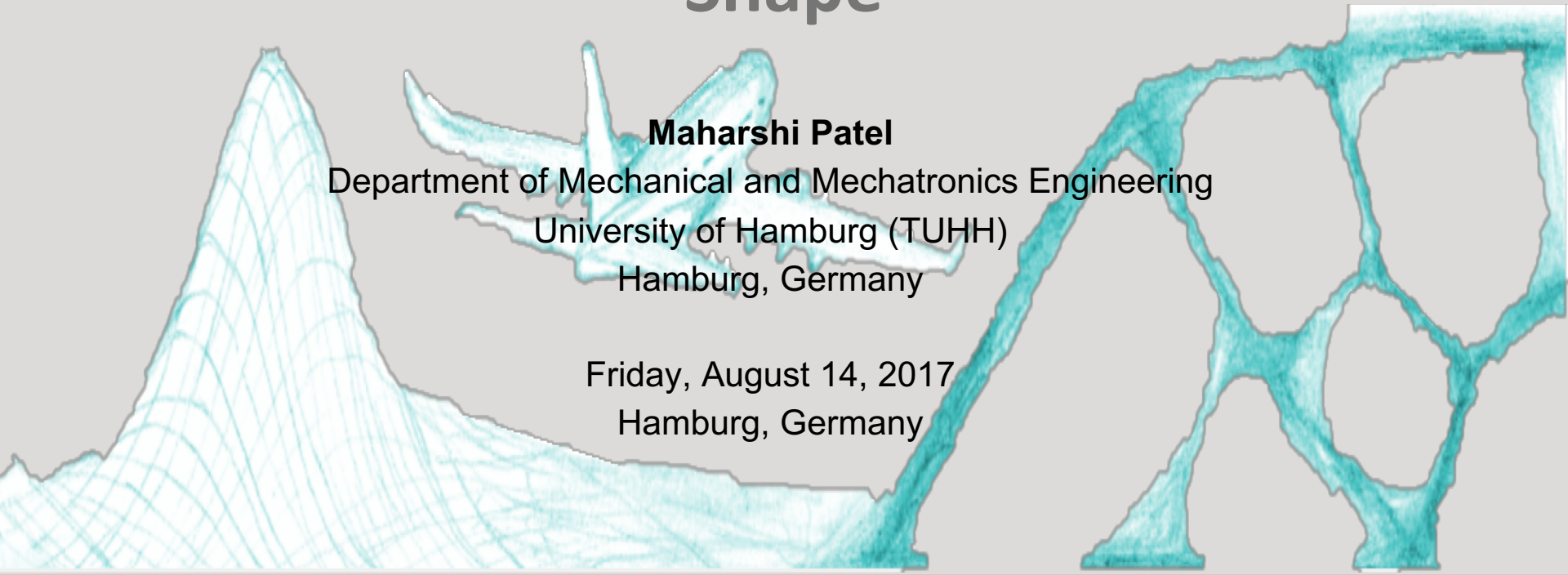
Structure and Beam Identification of 2D Bionic Shape



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Contents

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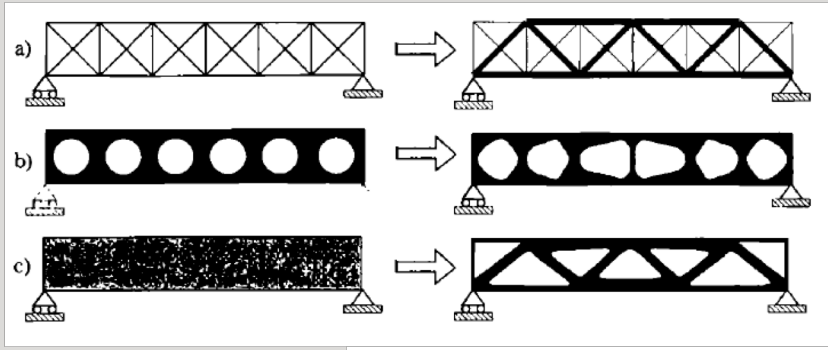
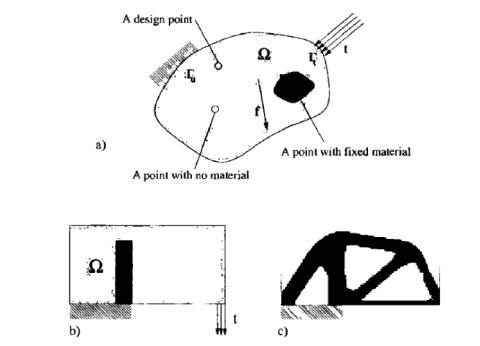
Introduction

