Cross Member Multi-Station Assembly – Case Study

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Digital Lifecycle Management (DLM) Research Group

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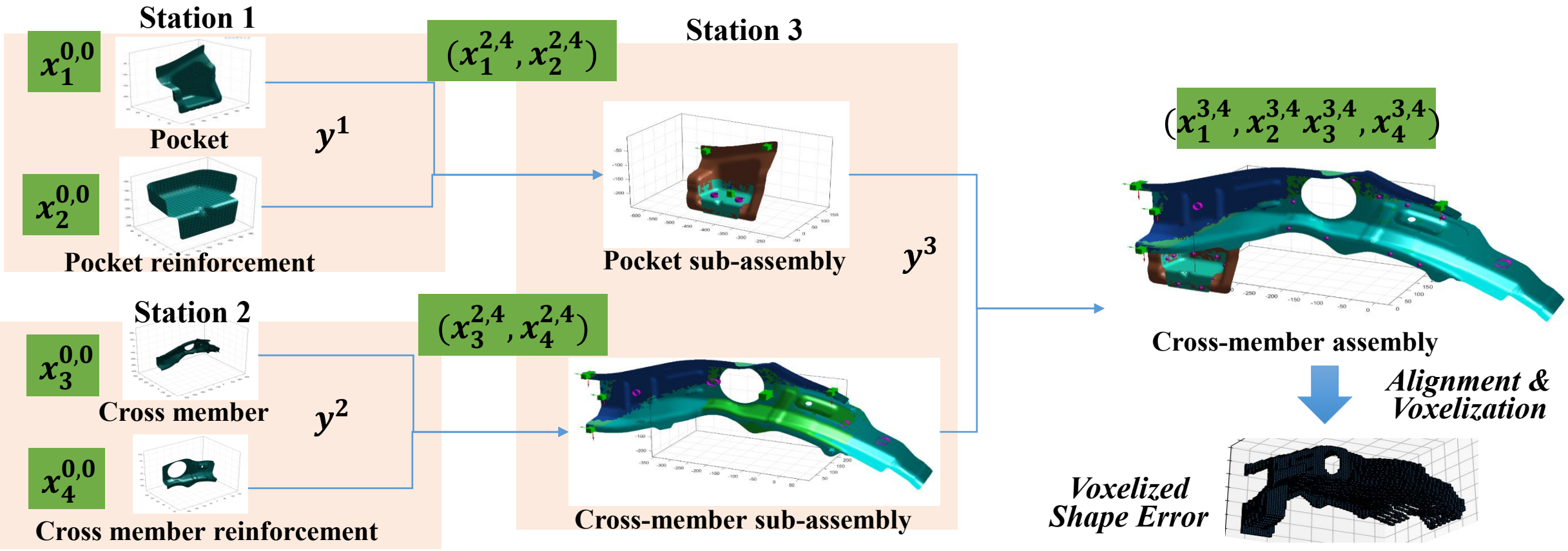
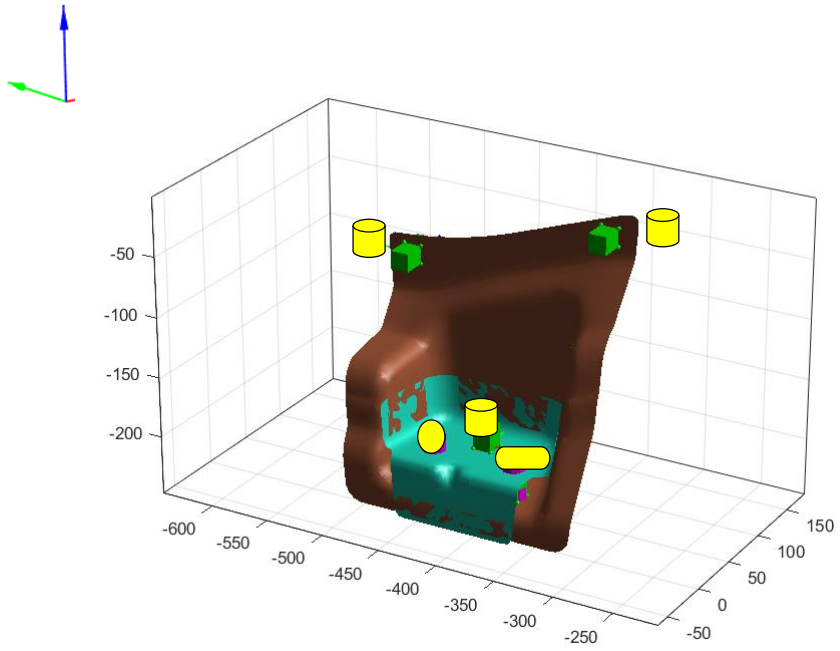
Multi-Station Cross Member Assembly

4 part, 3 station cross-member assembly is used for verification and validation of the model

