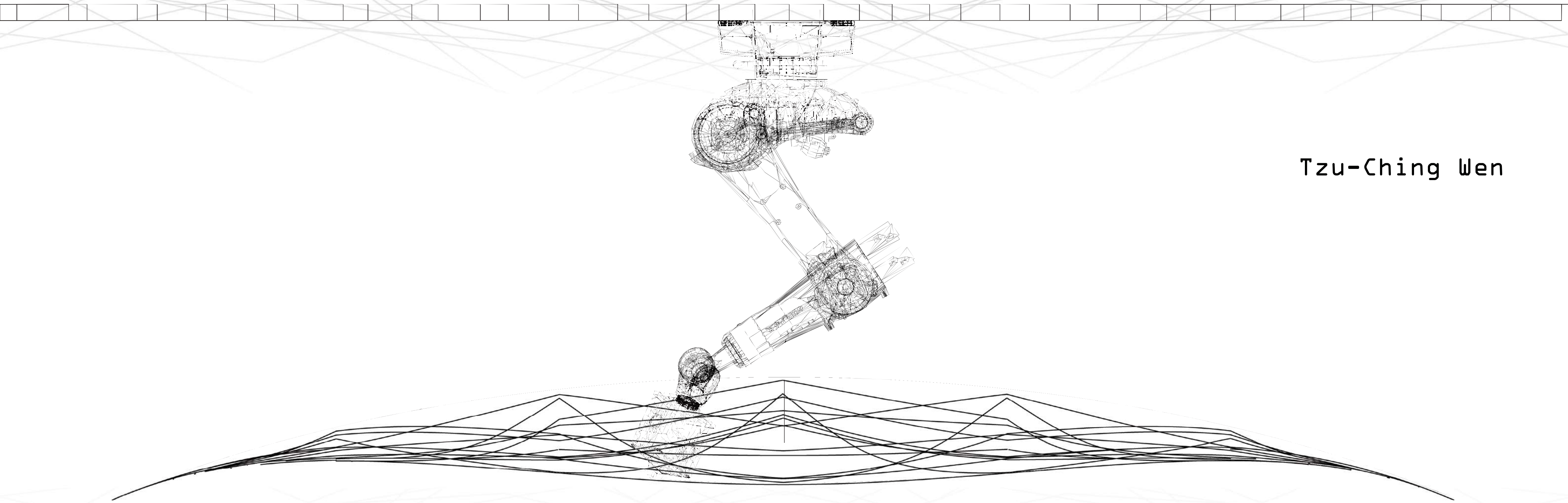
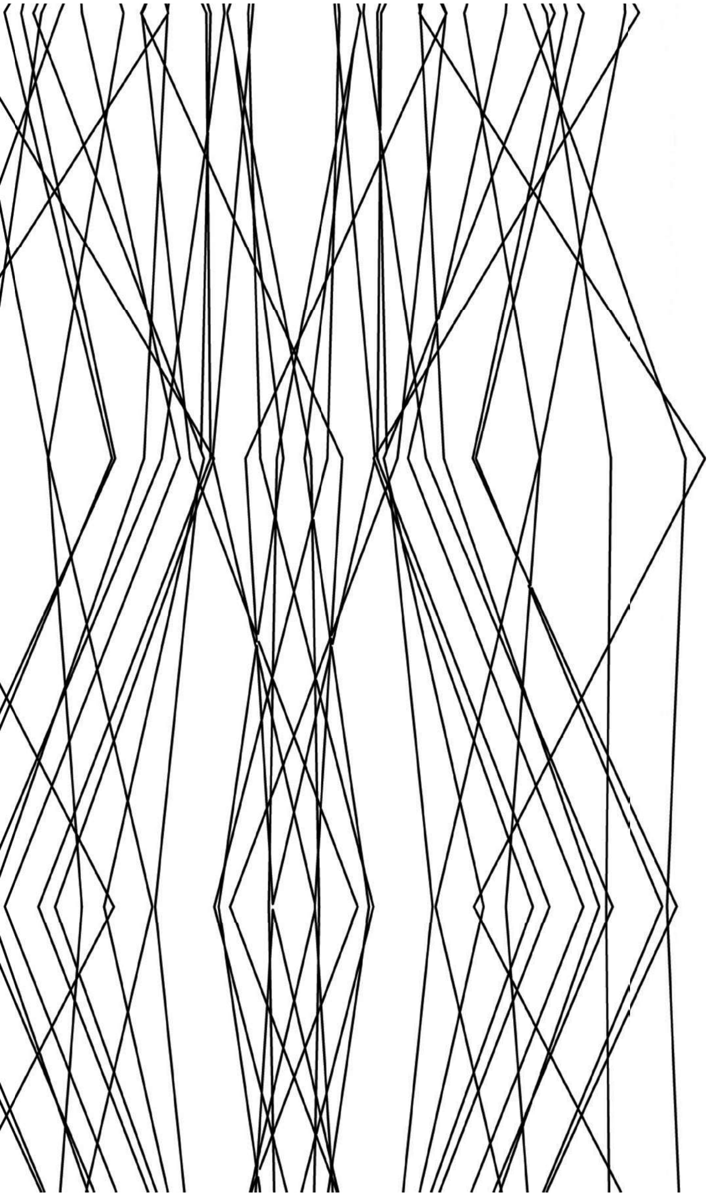


Tzu-Ching Wen

Multiple Supervised Machine Learning Driven Methods in Predicting the Performance of Single-Span Slab Structure and Visualization of Robotic Fiber Trajectory



INSPIRATION

We might all remember the most noticed human-robot chess match, Alphago vs. Lee Seldo in early 2016. Alphago is the human-trained Neural Network Algorithm. Lee Seldo is a professional GO player with 9 dan rank, which ranked as one of the best Go players in the world.

The matches between Lee Seldo and Alphago had run one per day after one, total in 5 matches. Lee Seldo was defeated by Alphago 1-4 in a series in the end. From the matches, there were several surprising moves from Alphago, the Move 37 for example is the most terrific, unusual, and non-easy understandable move from Alphago. This move was also the turning point of that match, which successfully turned a disadvantageous situation into a win situation, dominating the whole match against Lee Seldo.