Topological Optimization (TO)

- Optimizes material layout within a given design space
  - Maximize performance with a given set of load and boundary conditions
- Application for additive manufacturing





TO Formulation

- $min_\rho\ F = F(u(\rho), \rho) = \int_\Omega f(u(\rho), \rho) dV$
  - » $\rho \in \{0,1\}$
  - » $G_0(\rho) = \int_\Omega \rho(u) dV - V_0 \leq 0$
  - » $G_j\big(u(\rho)\big) \leq 0\ with\ j = 1, \dots, m$

- Nomenclature
  - » Ω – Design Space
  - » $\rho(u)$ – Density per element 1/0
  - » m – constraints

Method Implementation

NURBS MESH Derivatives

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NURBS Mesh Derivatives

- Main Functions
  - DensityToBionicShape
  - IdetifyBeams
    - Filterdata
    - Direction
    - BeamMatch
    - CenterPoint

```
function [ bionicShape ] = DensityToBionicShape( density )
    warning off;

    if nargin==0
        clc;clf('reset');
        density=load('OptStructEx5.mat');
        density=density.xe;
    end
    density=flip(density);
    [d,ang]=densityDerivations(density,0.1,0);
    [splines]=fitSplines(d,ang);
    bionicShape=BionicShape2d(splines(1),splines(2:end));
%     bionicShape.draw(1,'k');axis 'equal';
%     miny=min(nodes(:,2));
%     maxy=max(nodes(:,2));
%     midy=(maxy-miny)/2;
%     nodes(:,2)=midy-nodes(:,2);
%     model=FEModel([nodes,zeros(sizeN,1)],2);
%     model.addElementAssembly(elements,'TPN3',sizeN);
%     model.plot(0,1);
%     axis equal;
%     hold on
%     clf('reset')
    bionicShape.draw(0,'k');
    identifyBeams(bionicShape);
end

function [StoreCell, assignment, meshInline, meshOutline]=identifyBeams(bionicShape) ...

function [StoreCell] = filterdata(StoreCell) ...

function [DirectionPolyInlineStoreCell, DirectionDerivativePolyStoreCell]=direction(meshStoreCell) ...

function [] = BeamMatch(~, StoreCellDerPolyOut, StoreCell) ...

function [CenterStoreCell] = CenterPoints(StoreCell) ...

function [StoreCellPolyOut, StoreCellDerPolyOut] = BeamFittingDer(StoreCell)    ...

function [ splines ] = fitSplines(d,ang) ...

function [nodes,weights]=angleFilter(nodes,mindist,mindif) ...

function [ nodes,canidates ] = followLine(canidates,startNode,q,a) ...

function [ neighbors ]=getNeighbors(canidates,center) ...
```

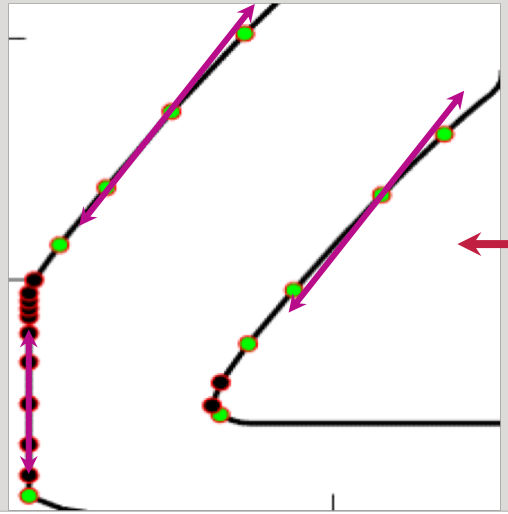
identifyBeams

- Gathering points from mesh and storing it for later use

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Gathering all the points for the bionic shape
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Outlines
%%%%%%%%%%
    meshTemp=bionicShape.outline.getMesh;
    meshOutline = meshTemp(:,1:2);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Inlines
%%%%%%%%%%
    meshTempInline = cell(length(lines),1);
    for i=1:length(lines)
        line=lines(i);
        mesh=line.getMesh;
        meshTempInline{i} = [meshTempInline{i}; mesh(:,1:2)];
    end

