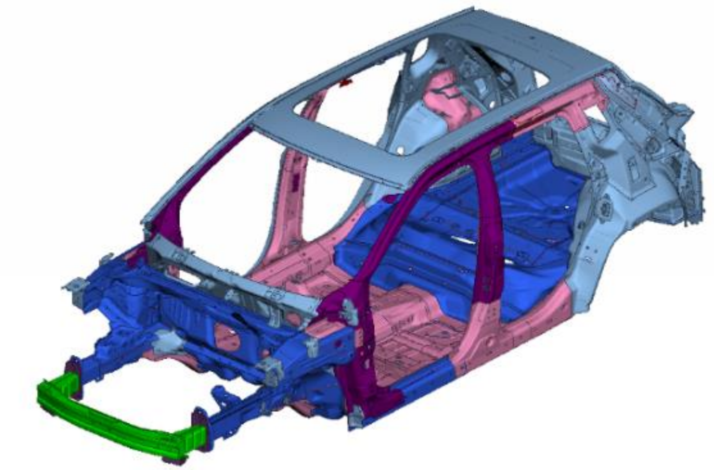

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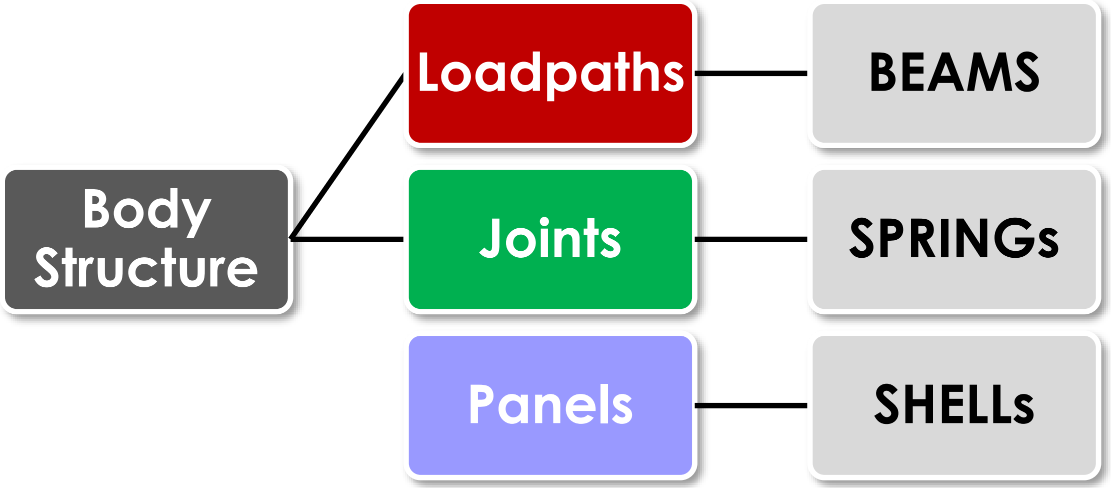
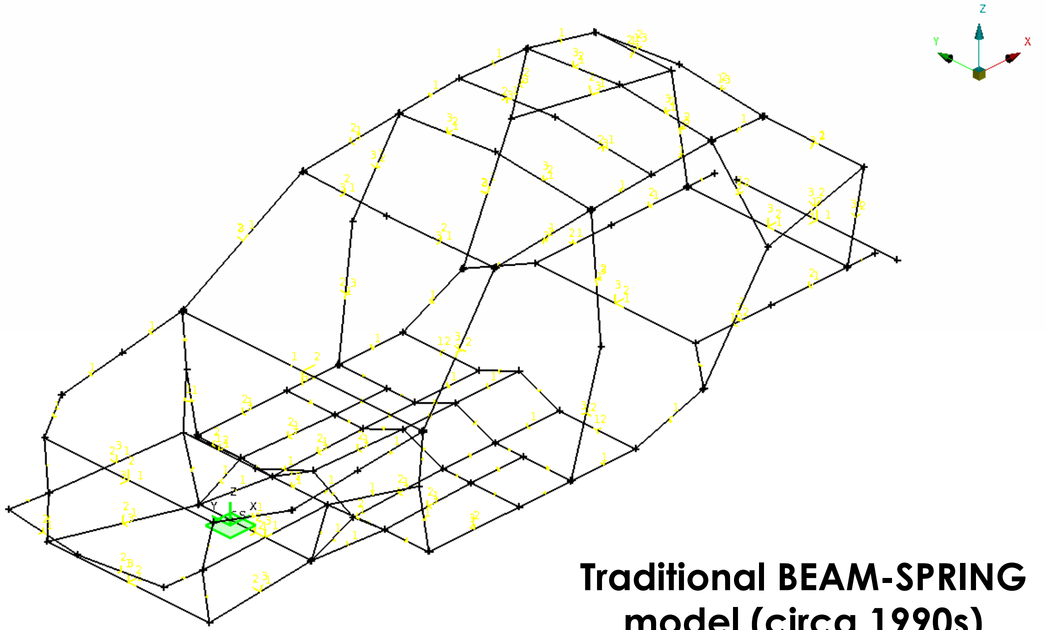


- Some body panels are not easily presented or substituted with BEAM elements
  - Roof, Dash, Floorpan, Body Side Panel

- The mass and stiffness contribution of these panels must be captured in the model



Traditional BEAM-SPRING model (circa 1990s)
480 Degrees of Freedom

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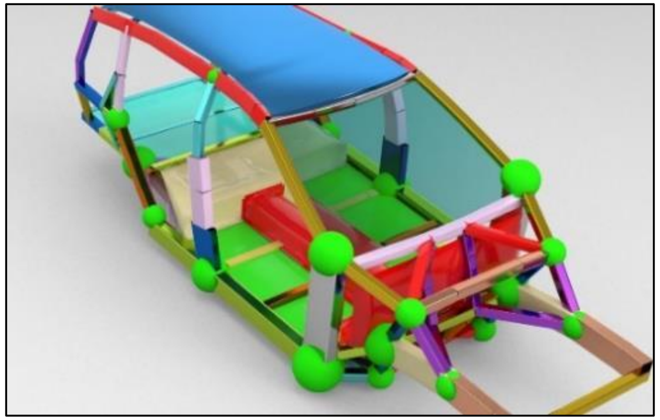
C^{123} – Simulation Driven Concept Design Support



C1	C2	C3
Identification of Optimum Structural Layout using Free Form Models	Rapid Optimum Sizing of Idealized Sections & Joints using Low Fidelity Models	Detailed Optimum Sizing of Manufacturable Sections & Joints using High Fidelity Models

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C123 – Simulation Driven Concept Design Support

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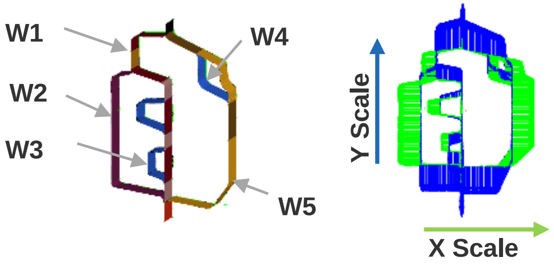
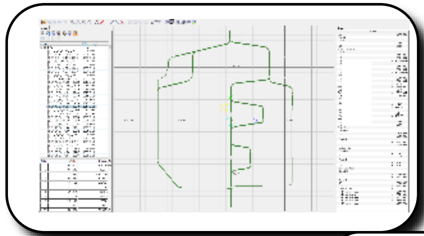
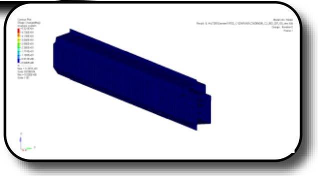
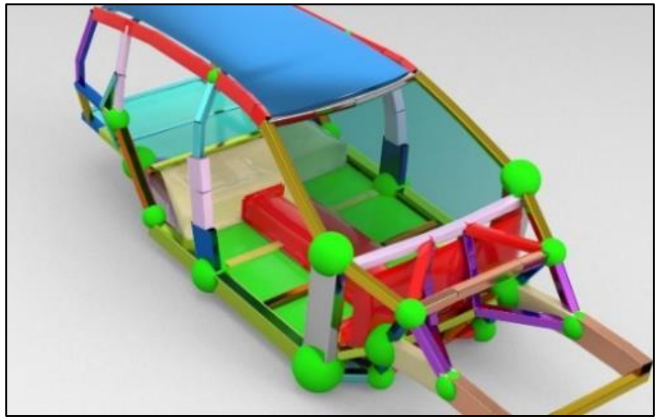
Cross Section Dimensioning





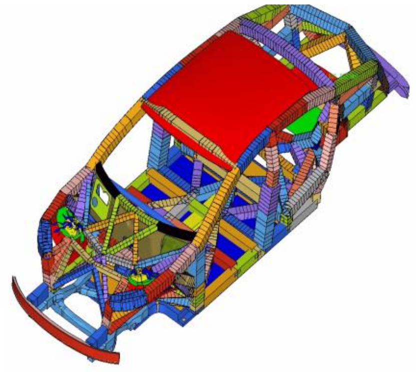


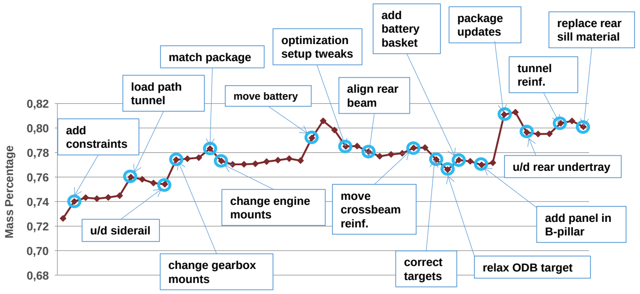


C2

Rapid Optimum Sizing of Idealized Sections & Joints using Low Fidelity Models

Design Exploration





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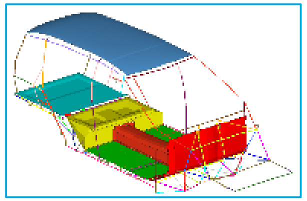
Maturing the Structure

Load Paths



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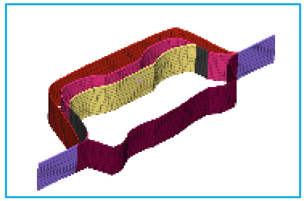
Cross Sections



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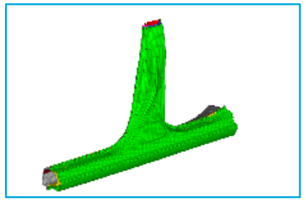
Structural Joints



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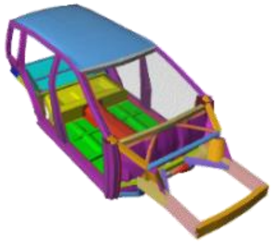

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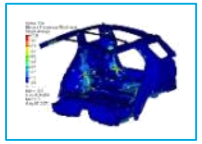
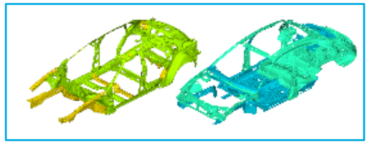
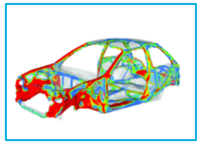
Optimization and Design Exploration



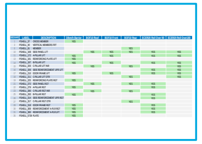
Free-Size



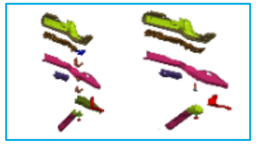
Gauge



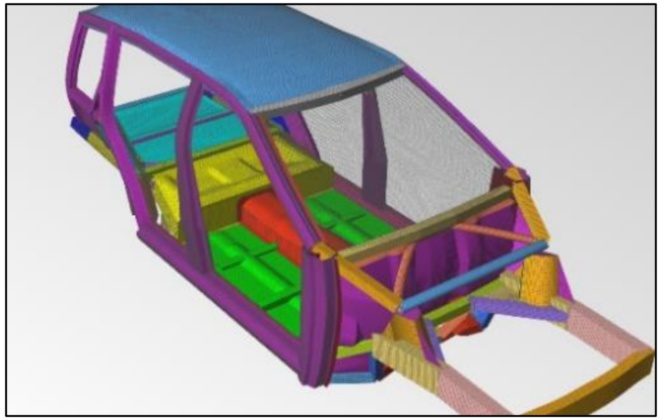
Topology



Grade



Value Eng.