Numeral cases ML Algorithms could search unusual but useful patterns from raw data and the whole training process, which won't easily be noticed and distinguished from the human perspective. This fully inspires and motivates us to explore the field of Machine Learning applications, especially in the architectural sector.

GOAL

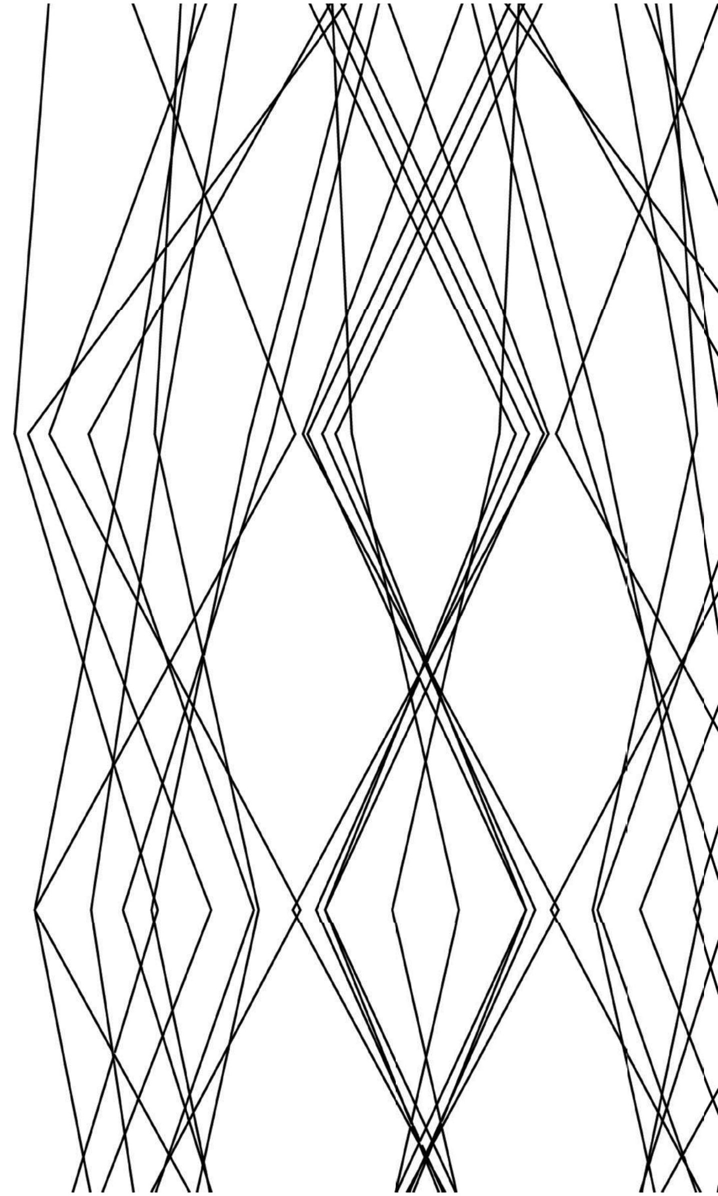
+ To explore the potential by using Machine Learning Algorithm to predict the structural performance without using FEM

  -> accelerate the design process between Design and Structural Simulation
  -> implement the trained model into portable lightweight edge devices

+ Improve the communication between multiple platforms

+ Visualized the Robotic Path for the fabrication Process to

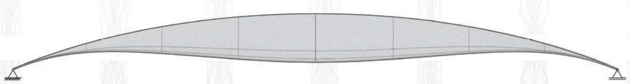
  improve the User Interface



DEFINITION OF ANALYSIS OBJECT

1 Boundary Condition
2 Front View
3 Top View - Reference Surface
4 Top View - Carbon Fiber Slab
5 Carbon Fiber Slab
6 Reference Surface

1



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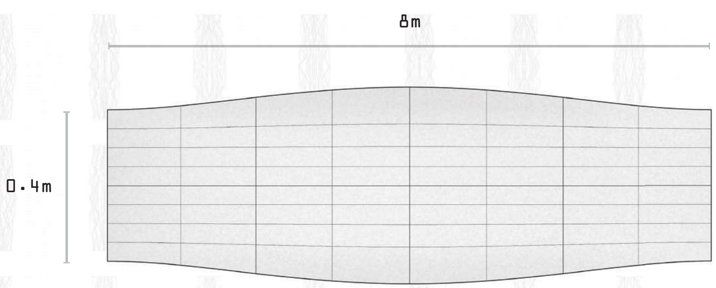

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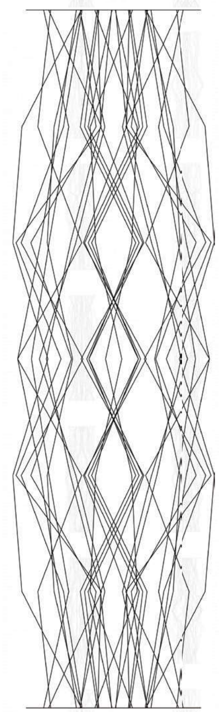

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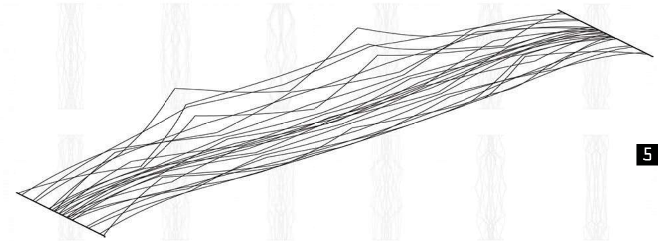