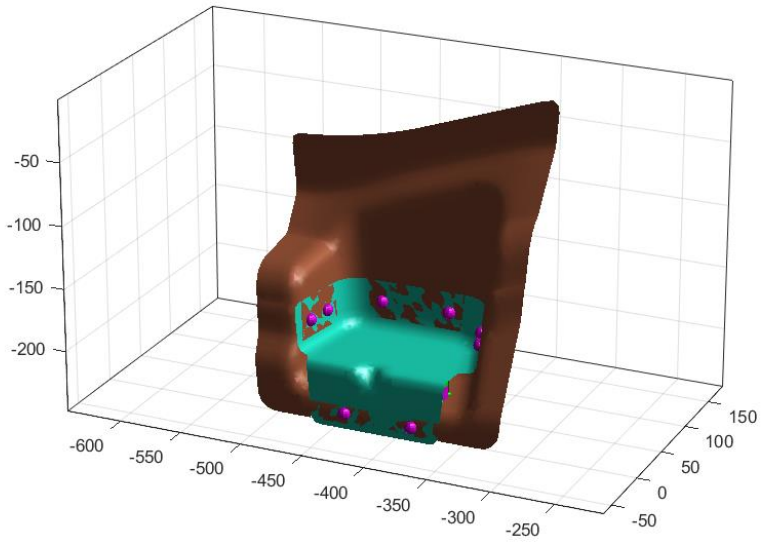


CROSS MEMBER ASSEMBLY

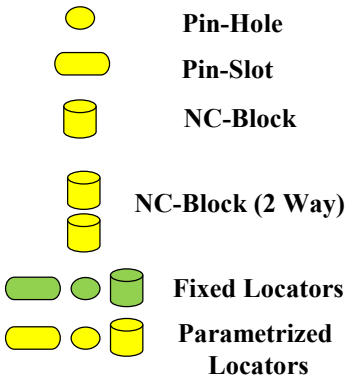
Station 1: Pocket and Pocket Reinforcement Assembly