C3

Detailed Optimum Sizing of Manufacturable Sections & Joints using High Fidelity Models

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Risk Assessment of SLM (C2) Integration

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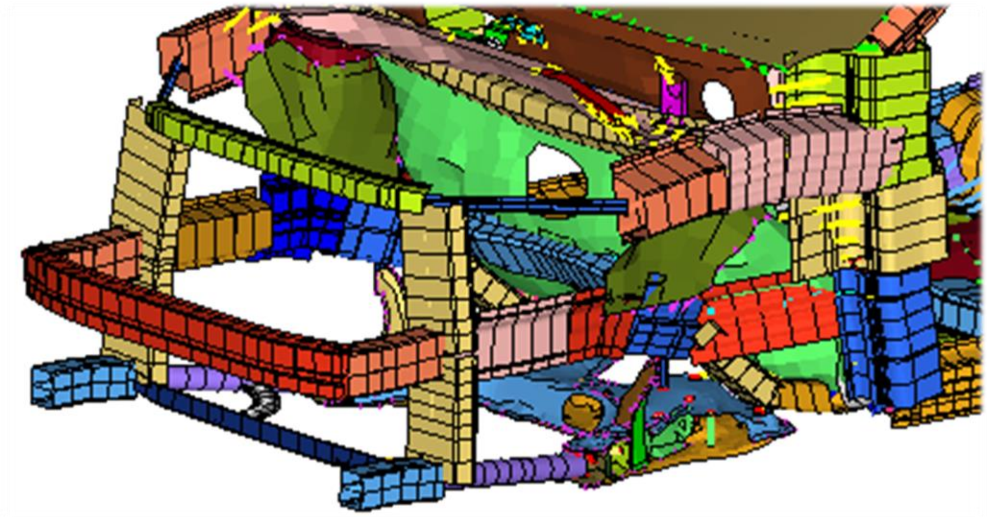
Perceived *Benefits*:

+ Improved results from section assessment vs 2-D calculations (Ixx, Iyy, J…)
+ Faster feedback loop than traditional CAD-CAE techniques
+ Altair has built many macros to automate and accelerate the conversion process
+ Ability to quickly run trade-off studies - optimize section and joint properties to meet program targets
+ Ability to apply on Upperbody only or full body structure

Perceived *Challenges*:

- Expertise in creating Simplified Loadpath Models
- Correlation of SLMs / C2 models



Advanced learning of structural sensitivities through increased simulation and optimization in the concept phase

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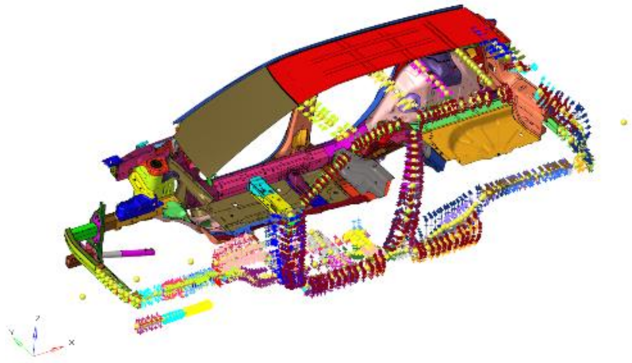
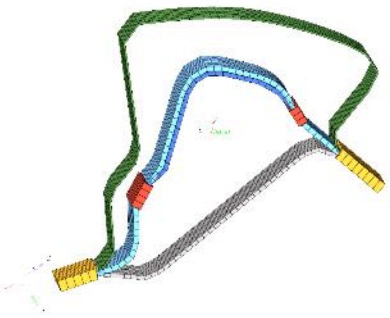
SLM Build Process Diagram

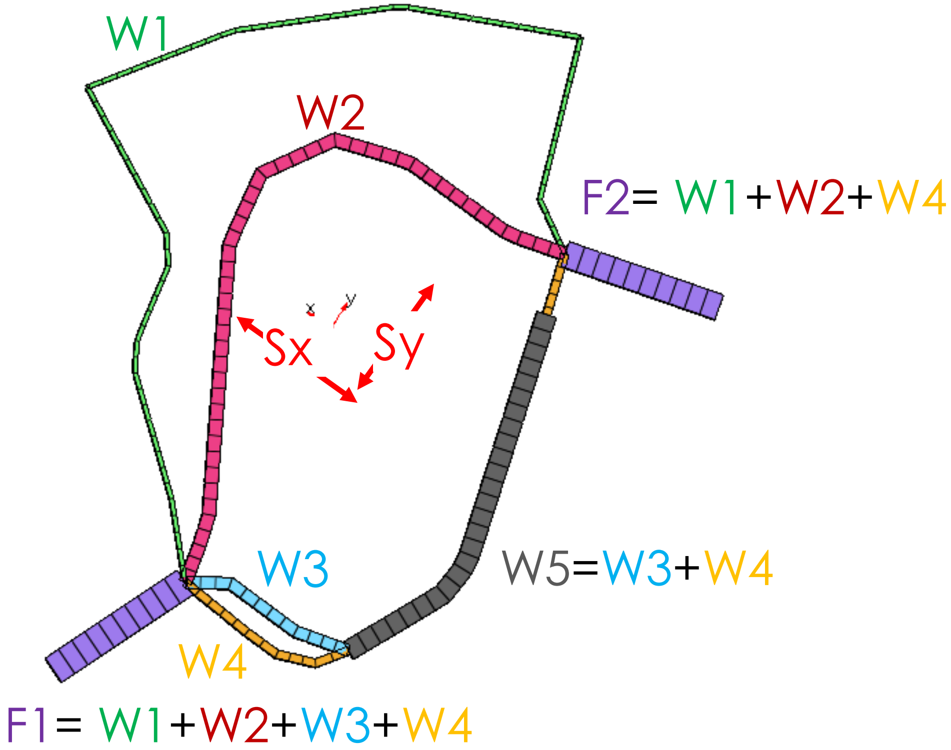
SLM Development
- Create Beams
- Identify body panels

Section Creation
- Create sections library and design variables

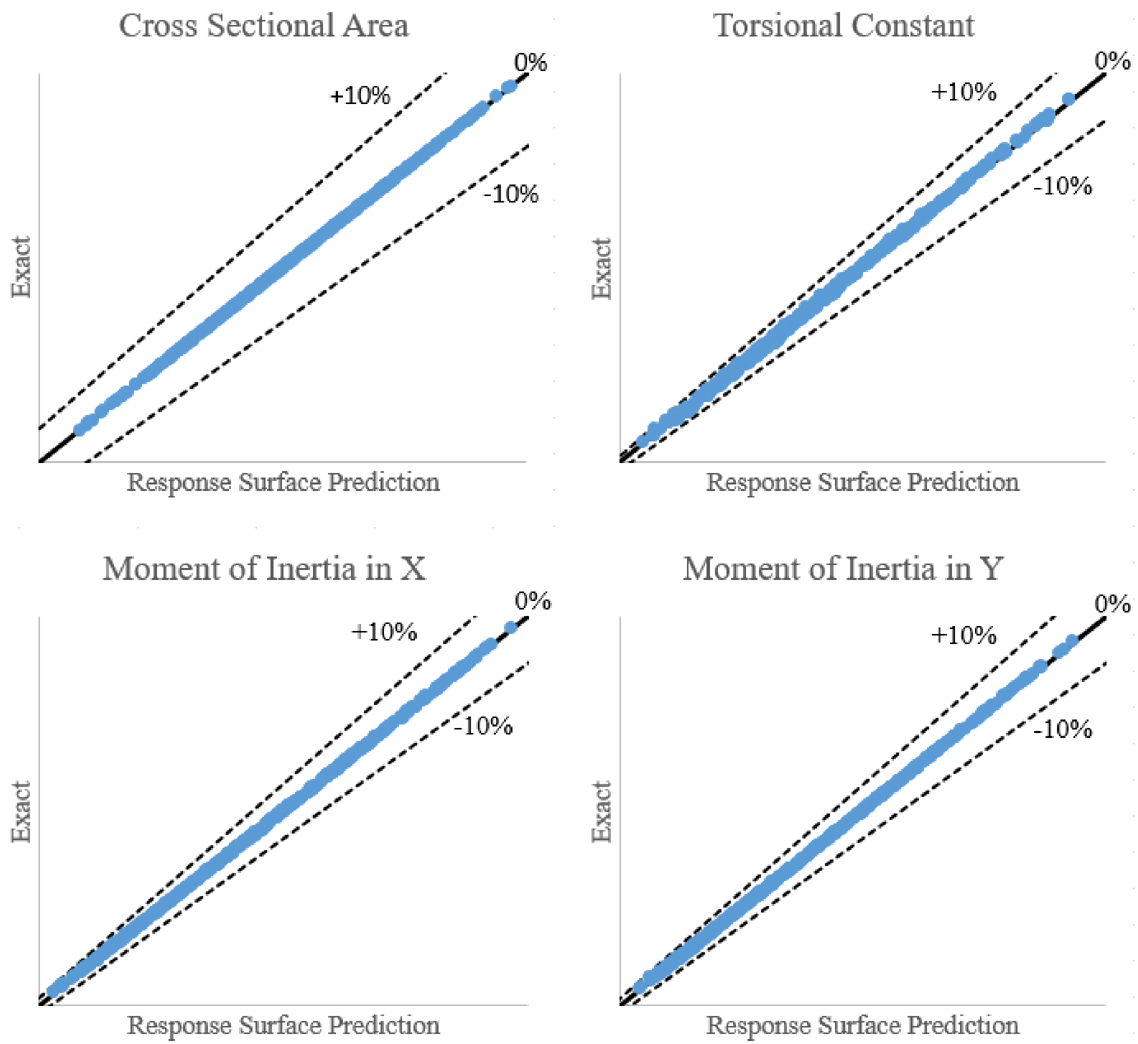




Example Cross Section Response Surface



Area=f(W1, W2, W3, W4, Sx, Sy)
J=f(W1, W2, W3, W4, Sx, Sy)
Ix=f(W1, W2, W3, W4, Sx, Sy)
Iy=f(W1, W2, W3, W4, Sx, Sy)