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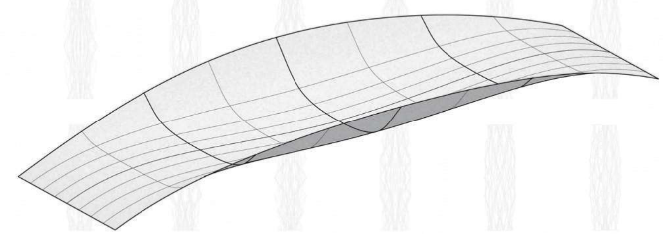
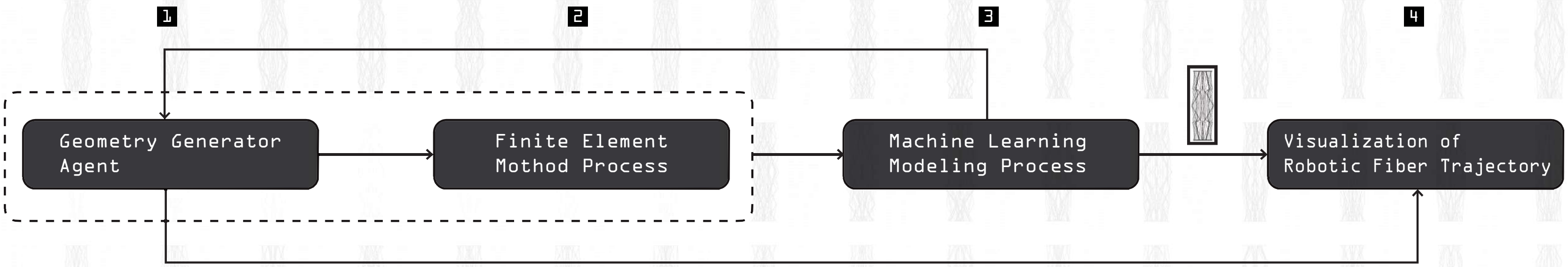


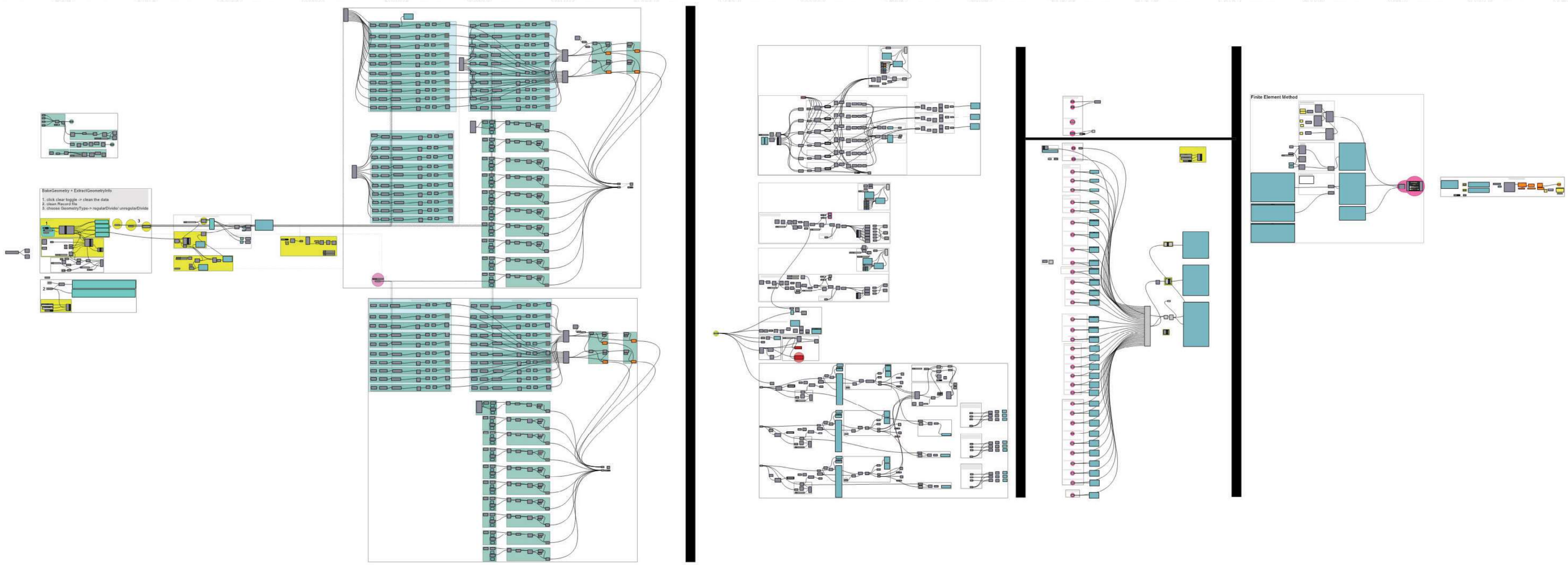
6

SCOPE



	1	2	3	4
Tasks	+Define Parameters of Slab Geometry +Develope 2 Geometry Generator Agents +Generate 220 Various Fiber Layout Geometries +Define Geometry Features +Features Extraction Process +Generate Training & Testing Dataset	+Sending Each Geometry into Sofistik +Run simulation & extract Simulation Results into Grasshopper +Features data collection +Generate training data (CSV file) for machine learning to train	+Data preprocessing +Identify & handling missing values + encod-ing categorical data +Features correlation analysis & selection +Splitting dataset into training & testset +Features scaling +Machine learning algorithm modeling & training +Use trained model to predict new geometries	+KUKA PRC Command Construction +KRL Code Anaylysis +Geometries Redraw +Rhino Viewport HUD
Language	C# Python	C#	Python	Python
Platform	Rhino Grasshopper	Sofistik	Google Colab Jupyter Notebook	Kuka PRC

Geometry Generator Agents: Carbon Fiber Slab



1 +Two Type of Geometry Generator Agents
-> Generate Slab Variations
+constant division type
+non-constant division type

2 +Define & Extract Geometry Features

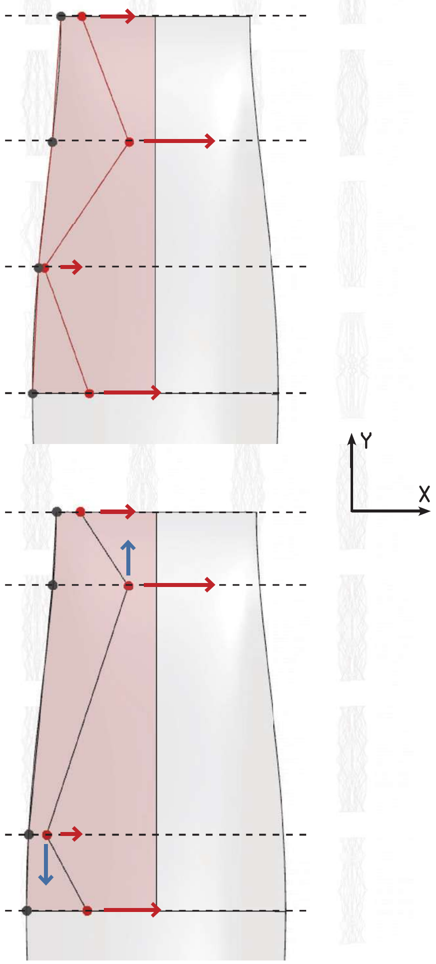
+Gather Extracted Geometry Information & Convert to csv file as Training Dataset