Stage 1: Positioning , *Stage 2*: Clamping

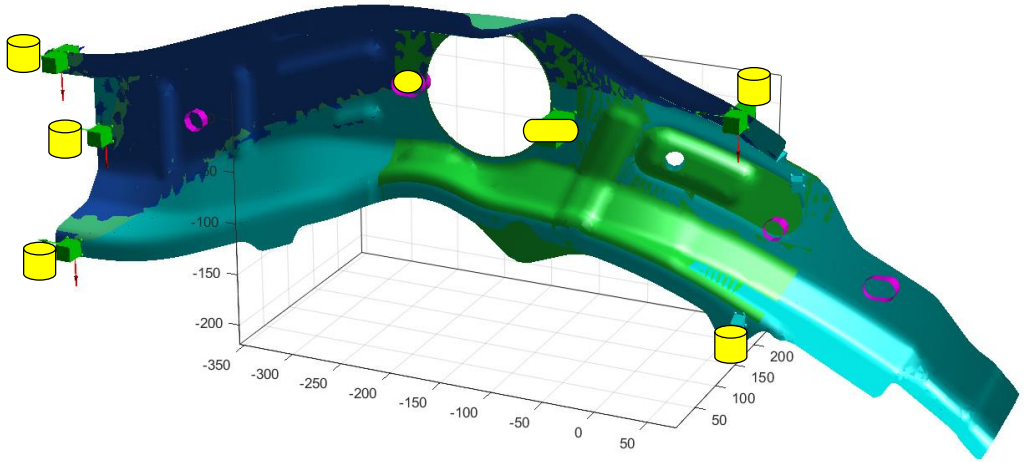


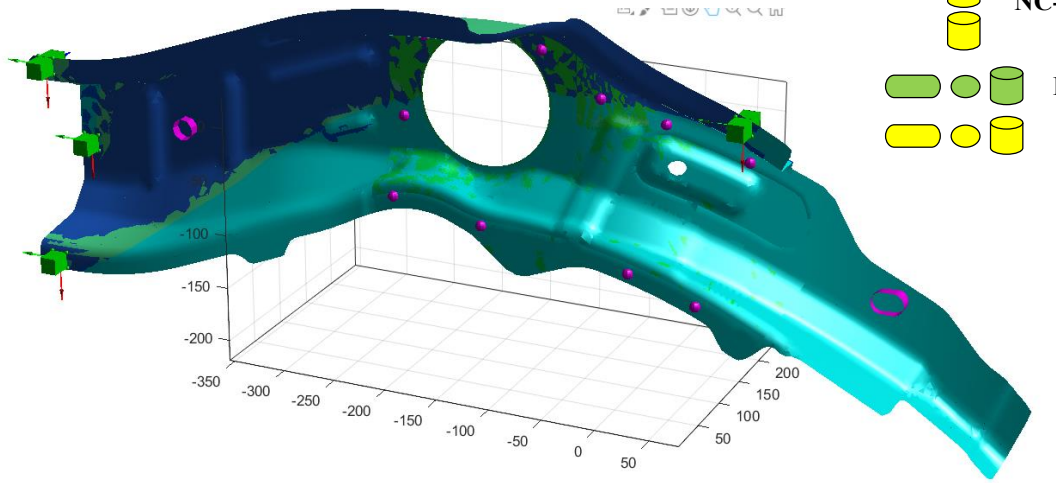
Stage 3: Fastening , *Stage 4*: Release

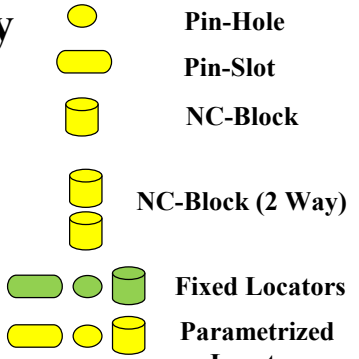


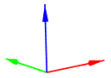
CROSS MEMBER ASSEMBLY

Station 2 (Non-Ideal Parts): Cross Member and Cross Member Reinforcement Assembly







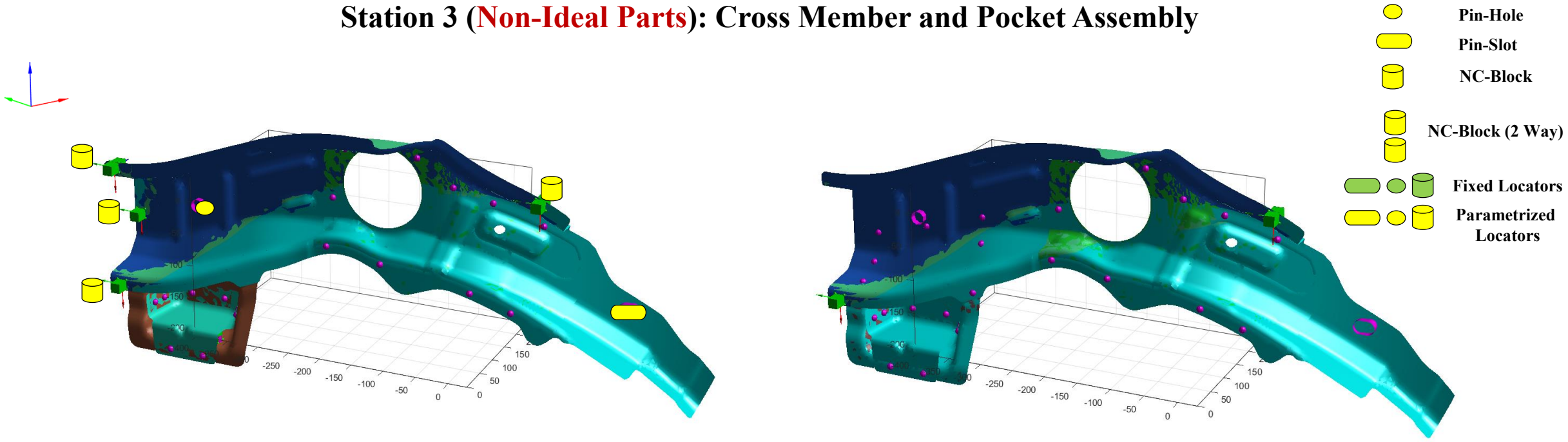


Stage 1: Positioning , *Stage 2*: Clamping

Stage 3: Fastening , *Stage 4*: Release

CROSS MEMBER ASSEMBLY

Station 3 (Non-Ideal Parts): Cross Member and Pocket Assembly



Stage 1: Positioning , *Stage 2*: Clamping

Stage 3: Fastening , *Stage 4*: Release

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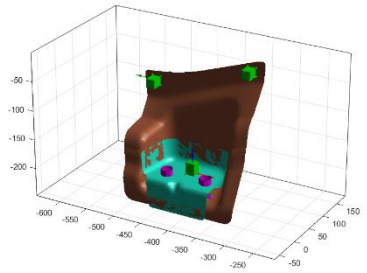
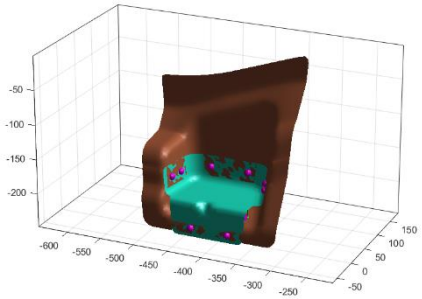
CROSS MEMBER ASSEMBLY