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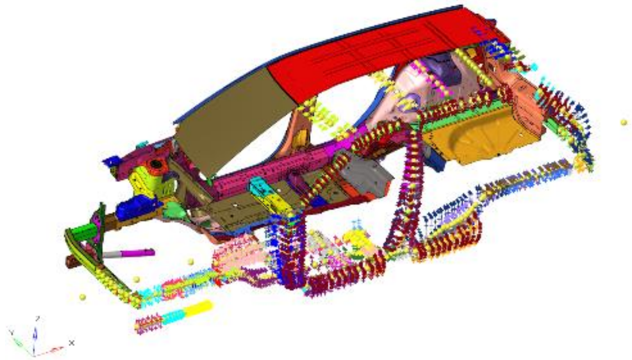
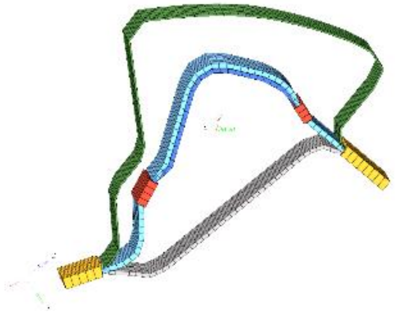
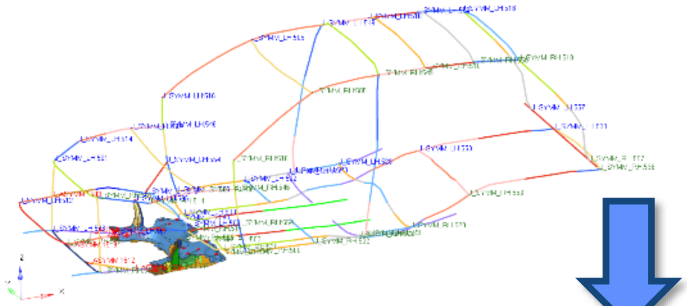


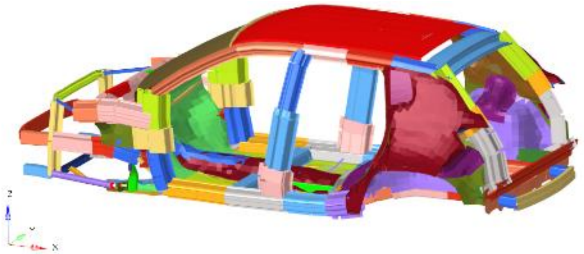
Section Creation
- Create sections library and design variables



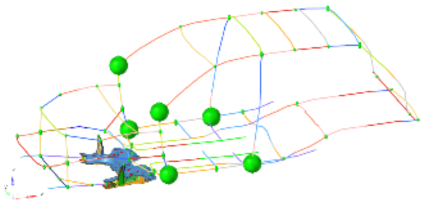
Introduce Joints
- Rotational spring (CBUSH) elements

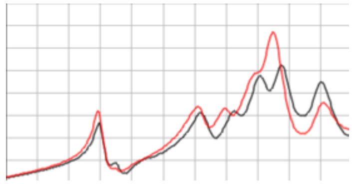


Initial Analysis
- De-bug and compare to Baseline model
- Validate Build strategy

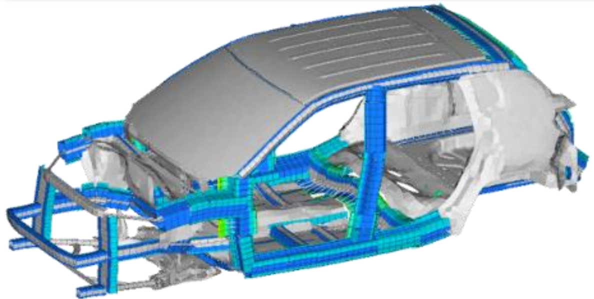


Joint Tuning Run
- Tuning joint stiffness to improve correlation





Optimization / Trade-Off Studies
- Concept alternatives
- Mass/performance studies



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BIW Model Size Comparison

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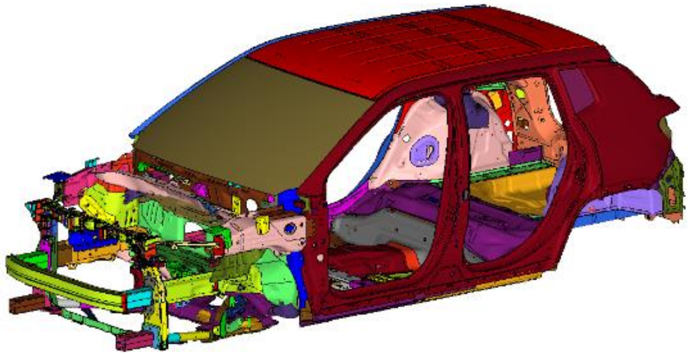
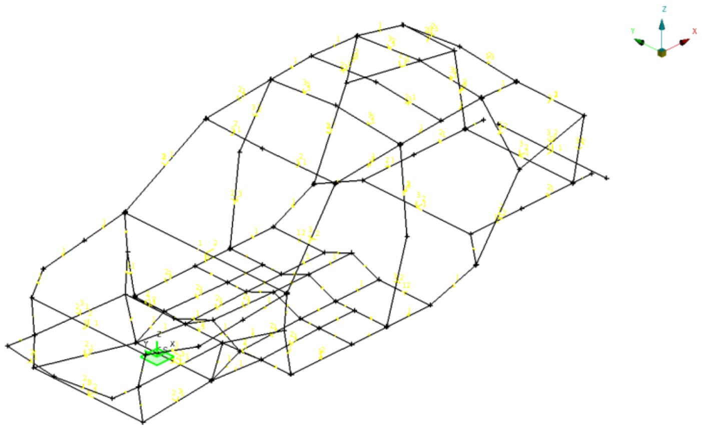
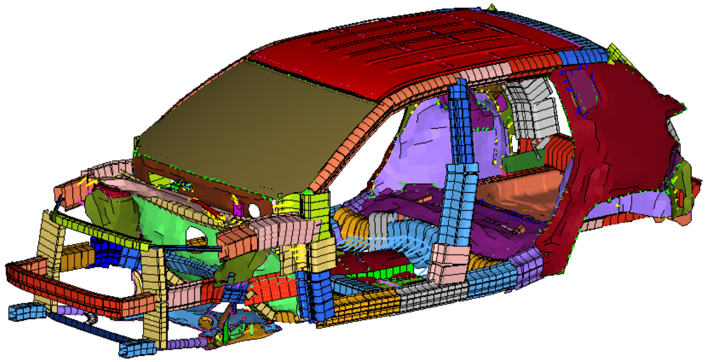


4.9M DOF



480 DOF



150k DOF

97% Reduction

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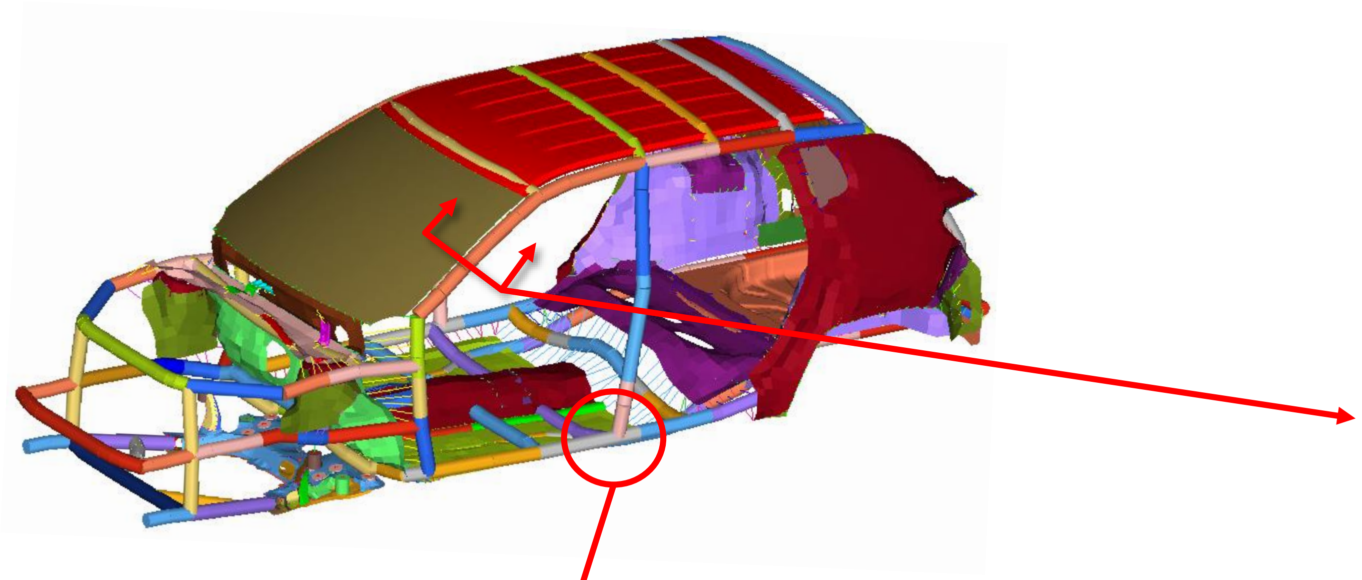
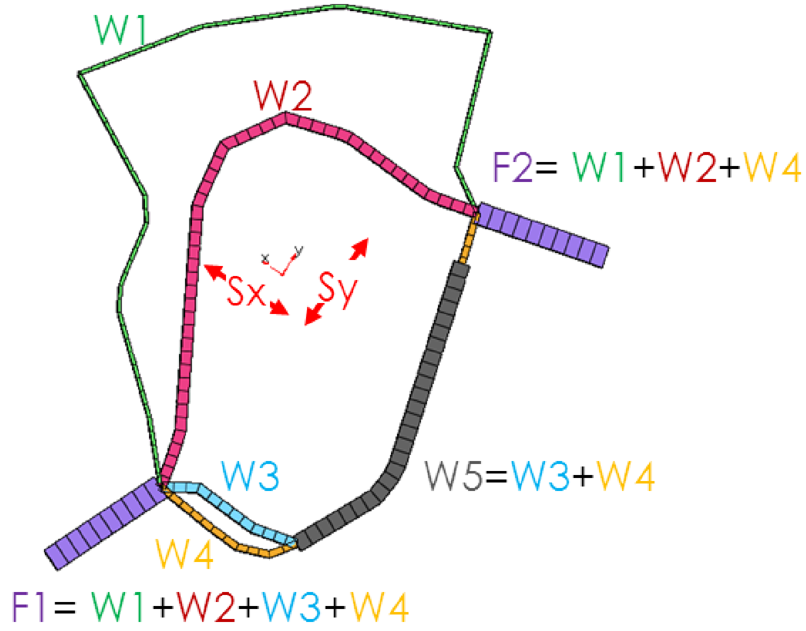
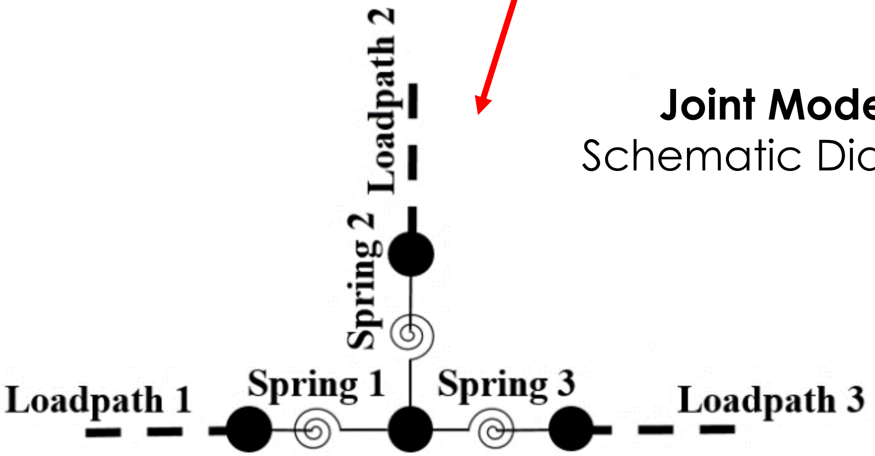
Simplified Model Details