+Create and Send the csv file to the defined folder

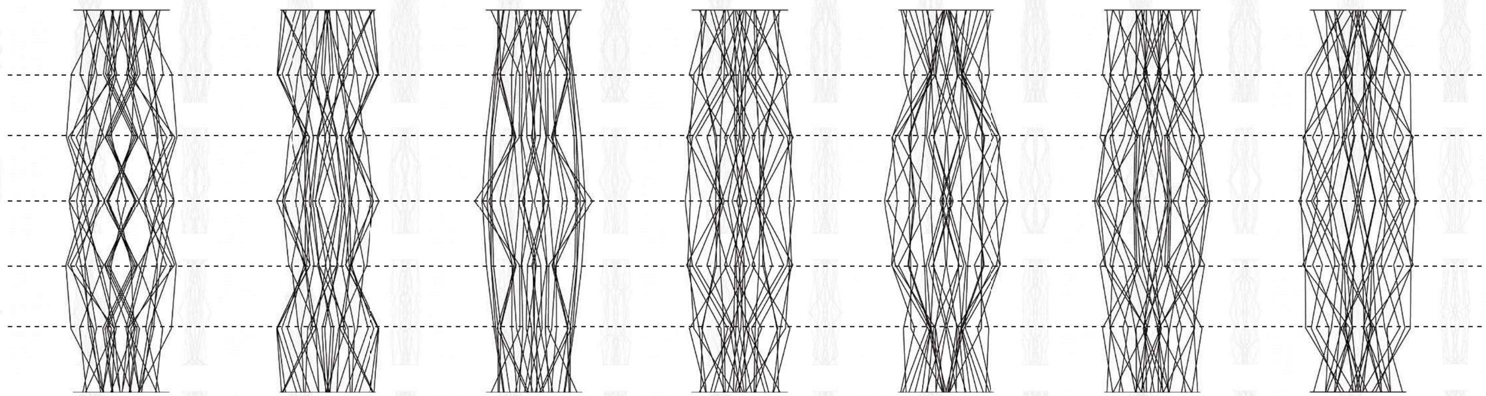
3 +Send Structural Definition to Sofistik and Run Finite Element Simulation

+Send result back into GH

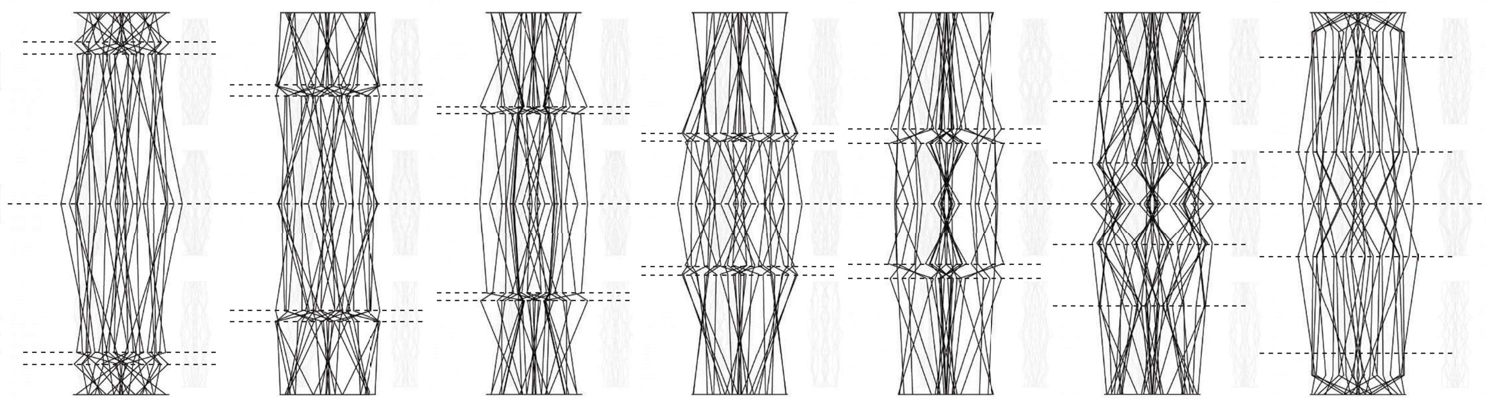
Geometry Generator Agents: Carbon Fiber Slab



CONSTANT DIVISION



NON-CONSTANT DIVISION

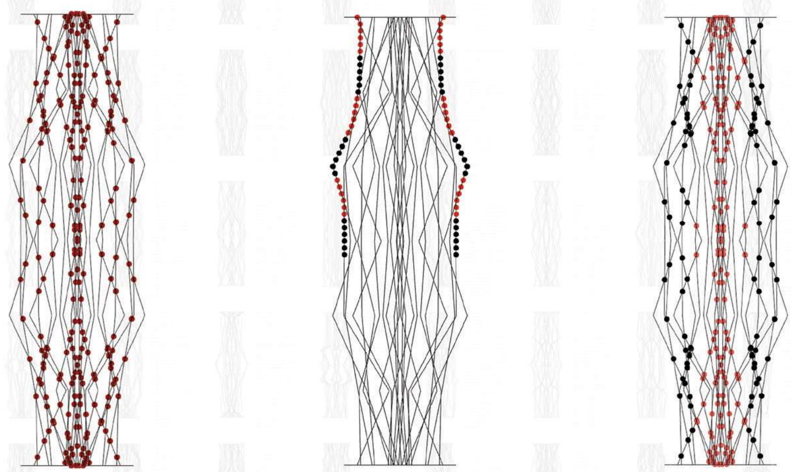


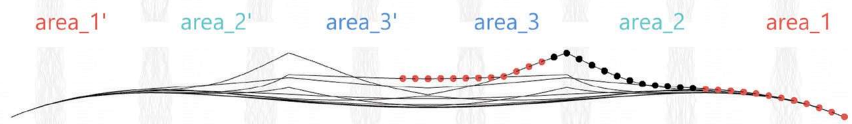
Geometry Generator Agent | Finite Element Method Process | Machine Learning Modeling Process | Fiber Trajectory Visualization