Station 1: Pocket and Pocket Reinforcement Assembly – 48 Process Parameters



Stage 1: Positioning , *Stage 2*: Clamping



Stage 3: Fastening , *Stage 4*: Release

Stage ID	Process Parameter	# Process Param	Description
Non-Ideal (Stage 0)	Displacement of control point With large correlation length	1 Process Parameter	Part Variation (Part 1), Global effect
Non-Ideal (Stage 0)	Displacement of control point with a small correlation length	1 Process Parameter	Part Variation (Part 1), Local effect, Bending of flange
Non-Ideal (Stage 0)	Displacement of control point With large correlation length	1 Process Parameter	Part Variation (Part 2), Global effect
Non-Ideal (Stage 0)	Displacement of control point with a small correlation length	1 Process Parameter	Part Variation (Part 1), Local effect, Bending of flange
Positioning (Stage 1)	Pinhole, Pinhole	3 Process Parameters	Positioning (in plane movement)
Clamping (Stage 2)	Clamp (x,y and z) displacement	3*3=9 process parameters	Clamping
Fastening (Stage 3)	Tool Displacement in x,y and z direction	8*3=24 process parameters	Joining tool
Fastening (Stage 3)	Joint failure if Gap > threshold	8 binary variables for successful joints	Joining Tool

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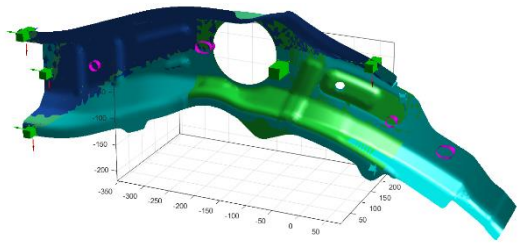
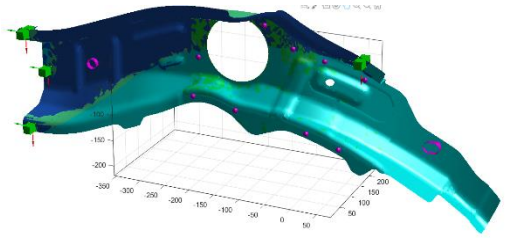
CROSS MEMBER ASSEMBLY

Station 2: Cross Member and Cross Member Reinforcement Assembly – 65 Process Parameters



Stage 1: Positioning ,
Stage 2: Clamping



Stage 3: Fastening ,
Stage 4: Release

Stage ID	Process Parameter		Description
Non-Ideal (Stage 0)	Displacement of control point With large correlation length	1 Process Parameter	Part Variation (Part 1), Global effect
Non-Ideal (Stage 0)	Displacement of control point with a small correlation length	1 Process Parameter	Part Variation (Part 1), Local effect, Bending of flange
Non-Ideal (Stage 0)	Displacement of control point With large correlation length	1 Process Parameter	Part Variation (Part 2), Global effect
Non-Ideal (Stage 0)	Displacement of control point with a small correlation length	1 Process Parameter	Part Variation (Part 2), Local effect, Bending of flange
Positioning (Stage 1)	Pin-Hole and Pin-slot	3 Process Parameters	Translation of pin hole and translation about pin-slot (rotation around pin hole)
Clamping (Stage 2)	x,y and z displacement of each clamp	**4*3=12 (Clamp S)**+2*3=6 (Clamp M) - 18	Clamping deviations of nominal
Fastening (Stage 3)	Tool Displacement in x,y and z direction	10*3=30 process parameters	Joining tool
Fastening (Stage 3)	Joint failure if Gap > threshold	10 binary variables for successful joints	Joining Tool

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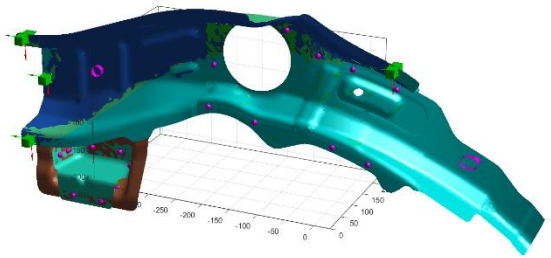
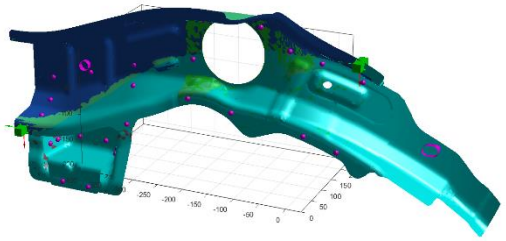
CROSS MEMBER ASSEMBLY

Station 3: Cross Member and Pocket Assembly – 43 Process Parameters



Stage 1: Positioning , *Stage 2*: Clamping



Stage 3: Fastening , *Stage 4*: Release

Stage ID	Process Parameter	# Process Params	Description
Positioning (Stage 1)	Pinhole, Pinslot	3 Process Parameters	Positioning (in plane movement)
Clamping (Stage 2)	Clamp (x,y and z) displacement	4*3=12 process parameters	Clamping
Fastening (Stage 3)	Tool Displacement in x,y and z direction	7*3=21 process parameters	Joining tool
	Joint failure if Gap > threshold	7 binary variables for successful joints	Joining Tool