    meshOutline(:,3) = 1;
    meshInline = meshTempInline;

    for O = 1:length(meshInline)
        meshInline{O}(:,3) = O + 1;
    end

    meshStoreCell = [meshOutline; meshInline]; % storing
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

idenfifyBeams → direction

- Calculates the derivative of each mesh point



```
%   Running direction for getting derivatives
    [~, DirectionDerivativePolyStoreCell]=direction(meshStoreCell);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
DirectionPolyInlineStoreCell = cell(length(Temp2),1);
DirectionDerivativePolyStoreCell = cell(length(Temp2),1);
for Z = 1:length(Temp2) % curve fitting each beam to know beam
    dirarray=zeros(length(Temp2{Z}),1);
    for B = 1:length(Temp2{Z})
        x = Temp2{Z}{B}(:,1);
        y = Temp2{Z}{B}(:,2);
        dof = 1;
        DirectionPolyInlineStoreCell = polyfit( x, y, dof);
        dirarray(B)=polyder(DirectionPolyInlineStoreCell);
    end
    DirectionDerivativePolyStoreCell{Z} = dirarray;
end

for i = 1:length(DirectionDerivativePolyStoreCell)
    Q = DirectionDerivativePolyStoreCell{i}(1,:);
    DirectionDerivativePolyStoreCell{i} = [DirectionDerivativePo
end
```

Cont…

- Determining the close points to compare the derivatives

```
%   Getting and Storing the lines

    Der_Tol = 0.3;
    meshInline = meshStoreCell;
    DirectionDerivativePolyInline = DirectionDerivativePolyStoreCell;
    DirectionDerivativePolyInlineTemp = DirectionDerivativePolyInline;
    meshInlineTemp = meshInline;
    onBeam = 1;
    i = 1;
    R = 1;
    for Q = 1:length(meshInline)
        inlineQ=meshInline{Q};
        meshInlineTemp{Q} = [];
        meshInlineTemp = meshInlineTemp(~cellfun('isempty',meshInlineTemp));
        dirderQ=DirectionDerivativePolyInlineTemp{Q};
        DirectionDerivativePolyInlineTemp{Q} = [];
        DirectionDerivativePolyInlineTemp = DirectionDerivativePolyInlineTemp(~cellfun('isem
        for p = 1:length(inlineQ)    % Selects 1 Lint to compare with various other inlines
            A = inlineQ(1,1:2);
            A_Temp = inlineQ(1,:);
            inlineQ(1,:)=[];
            ader=dirderQ(1);
            dirderQ(1)=[];
            for U = 1:length(meshInlineTemp)
                for V = 1:length(meshInlineTemp{U})
                    B = meshInlineTemp{U}(:,1:2);
                    distances = sqrt(sum(bsxfun(@minus, B, A).^2,2));      % compute distanc
                    [Min,ClosestBeamIndex] = min(distances);      %get index min value
                    inlineTemp(R,:) = U;
                    CloseIndexTemp(R,:) = ClosestBeamIndex;
                    MinDistanceTemp(R,:) = Min;
                end
                R = R + 1;
            end

            % Selects the min distance and index from all the inlines so it
            % make sures that it picks the closest one
            [~,inline] = min(MinDistanceTemp);
            CloseIndex = CloseIndexTemp(inline);
```

Cont…

- Storing of lines

```
        if abs(ader - (DirectionDerivativePolyInlineTemp{inline}(CloseIndex))) <= Der_Tol
            OuterPoint = A_Temp;
            InnerPoint = meshInlineTemp{inline}(CloseIndex,:);
            assignment(c) = 1;
            pj_1 = OuterPoint;
            pj_2 = InnerPoint;
            onBeam = 1;
            plot(pj_1(1),pj_1(2),'or','MarkerFaceColor','g');
            plot(pj_2(1),pj_2(2),'or','MarkerFaceColor','g');
            StoreCell{i*2-1} = [StoreCell{i*2-1}; pj_1 ];
            StoreCell{i*2} = [StoreCell{i*2}; pj_2 ];
        else
            OuterPoint = A;
            InnerPoint = meshInlineTemp{inline}(CloseIndex,:);
            assignment(c) = 0;
            pj_1 = OuterPoint;
            pj_2 = InnerPoint;
            plot(pj_1(1),pj_1(2),'or','MarkerFaceColor','k')
            plot(pj_2(1),pj_2(2),'or','MarkerFaceColor','k')
            if onBeam==1
                i = i + 1;
                onBeam = 0;
            end
        end
        R = 1;
    end
    i = i + 1;
    onBeam = 0;
    meshInlineTemp = meshInline;
    DirectionDerivativePolyInlineTemp = DirectionDerivativePolyInline;
end
StoreCell = StoreCell(~cellfun('isempty',StoreCell));
```