C2 Cross Section
Panel Representation



Joint Models
Schematic Diagram

Concept Body Structure Development Process

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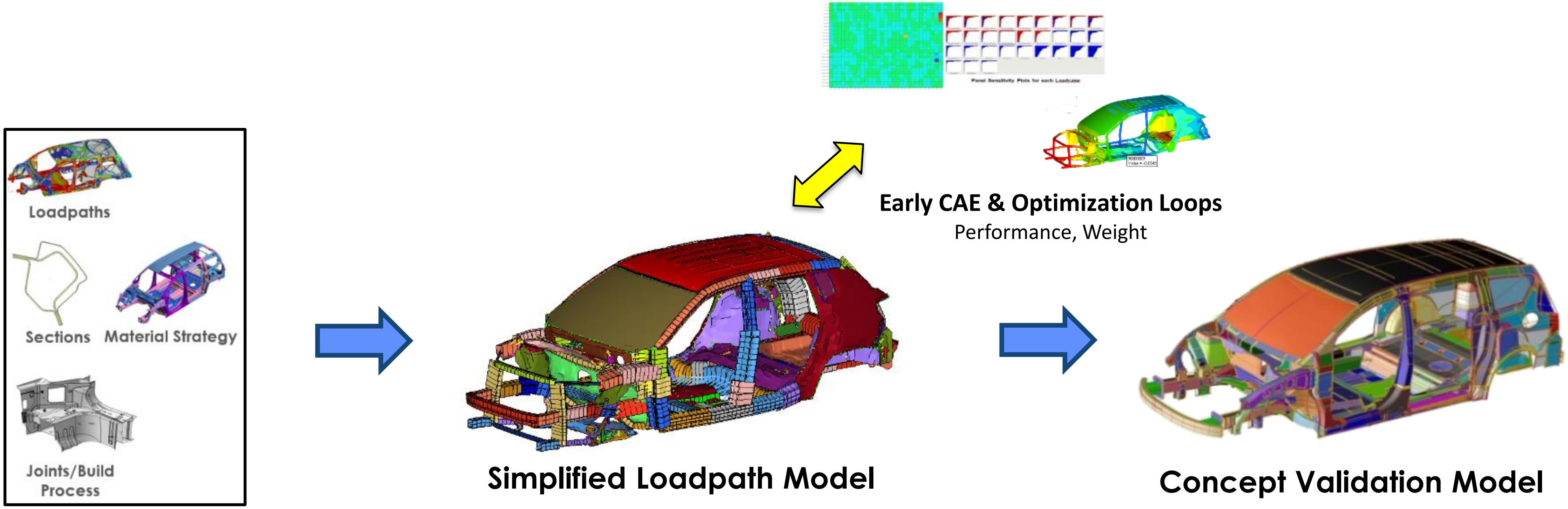

Identified section parameters and joint designs must be validated in a concept model

- Mass/Performance validation & optimization
- Vehicle package integration & validation
- Process and assembly validation

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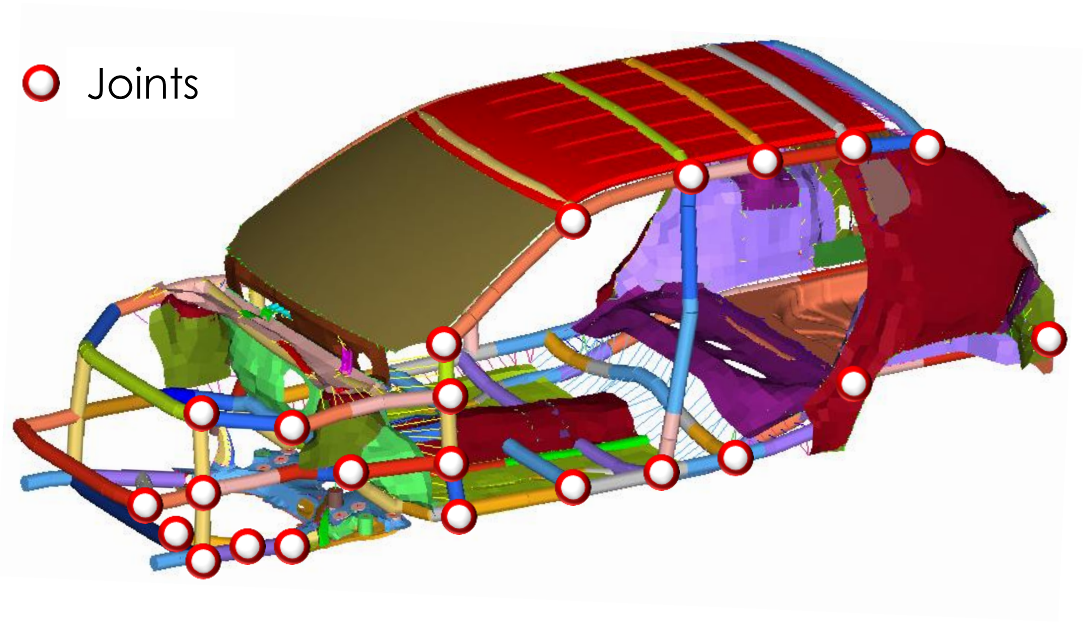
BIW Model Correlation

Tuning the joint stiffness makes it possible to achieve correlation to the analyst's prescribed stiffness metrics

- Model accuracy increases as more loadcases are used as correlation objectives/constraints
- However, as more loadcases are added, error constraints (violations) may need adjustment



Error to Shell Model	Initial SLM (Rigid Joints)	Final SLM (Tuned Joints)
Natural Frequencies:		
Torsion	+52%	1%
Front Lateral Bending	+46%	0%
Global Vertical Bending	+37%	-2%
Static Stiffness:		
Static Torsion Stiffness	+93%	0%
Static Bending Stiffness	+125%	+4%

Torsion Mode Comparison

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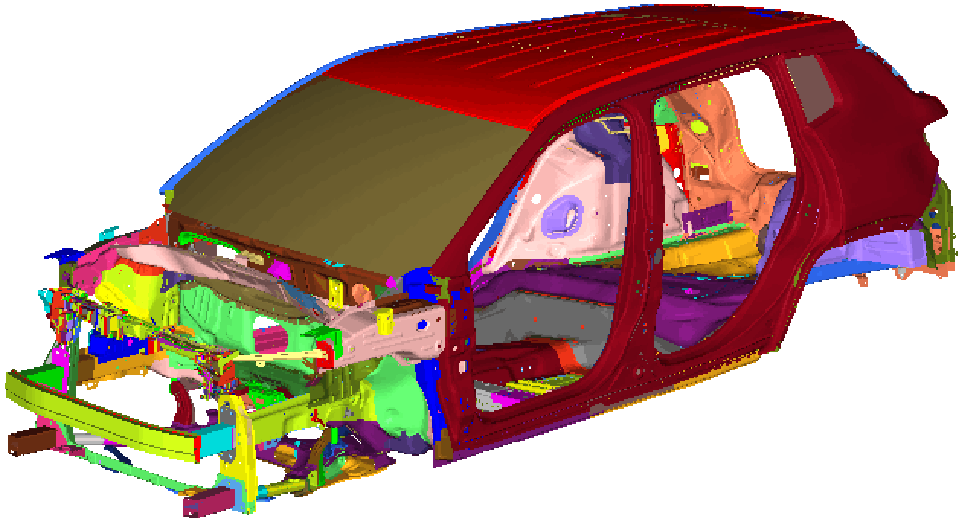
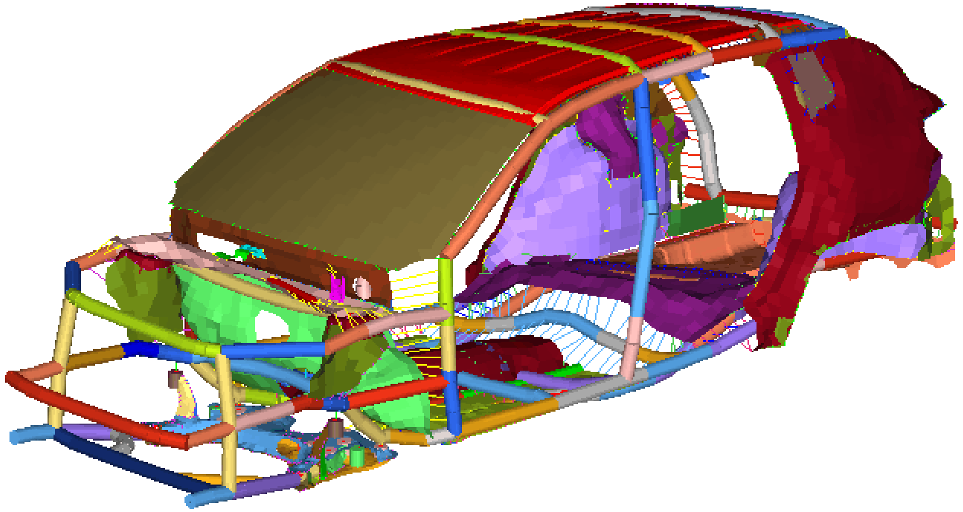
+1%





Baseline Model

Final SLM

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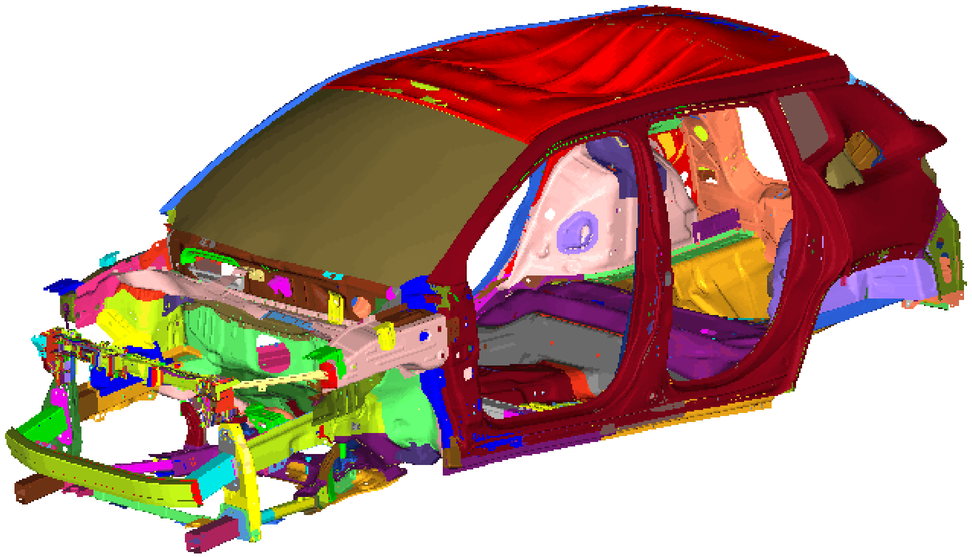
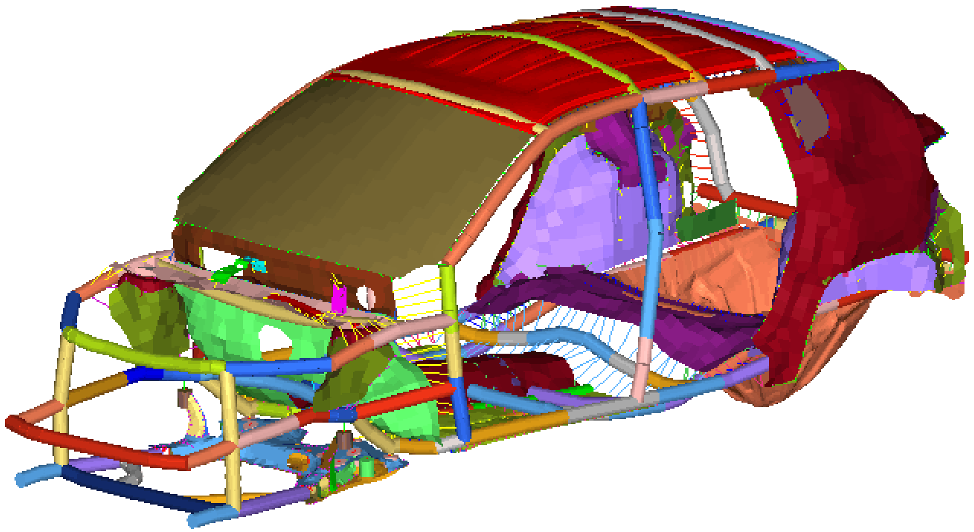
Vertical Bending Mode Comparison