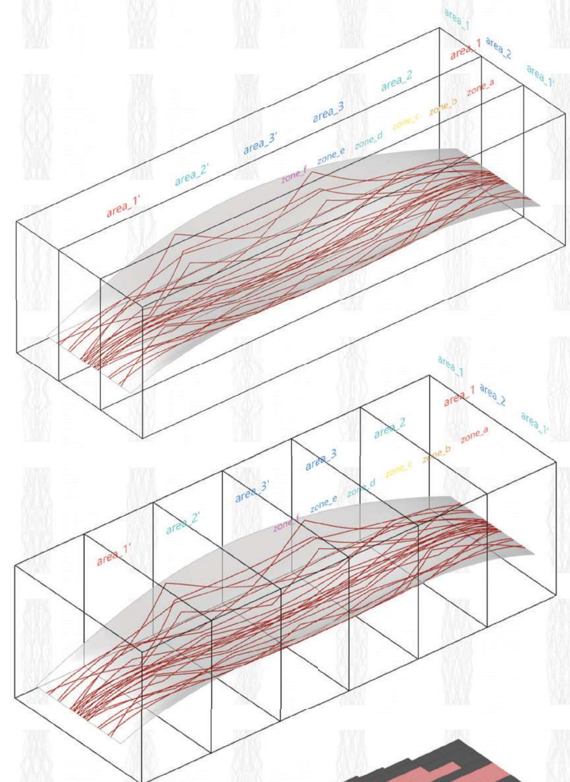
Features Extraction
To Generate Training Dataset

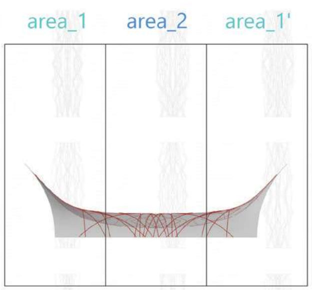
34 Geometry Features

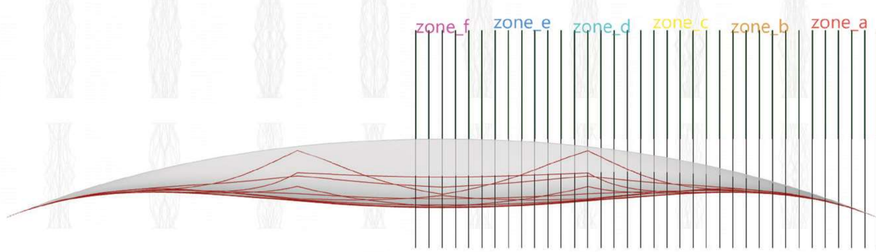
GeoType
TotalIntersxPts
Y_PtAmountArea1
Y_PtAmountArea2
Y_PtAmountArea3
X_PtAmountArea1
X_PtAmountArea2
TotalCarbFibLen
TotalNumFibUnit
MaxLenCarbFibUnit
minLenCarbFibUnit
MaxHeight
Y_MaxHeightArea1
Y_MaxHeightArea2
Y_MaxHeightArea3
MaxWidth
minWidth
avgWidth
X_avgWidthZoneA
X_avgWidthZoneB
X_avgWidthZoneC
X_avgWidthZoneD
X_avgWidthZoneE
X_avgWidthZoneF
Y_Area1_PtDens_CentReg
Y_Area1_PtDens_BtwReg
Y_Area1_PtDens_EdgeReg
Y_Area2_PtDens_CentReg
Y_Area2_PtDens_BtwReg
Y_Area2_PtDens_EdgeReg
Y_Area3_PtDens_CentReg
Y_Area3_PtDens_BtwReg
Y_Area3_PtDens_EdgeReg
MaxDisplacement

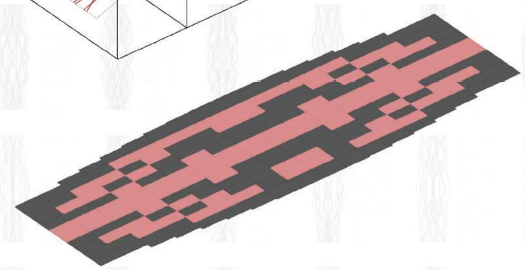








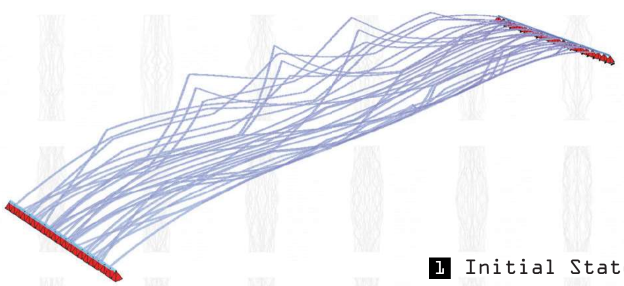




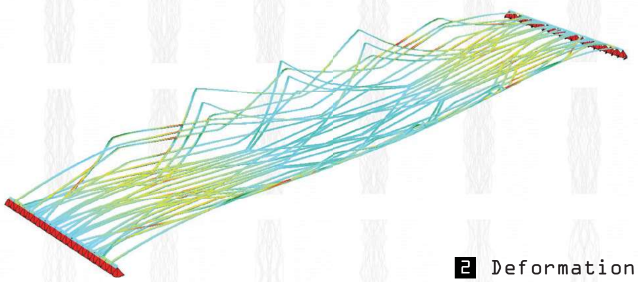
Finite Element Simulation

+Structural Model will be defined in GH & and sent to sofistik

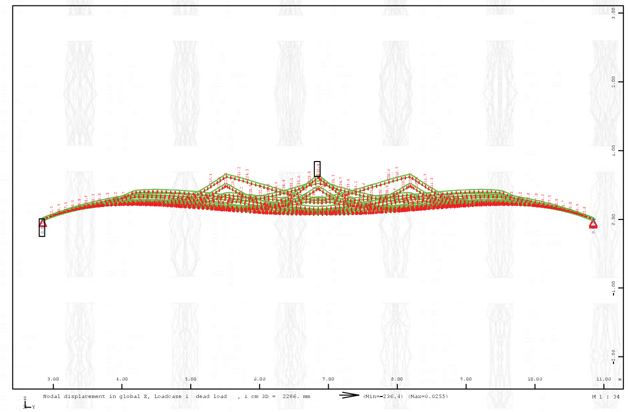
+In this project we define one load case & extract only one result: ⌞MaxDisplacement⌝ as dependent variable for dataset.