Total: 158 Process Parameters

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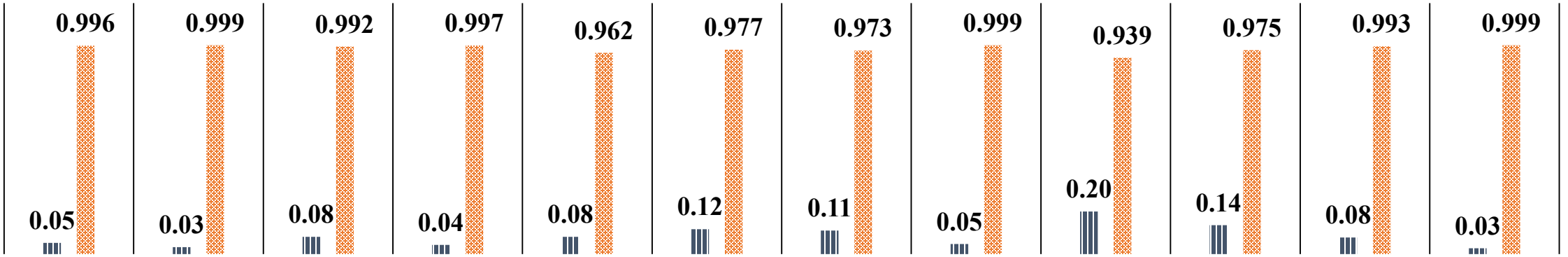
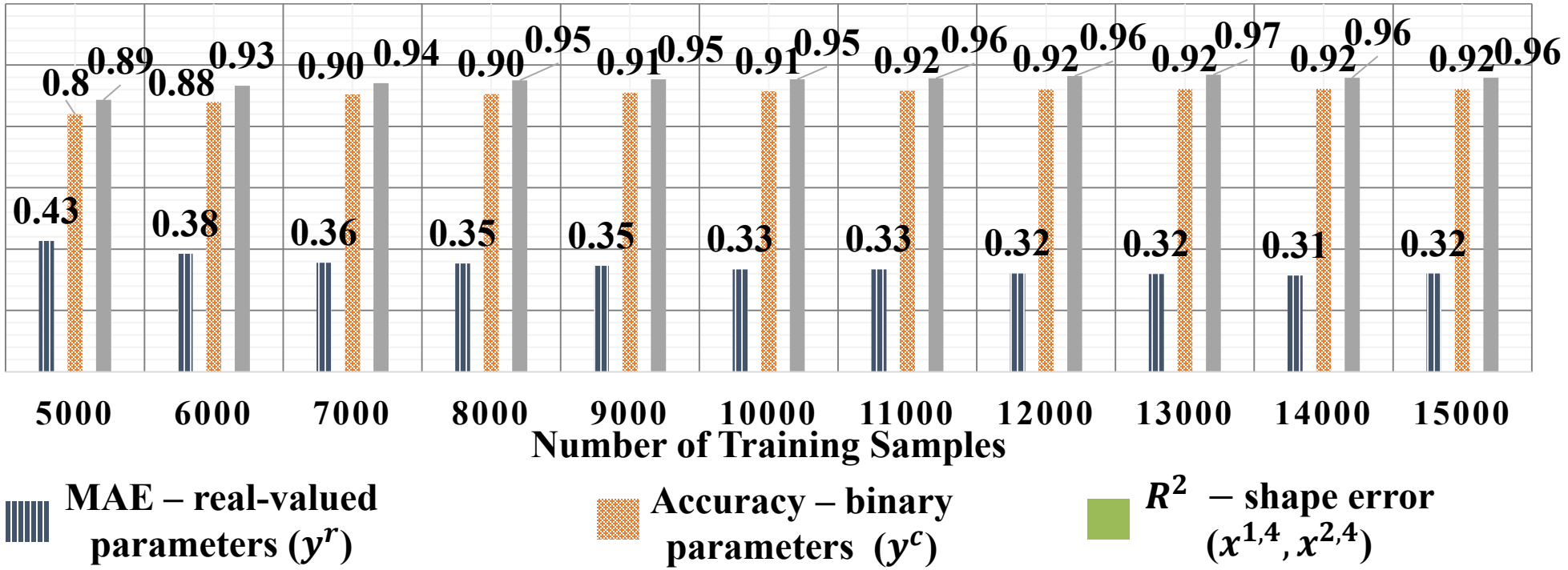
OSER Process Parameter Estimation Performance



The Average MAE across all process parameters is 0.08 mm and the Average R^2 is 98% at 100% Fault Multiplicity