-2%





Baseline Model **Final SLM**

Lateral Bending Mode Comparison

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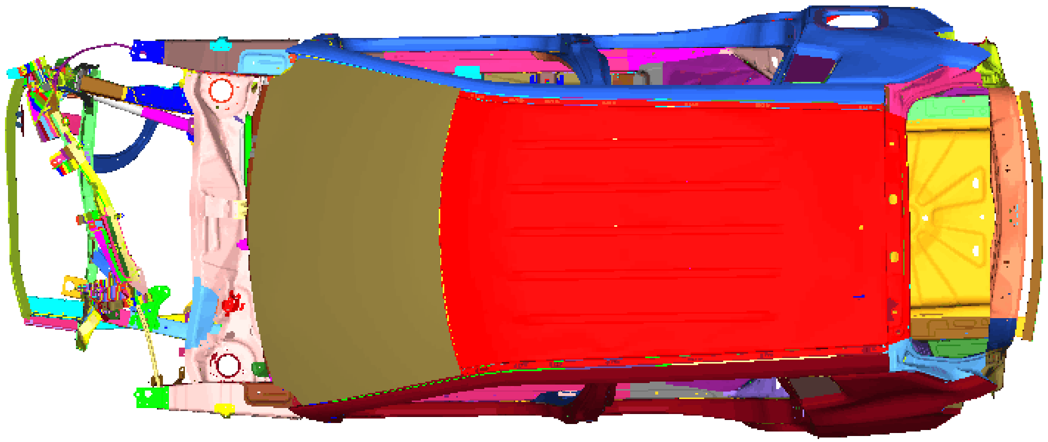
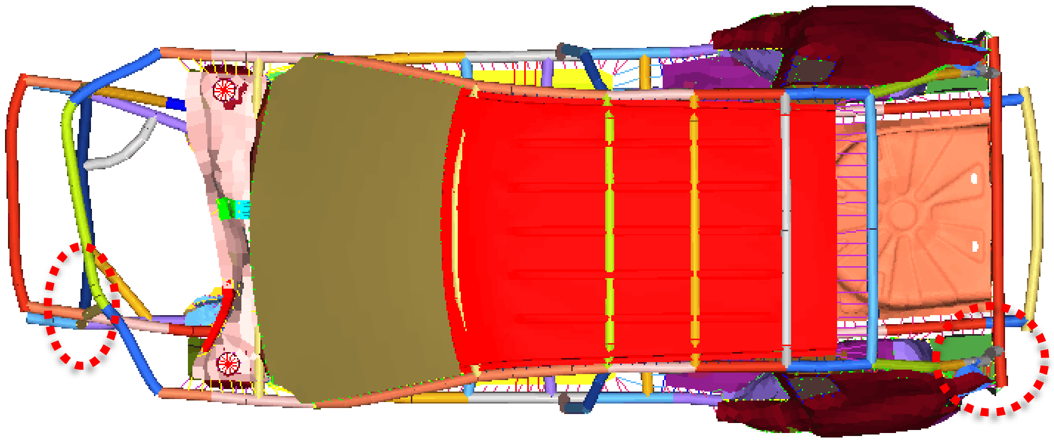
0%





Baseline Model **Final SLM**

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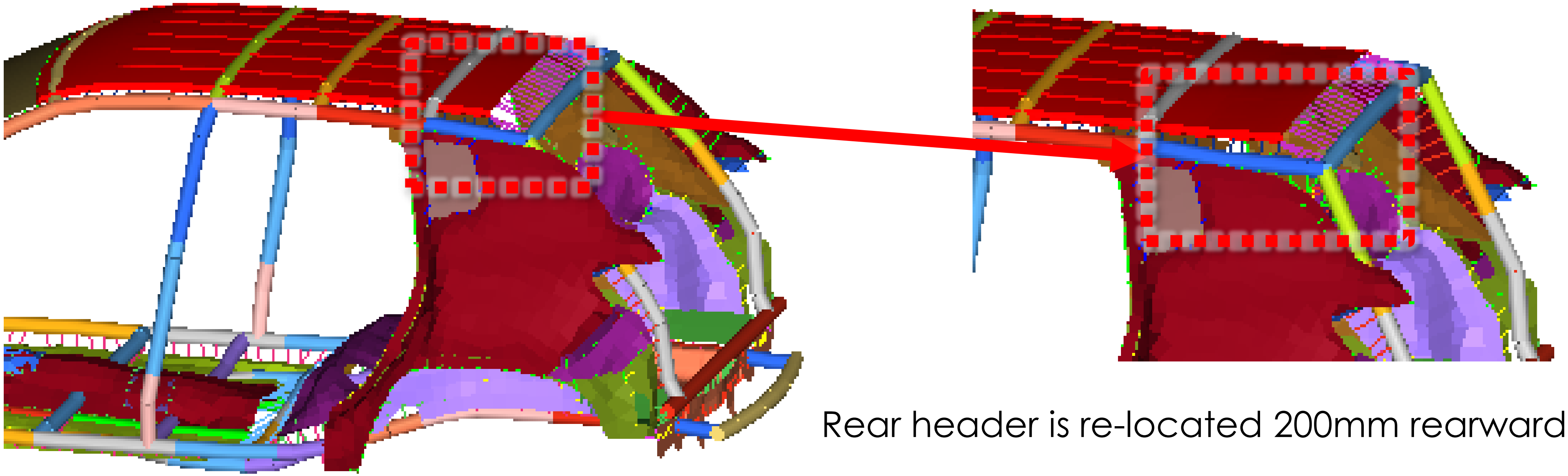
- **Study Objective:**
    1. Identify the effect on global stiffness with common sections
    2. Identify the mass reduction opportunity through gauge and section optimization



Rear header is re-located 200mm rearwards

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Rear Torsion Mode Effects

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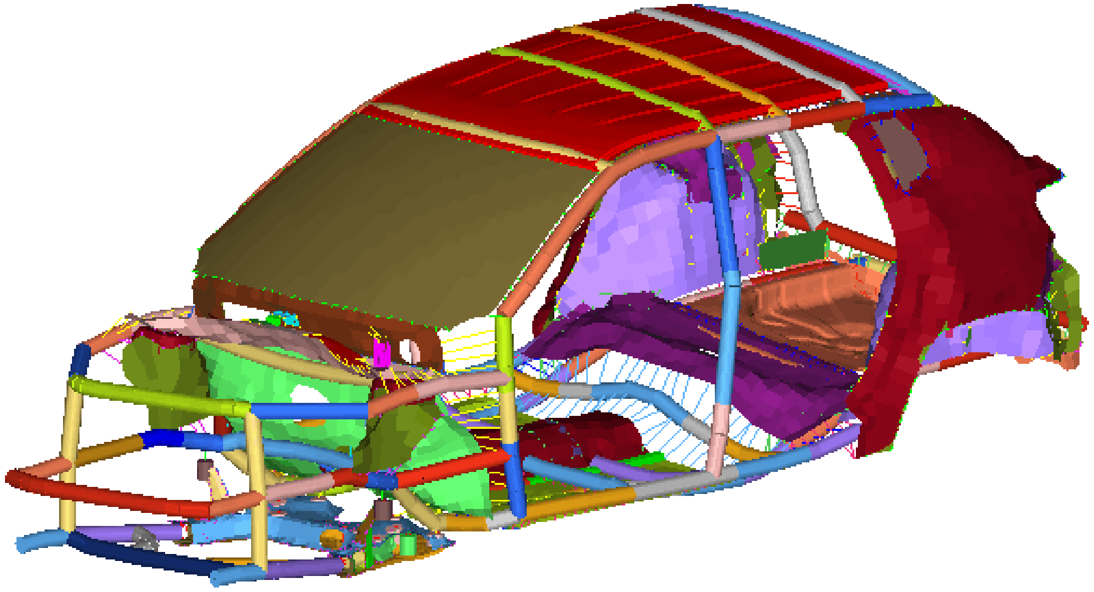
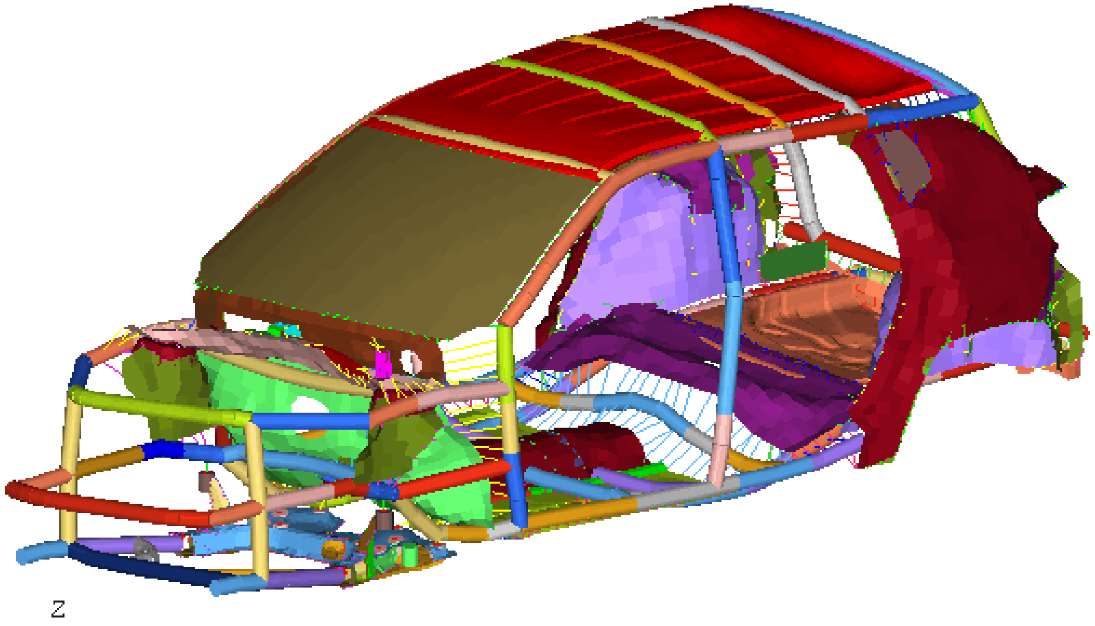
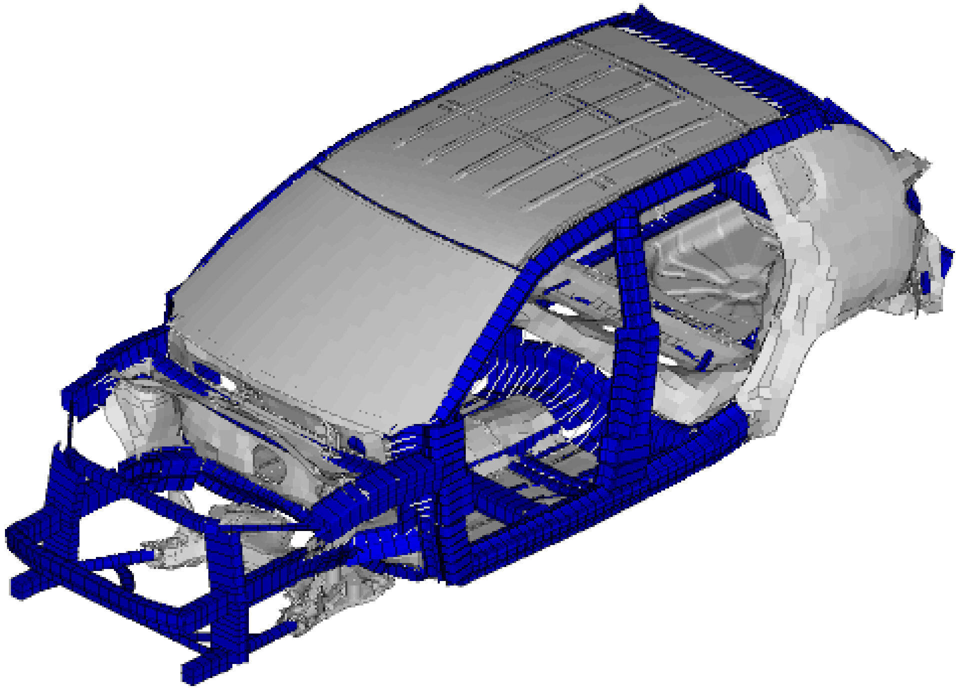