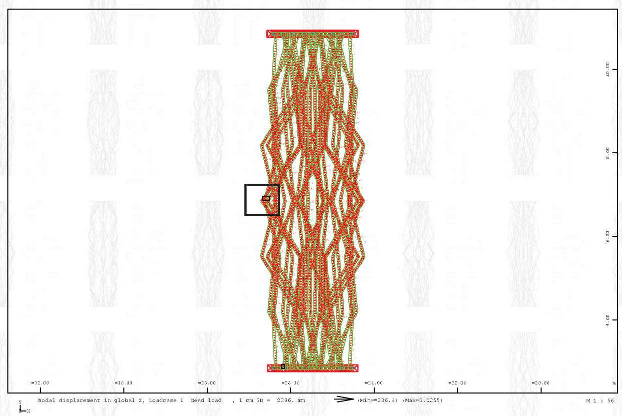


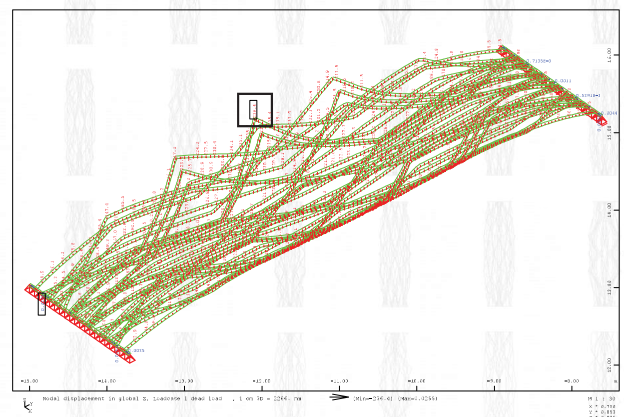
1 Initial State



2 Deformation







Data Preprocessing

1

	TotalIntersxPts	Y_PtAmountArea1	Y_PtAmountArea2	Y_PtAmountArea3	X_PtAmountArea1	X_PtAmountArea2	TotalCarbFibLen	TotalNumFibUnit	MaxLenCarbFibUnit	...	Y_Area1_PtDens_CentReg	Y_Area1_PtDens_BtwReg	Y_Area1_PtDens_EdgeReg	Y_Area2_PtDens_CentReg	Y_Area2_PtDens_BtwReg	Y_
0	452	104	198	150	186	266	253.84	30	9.00	...	12	0	4	8	6	
1	596	192	212	190	226	370	256.54	30	9.38	...	12	6	0	10	6	
2	560	250	204	104	168	392	254.16	30	8.99	...	14	0	0	8	6	
3	438	116	146	172	174	264	252.22	30	9.08	...	8	8	2	12	8	
4	502	210	157	131	188	313	253.72	30	9.56	...	14	6	0	14	6	

+ import dataset
+ clean data
+ split dataset into training & testing dataset
+ inspect data
+ split features from labels

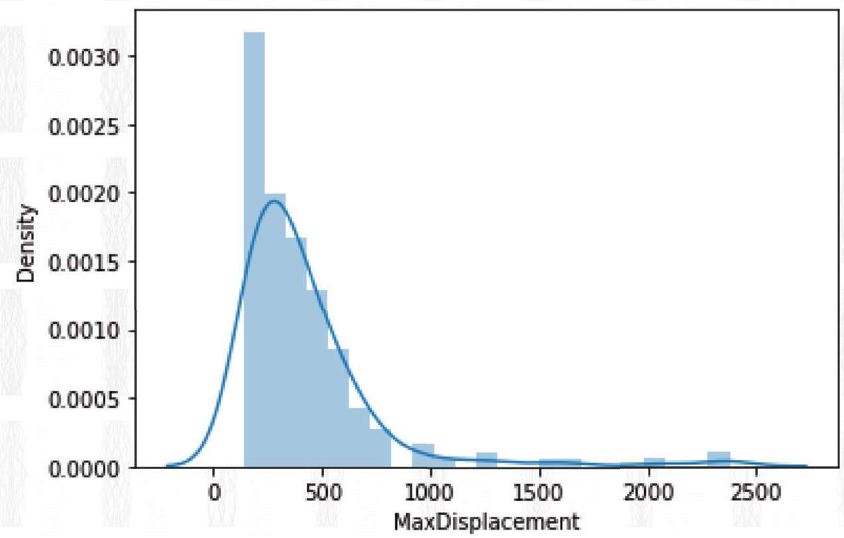
2

GeoType
TotalIntersxPts
Y_PtAmountArea1
Y_PtAmountArea2
Y_PtAmountArea3
X_PtAmountArea1
X_PtAmountArea2
TotalCarbFibLen
TotalNumFibUnit
MaxLenCarbFibUnit
minLenCarbFibUnit
MaxHeight
Y_MaxHeightArea1
Y_MaxHeightArea2
Y_MaxHeightArea3
MaxWidth
minWidth
avgWidth
X_avgWidthZoneA
X_avgWidthZoneB
X_avgWidthZoneC
X_avgWidthZoneD
X_avgWidthZoneE
X_avgWidthZoneF
Y_Area1_PtDens_CentReg
Y_Area1_PtDens_BtwReg
Y_Area1_PtDens_EdgeReg
Y_Area2_PtDens_CentReg
Y_Area2_PtDens_BtwReg
Y_Area2_PtDens_EdgeReg
Y_Area3_PtDens_CentReg
Y_Area3_PtDens_BtwReg
Y_Area3_PtDens_EdgeReg
MaxDisplacement