OSER CONVERGENCE STUDY



data_study_plot_test.html

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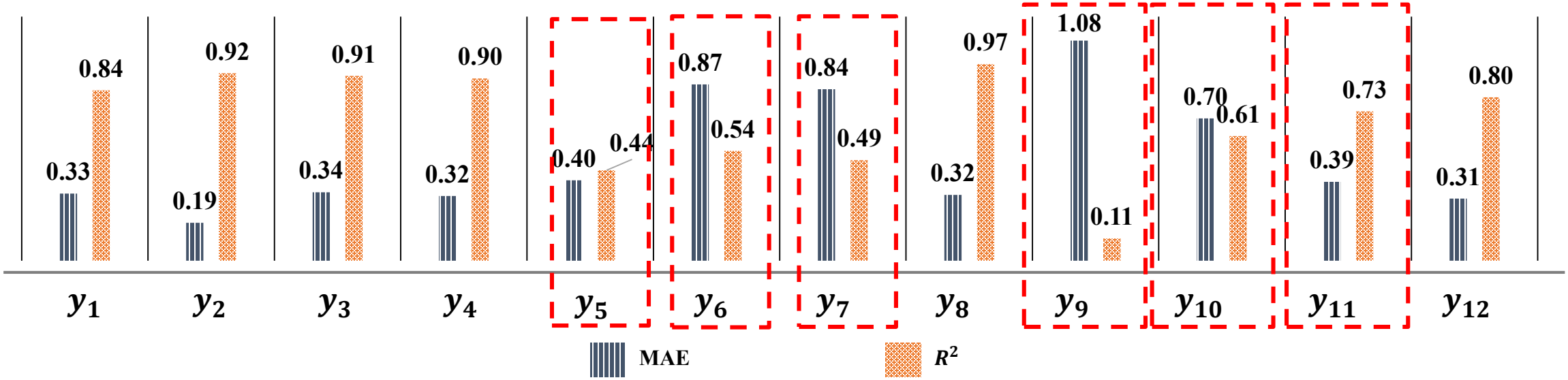
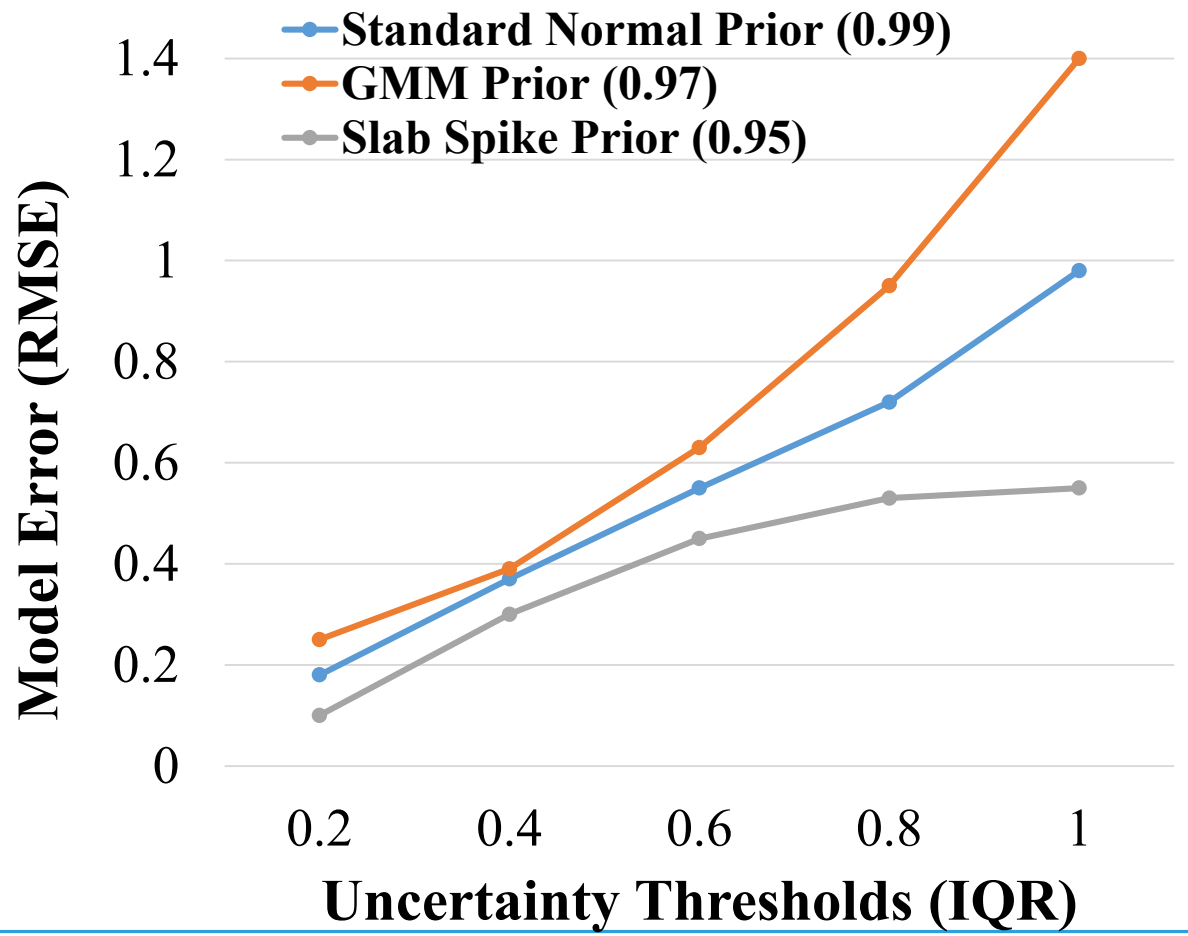
OSER OUT-OF-RANGE PROCESS PARAMETER ESTIMATION ACCURACY