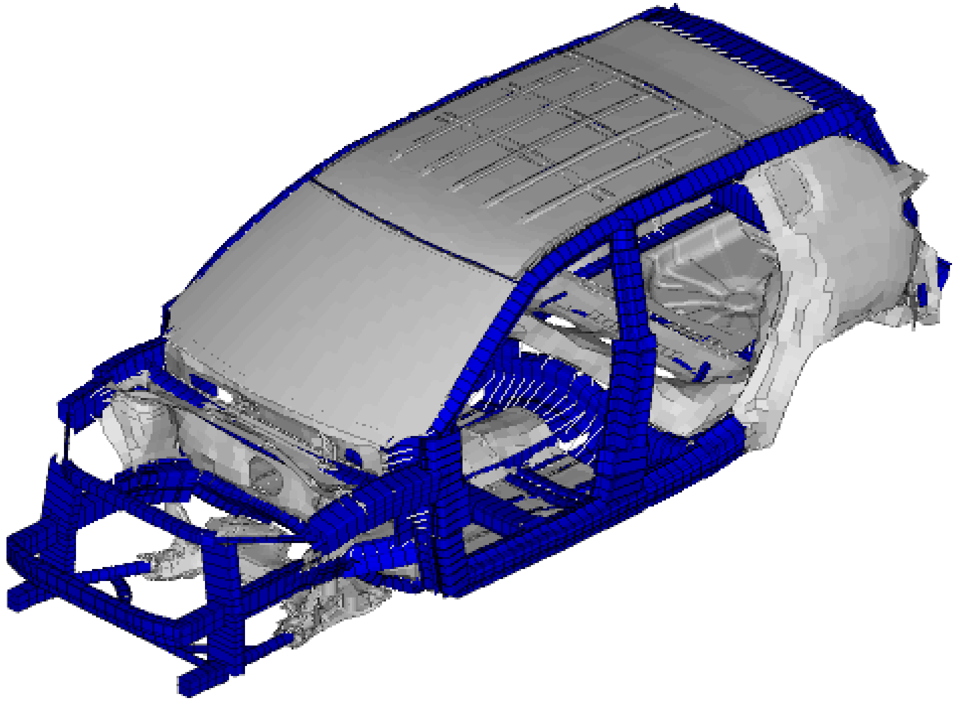
Baseline SLM

Modified Rear Header Location

Section Optimization Results

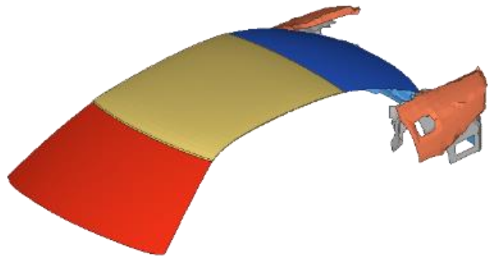


Baseline SLM

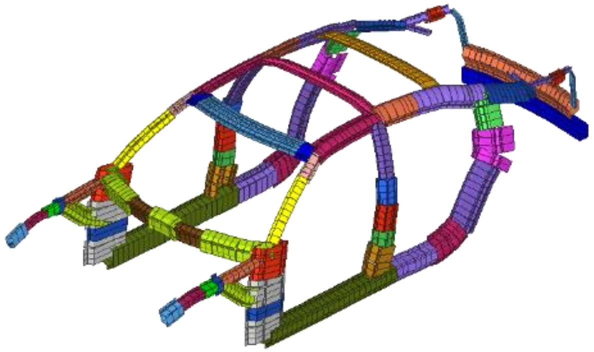


Modified Rear Header Location

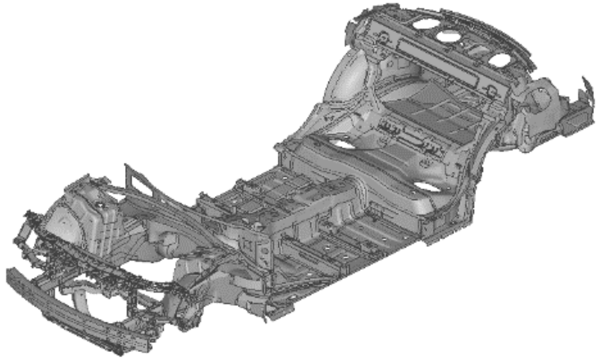
Upperbody Development Example



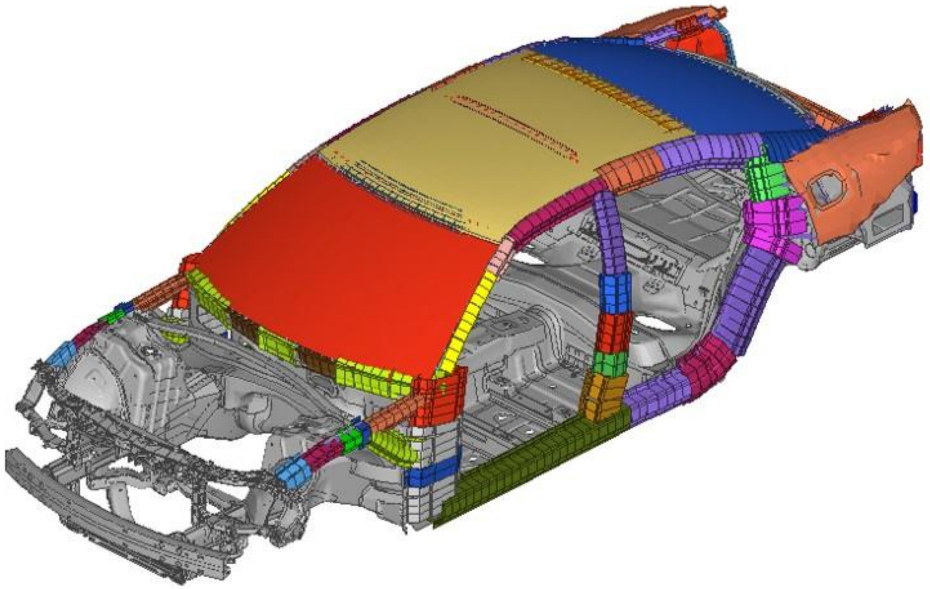
Upperbody
Closeout Panels



Upperbody
C2 Model



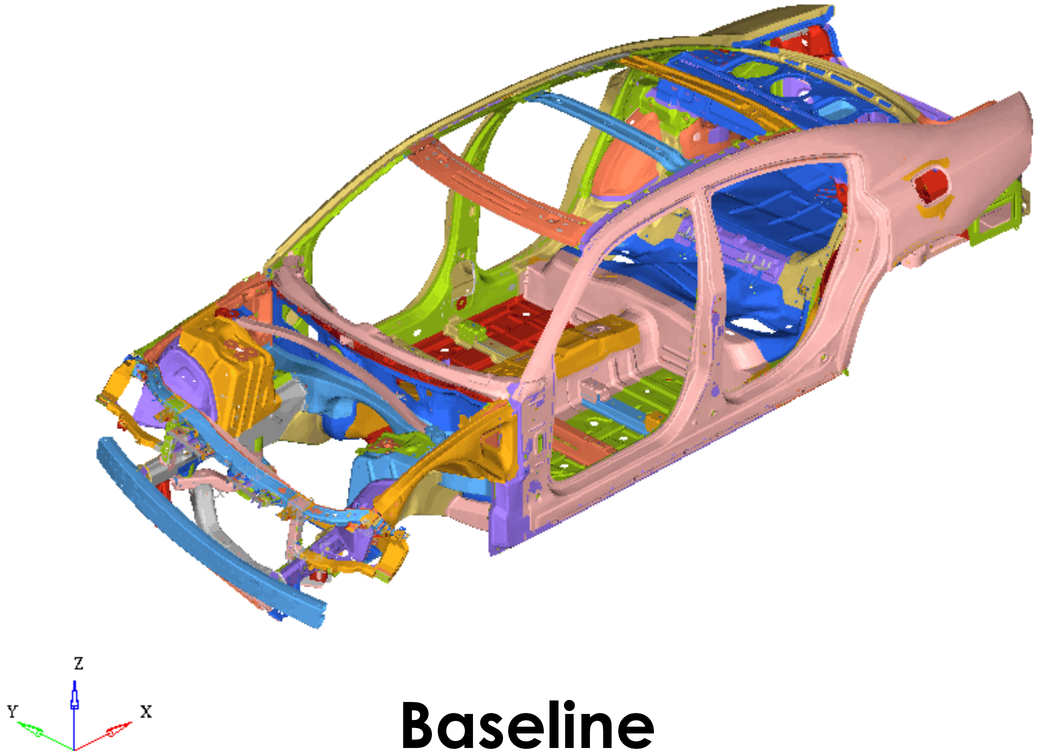
Underbody
Shell Mesh



Full BIW Model
Optimization-Ready

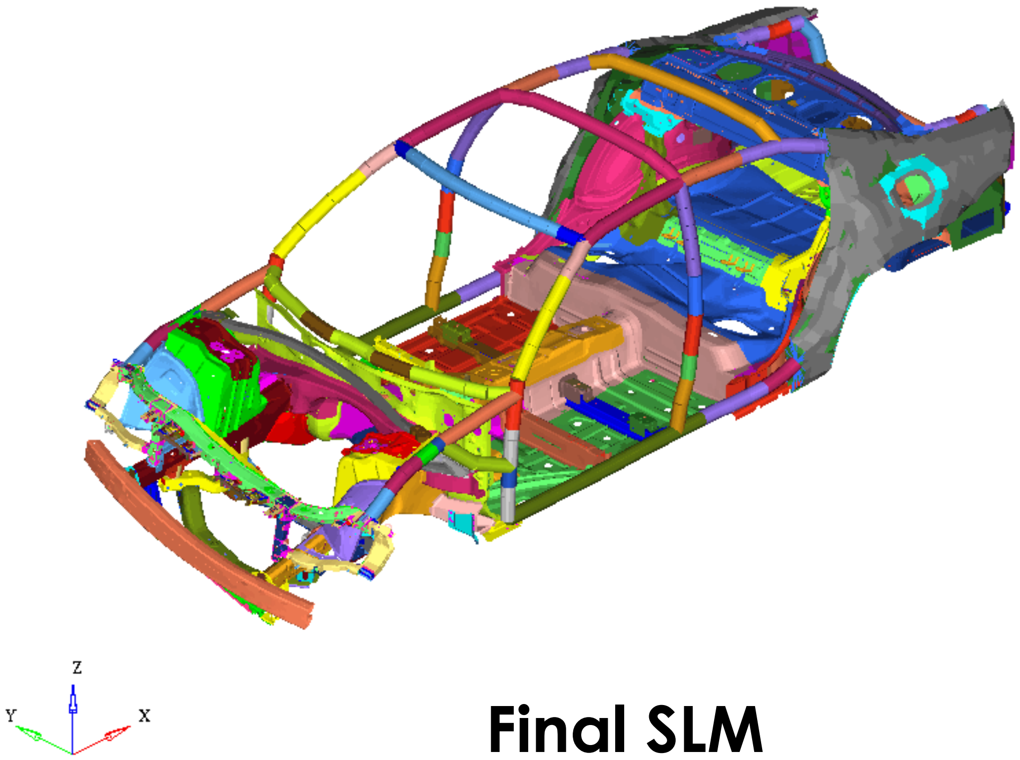
- Theme verification
- Material optimization
- Weight optimization