Skewness: 3.402625
Kurtosis: 14.938120

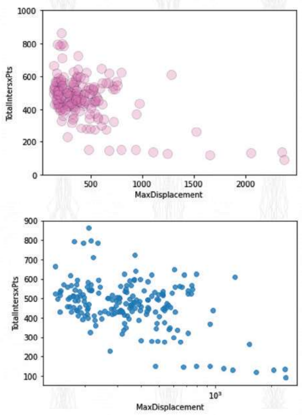
Constant : Non-Constant = 110 : 81

3

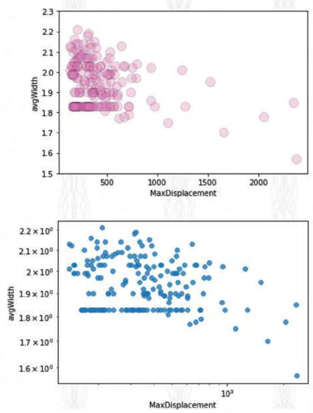


1 Dataframe of Training Dataset
2 Geometry Features (Independent:denpendent = 34:1)
3 Dataset Skewness & Kurtosis

Correlation Matrix



1



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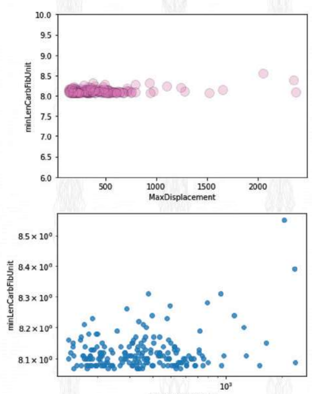

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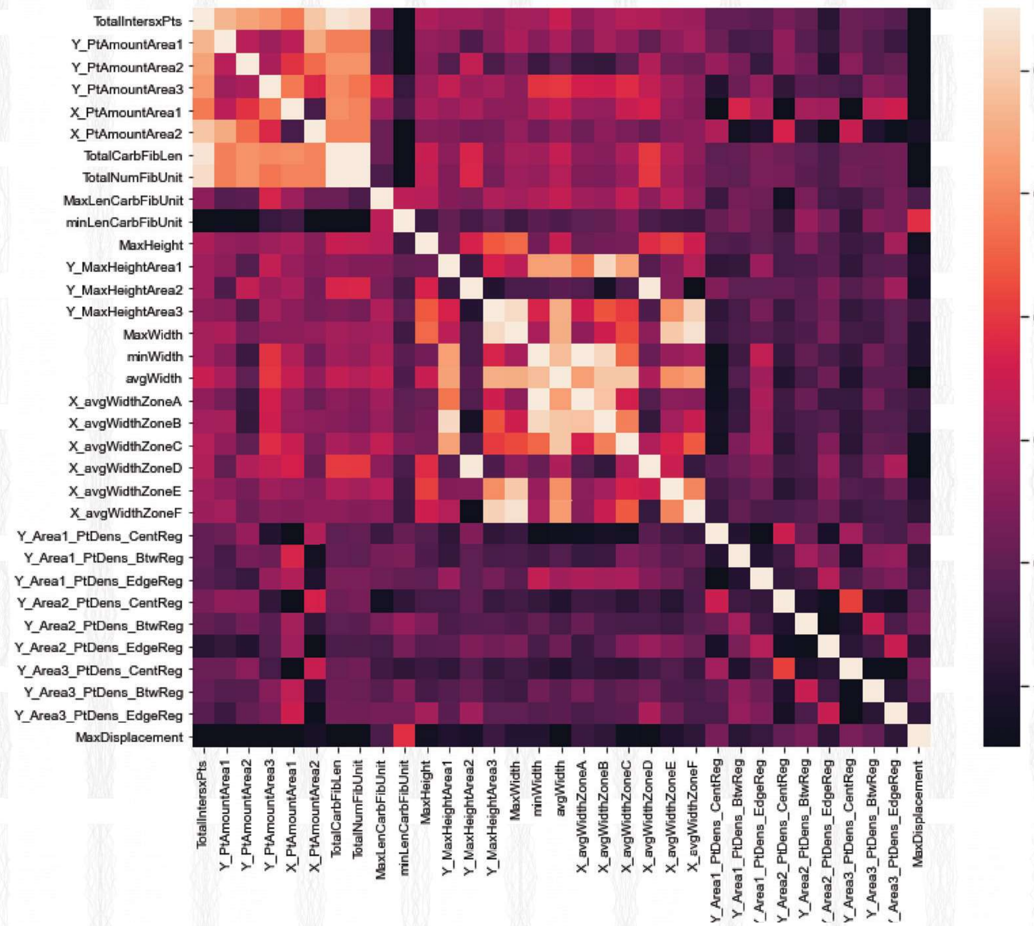


4

1 TotalIntersxPts
vs. MaxDisplacement

2 avgWidth
vs. MaxDisplacement

3 minLenCarbFibUnit
vs. MaxDisplacement

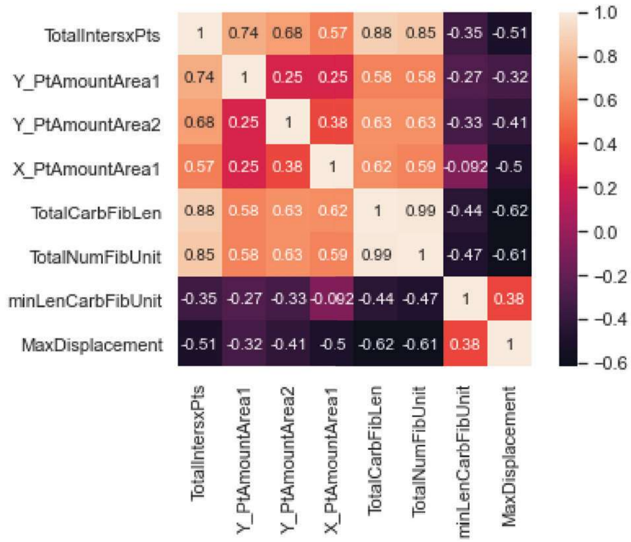
Correlation Matrix

+ Based on the Correlation Matrix, we pick up 7 features, which show strong relation with MaxDisplacement