- **Given the Multi-Station process the model Out-of-range performance capabilities are up to 70%**
- **Given the non- continuous non- linearity of the process under different ranges of process parameters as compared to the continuous non-linearity of single stage assemblies**
- **This can be improved by adding training samples for a larger range**
- **The Extrapolation capabilities were up to 90% in a single station assembly**

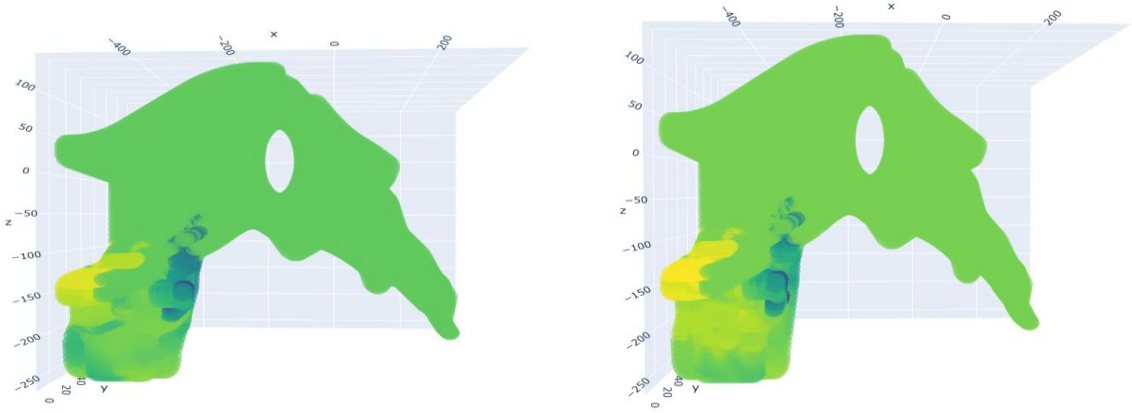
UNCERTAINTY QUANTIFICATION



Results

The average MAE across all process parameters is 0.08 mm and the Average R^2 is 98% at 100% Fault Multiplicity

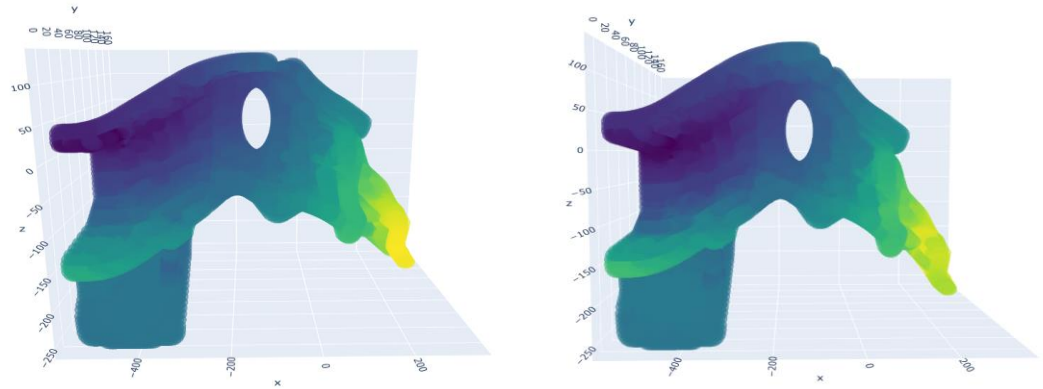
Object Shape Error Estimation accuracy for previous stages is at $RMSE = 0.0012$ and $R^2 = 0.96$