Front Torsion Mode



Baseline

+1.6Hz



Final SLM

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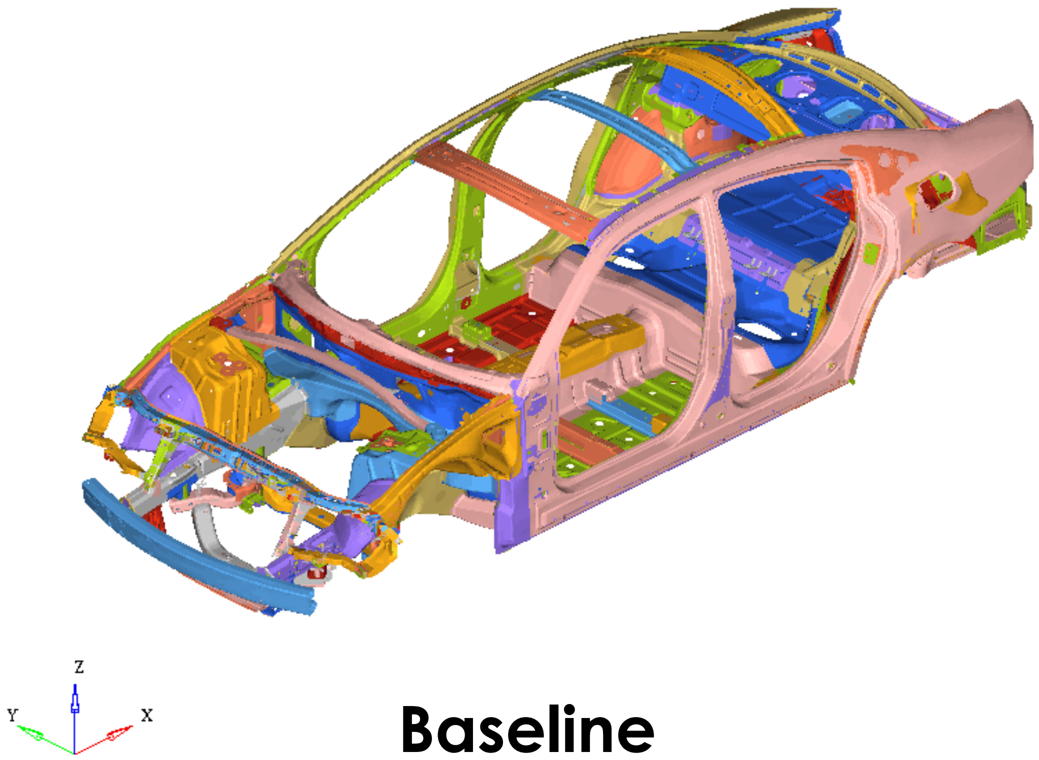
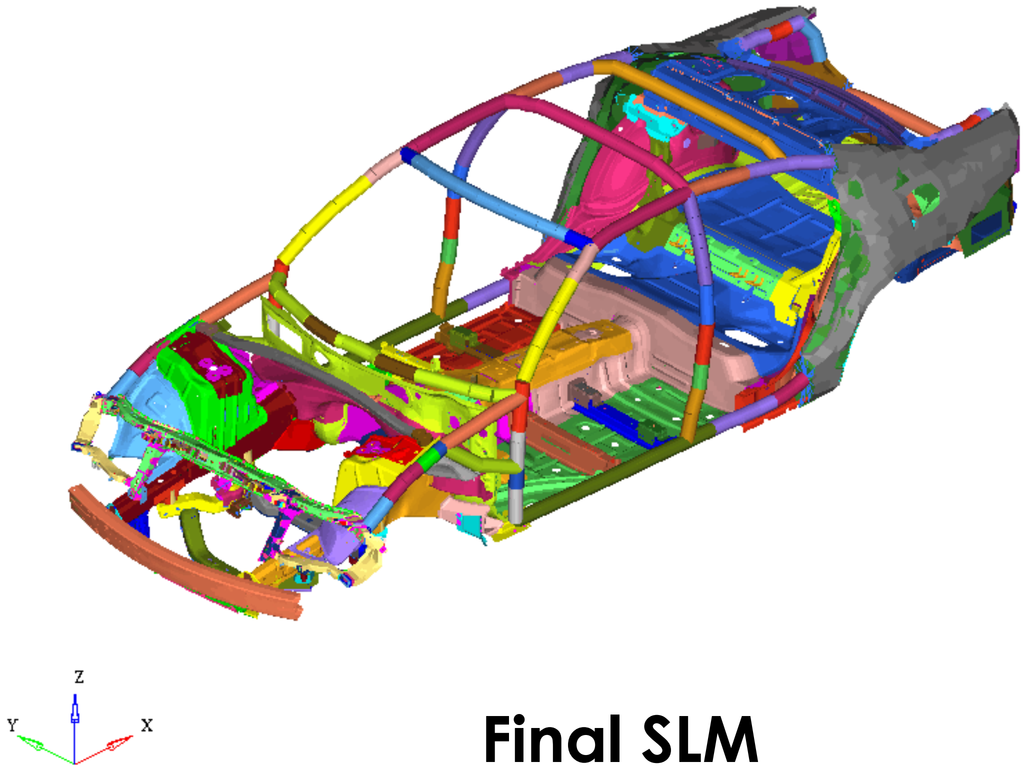
Front Vertical Bending Mode

-0.1Hz



Baseline



Final SLM

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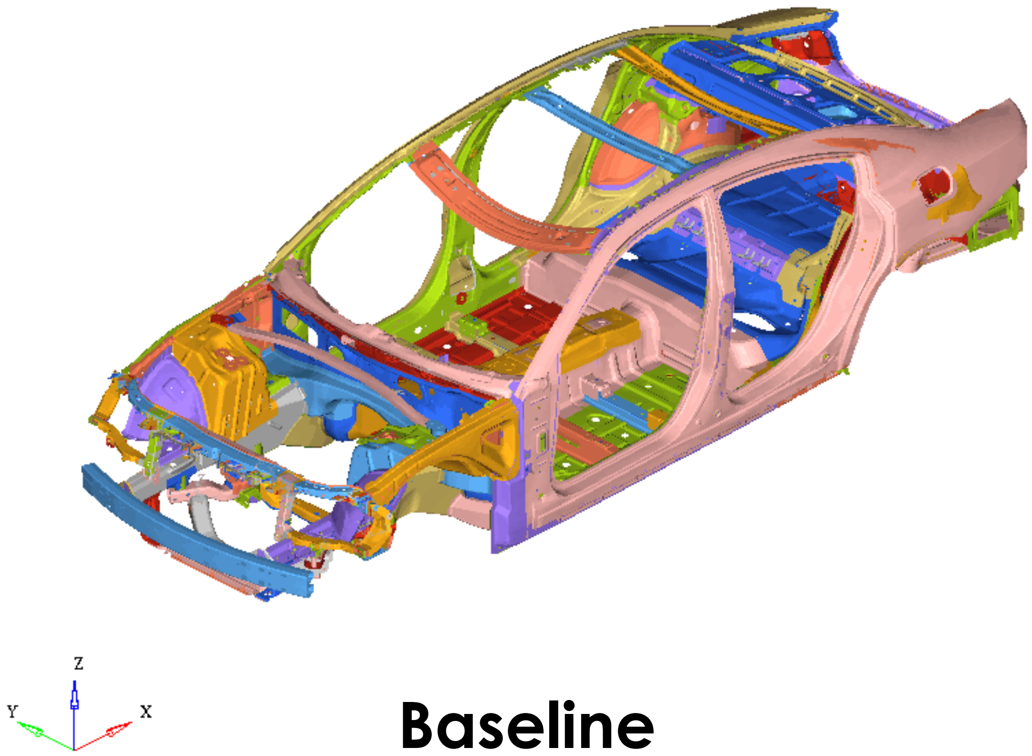
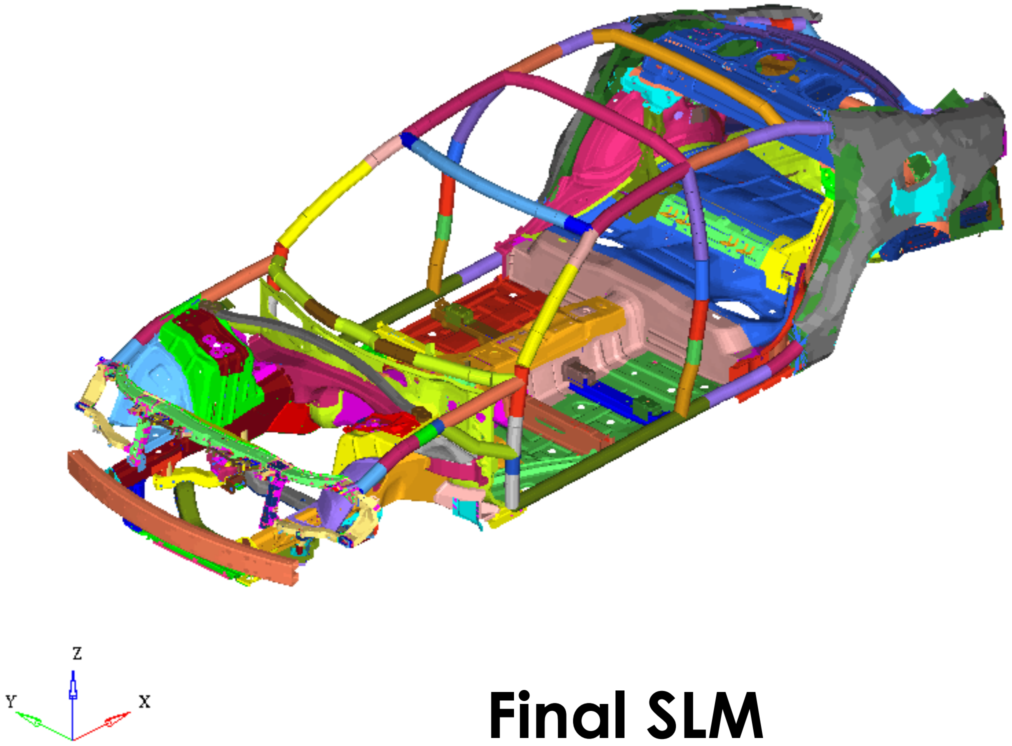
Rear Vertical Bending Mode