1 Correlation Map with 7 Most Related Features
2 Scatter plots

1

	corr value
TotalIntersxPts	-0.506087
Y_PtAmountArea1	-0.323826
Y_PtAmountArea2	-0.414730
X_PtAmountArea1	-0.500663
TotalCarbFibLen	-0.617234
TotalNumFibUnit	-0.608951
minLenCarbFibUnit	0.379298
MaxDisplacement	1.000000



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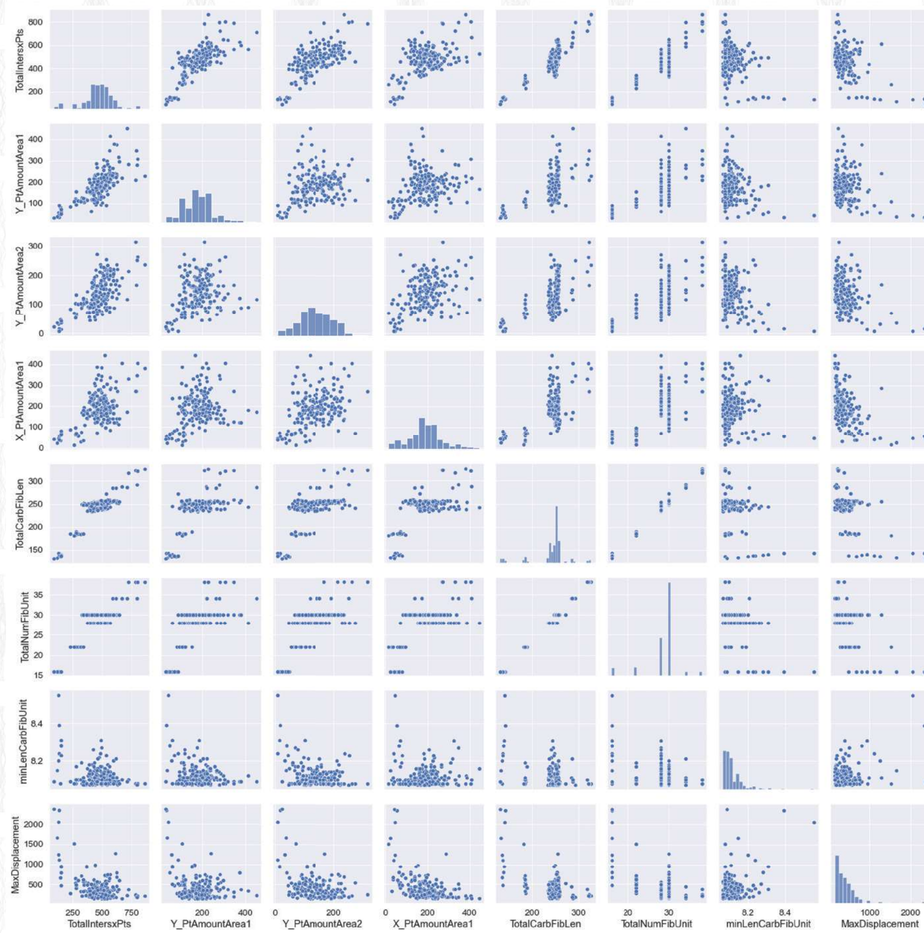


Construct & Train ML Algorithm

+Build 4 Machine Learning Algorithms to train with training data:
- x1 Linear Regression
- x3 Deep Neural Network

+Use trained Algorithms to predict 21 new geometry & compare the predicted value and actual value

Algorithm Architecture

Model 1: Linear Regression

+ 7 Input
+ 1 Output
+ With Linear Structure

Model 2: Neural Network

+ 4 Layers
+ layer1: 28 Neutrons
  layer2: 28 Neutrons
  layer3: 14 Neutrons
  layer4: 1 Neutron

+ relu activate function

Model 3: Neural Network

+ 6 Layers
+ layer1: 28 Neutrons
  layer2: 28 Neutrons
  layer3: 28 Neutrons
  layer4: 28 Neutrons
  layer5: 14 Neutrons
  layer6: 1 Neutron

+ relu activate function

Model 4: Neural Network

+ 8 Layers
+ layer1: 28 Neutrons
  layer2: 28 Neutrons
  layer3: 28 Neutrons
  layer4: 28 Neutrons
  layer5: 28 Neutrons
  layer6: 28 Neutrons
  layer7: 14 Neutrons
  layer8: 1 Neutron

+ relu activate function

Evaluate ML Algorithm's Performance

Comparision between 4 Machine Learning Models

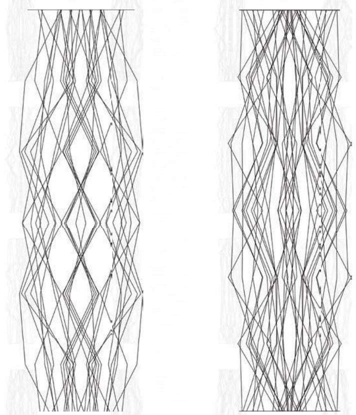
On predicting 0.4m x 8m Carbon Fiber Slab, the Machine Learning Algorithms have respectively the following results:

Model 1 (LinearRegression) -> Average Predicted MaxDisplacement= 303.257 [mm]

Model 2 (NeuralNetworkRregression) -> Average Predicted MaxDisplacement= 150.297 [mm]

Model 3 (NeuralNetworkRregression) -> Average Predicted MaxDisplacement= 144.139 [mm]

Model 4 (NeuralNetworkRregression) -> Average Predicted MaxDisplacement= 140.114 [mm]



Summary

From the results above, we can tell the Deep Neural Network, which with nonlinear layers can fit much better to the observed data and performed much better predicting on new data than Linear Regression. In addition, compared to those 3 Neural Network Models against each other, obviously by increasing the number of hidden layers and neurons in each layer also has imporved the accuracy of the prediction.

Further Opimization Strategy might could be improved by:
+ tune the hyperparameters
+ much bigger dataset
+ increase more and better geometry features
+ remove outliers from dataset