Actual *Predicted*

Station S_1

MAE	**0.0002 mm**
RMSE	**0.002 mm**
R^2	**0.97**
R^2 Adjusted	**0.97**



Actual *Predicted*

Station S_2

MAE	**0.0012 mm**
RMSE	**0.014 mm**
R^2	**0.96**
R^2 Adjusted	**0.96**

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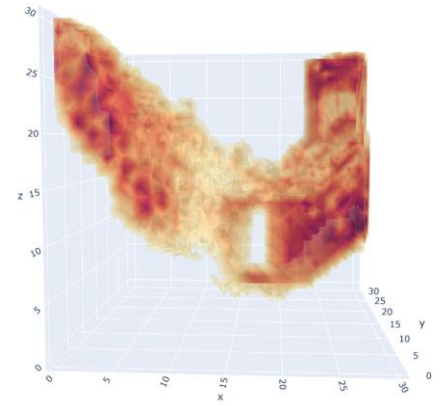
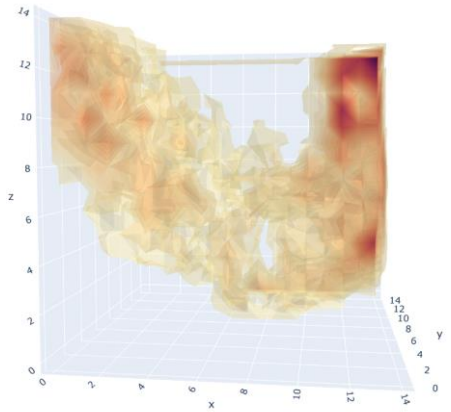
Gradient and Feature Maps

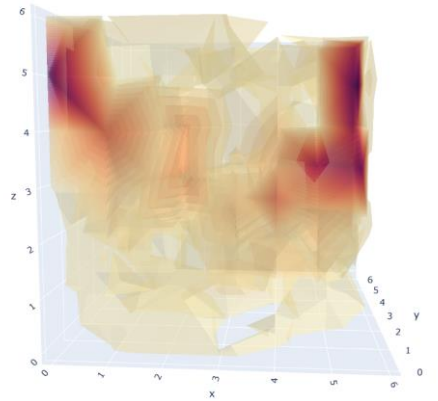
Feature Maps



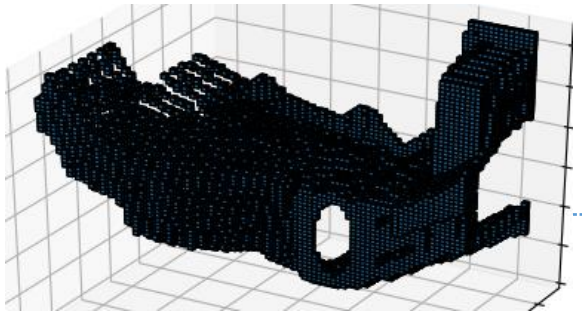
Convolutional Block 1



Convolutional Block 2

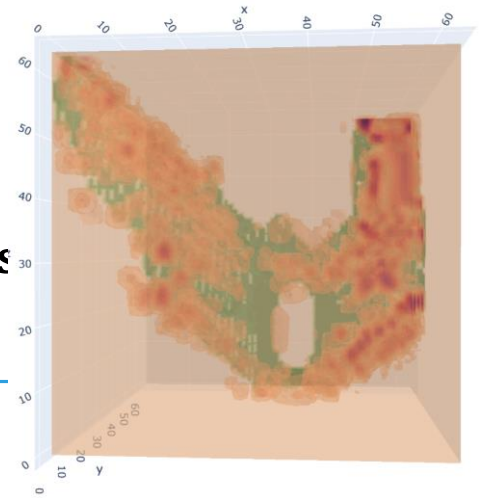


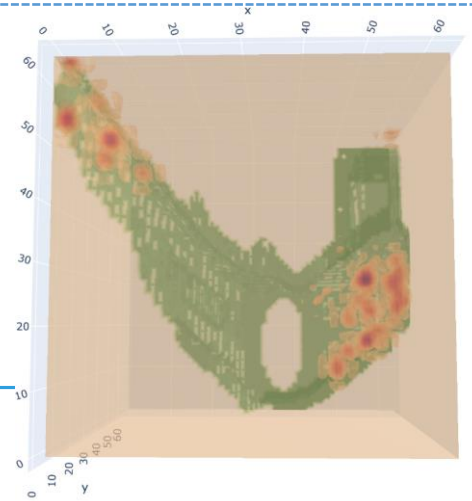
Convolutional Block 3

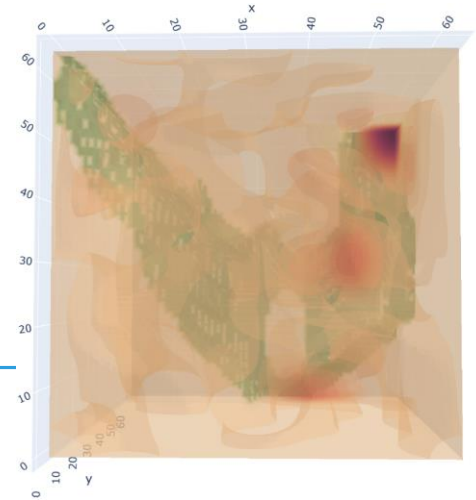


Voxelized Input

Network Gradients







$y_1 = 2$ (all other process parameters $= 0$)

Thank-you

Digital Lifecycle Management (DLM) Research Group

Please contact Sumit Sinha (email: sumit.sinha.1@warwick.ac.uk) in case of any doubts

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