-2.2Hz



Baseline



Final SLM

Global Lateral Mode

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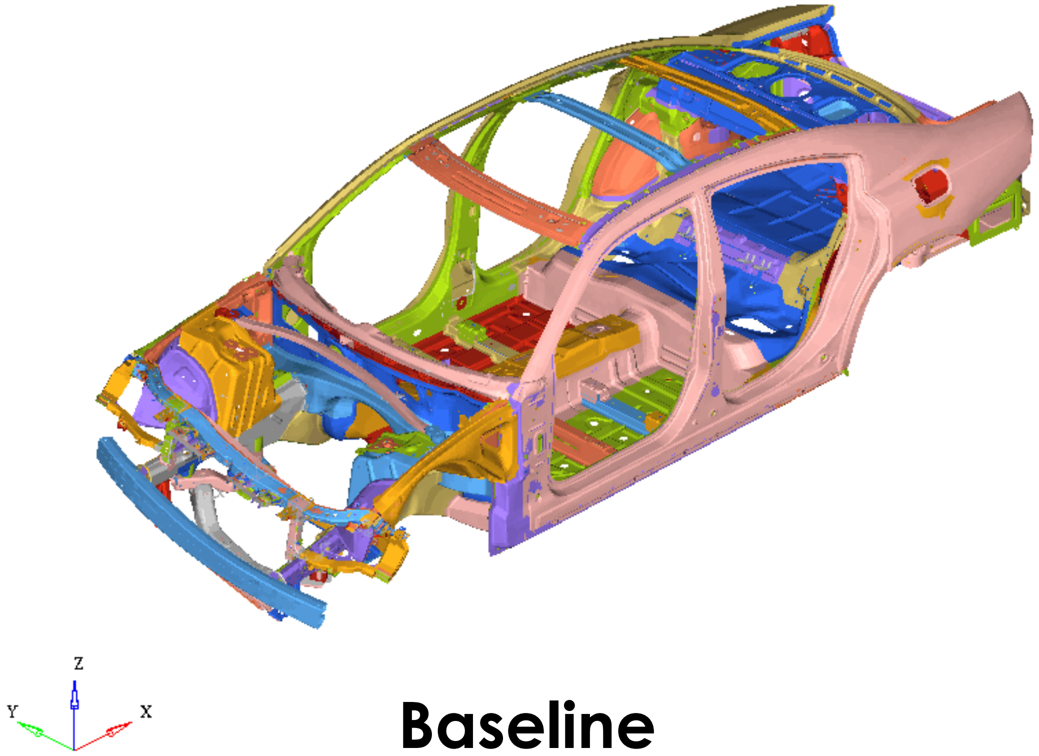
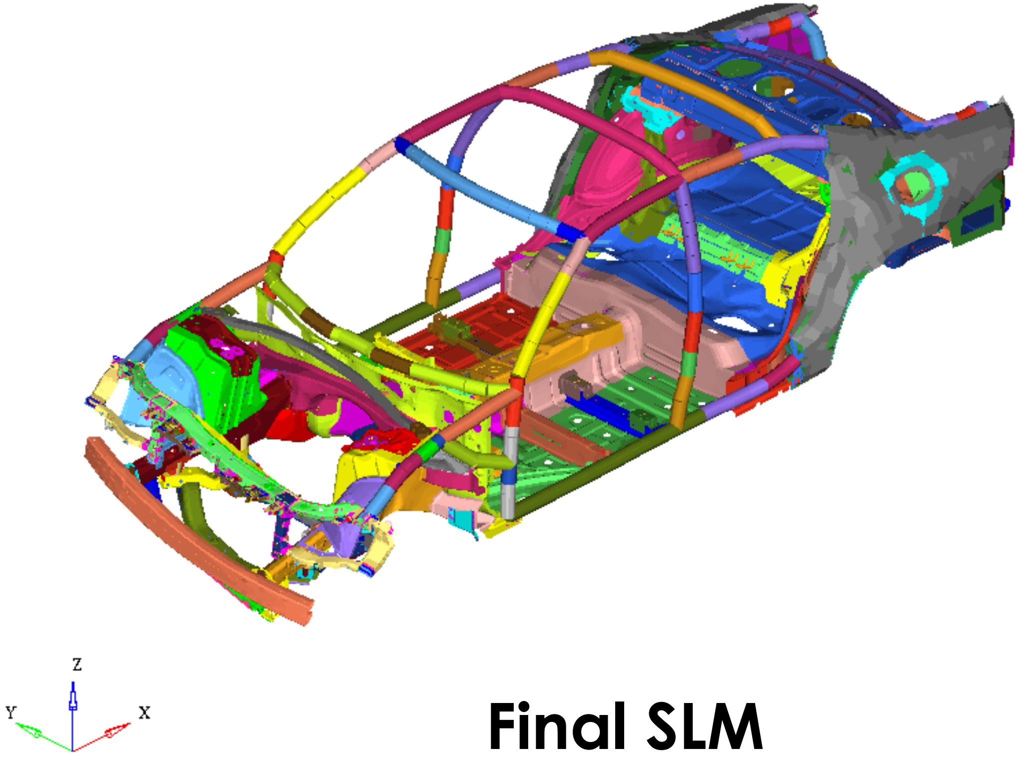
+2.2Hz



Baseline



Final SLM

Summary

FIAT CHRYSLER AUTOMOBILES

1. **Modern, advanced automotive body engineering requires state-of-the art tools and processes to yield time and mass efficiencies**
   - *Different tools are required for each phase of product development*

2. **Modern lightweighting requirements challenge BIW engineers to find every efficiency in the design**
   - *Increasing high strength steel utilization, leading to thinner gauges, motivate upfront tools to solve NVH issues before they arise in the development process*

3. **FCA US LLC has a broad toolbox of design tools to optimize the BIW system**
   - *First order tools evolve and mature into concept validation models*
   - *Accurate simplified loadpath models lead to a better optimized body structure*

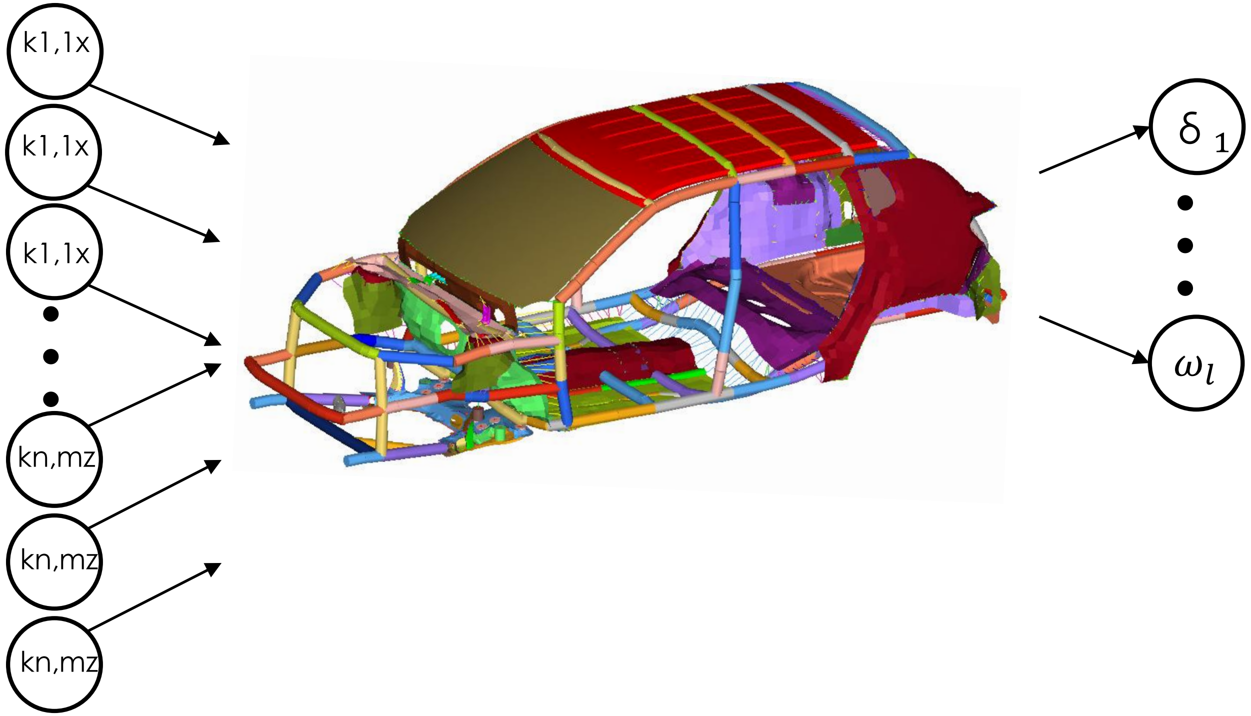
Avenues for Future Work

Standardize loadcases and accuracy requirements for SLMs

- *Identify most suitable loadcases for local and global body stiffness correlation*
- *More advanced correlation metric for modeshapes (e.g. MAC)*

Explore sensitivity of responses to changes in joint stiffness

- *DOE with joint directional stiffnesses as inputs*
- *Body stiffness metrics as outputs*
- *Rank importance of joints and directional stiffnesses for each loadcase*



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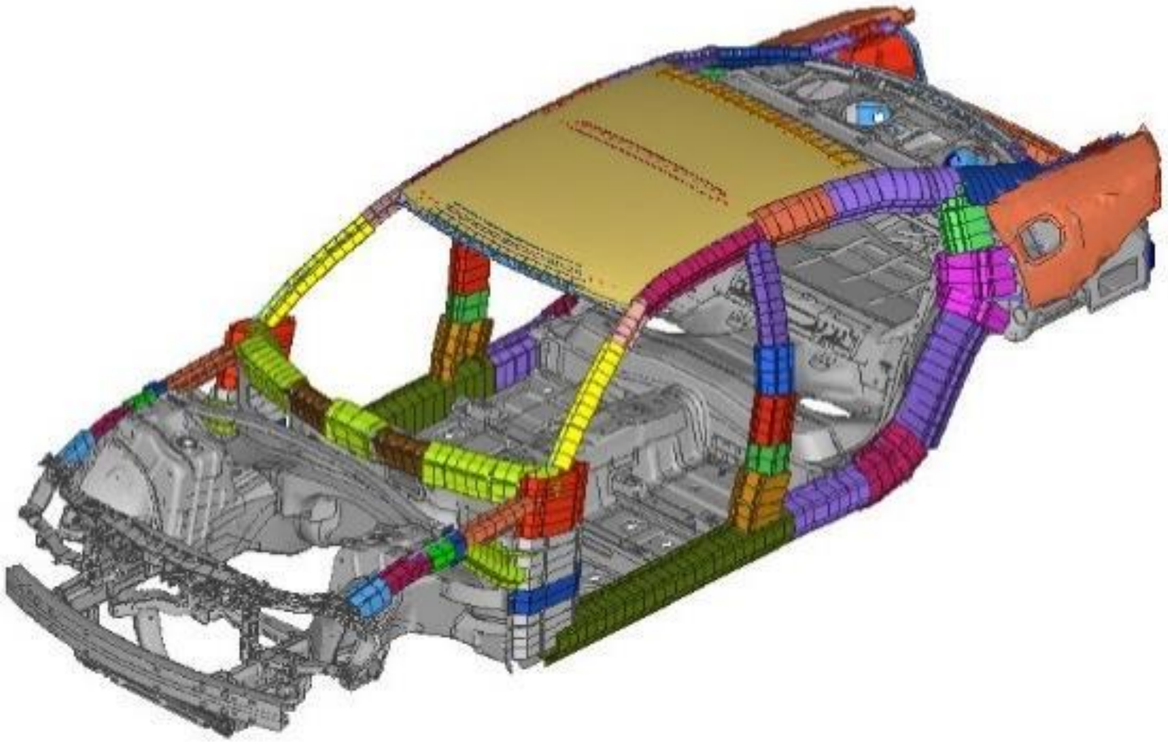

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