Cont → Other function calls

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%    Identifing Inlines for the bionic structure
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    [StoreCell] = filterdata(StoreCell);
    [StoreCellPolyOut, StoreCellDerPolyOut] = BeamFittingDer(StoreCell);
    BeamMatch(StoreCellPolyOut, StoreCellDerPolyOut, StoreCell);
```

identifyBeams →filterdata

- Deleting and rearranging StoreCell for later use

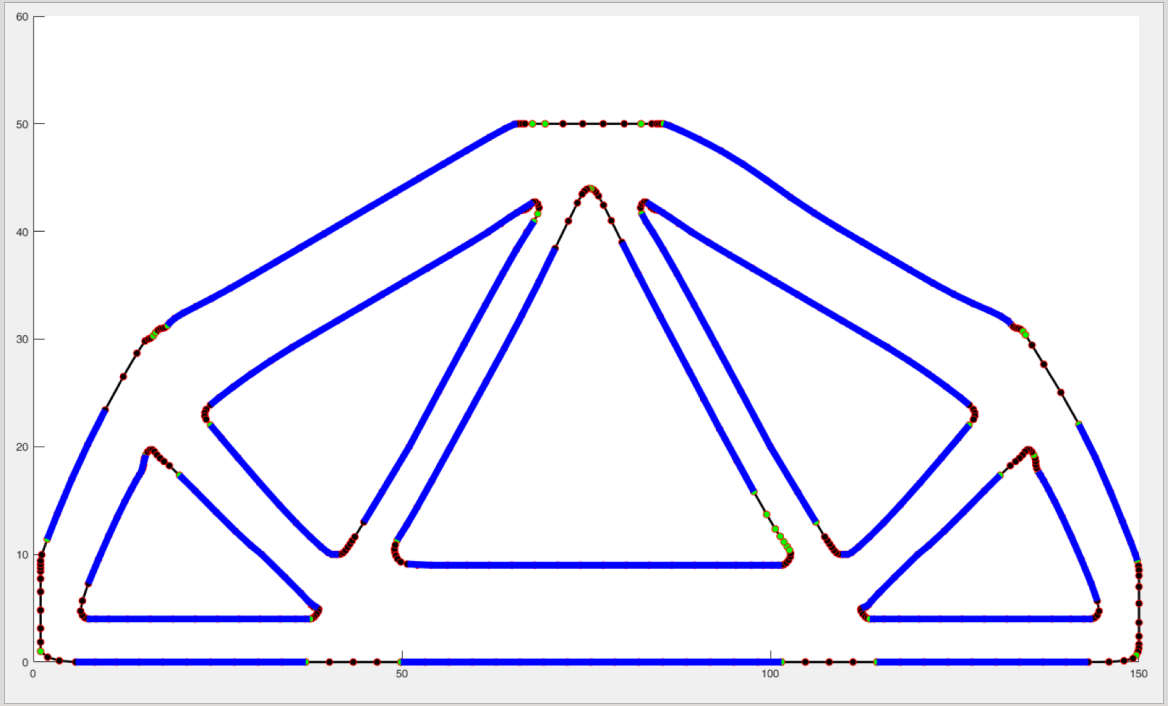
```
function [StoreCell] = filterdata(StoreCell)

%   deleting reoccuring points
    for I = 1:length(StoreCell)
        StoreCell{I} = unique(StoreCell{I},'rows');
    end

%   Deleting non valid lines for the structure
    for B = 1:length(StoreCell)
        if size(StoreCell{B},1) <= 3
            StoreCell{B} = [];
        end
    end
    StoreCell = StoreCell(~cellfun('isempty',StoreCell));

    Temp_Ind = [];
    P = 1;
    for I = 1:length(StoreCell)
        MODE_3 = mode(StoreCell{I}(:,3));
        for U = 1:length(StoreCell{I})
            if StoreCell{I}(U,3) ~= MODE_3
              Temp_Ind(P,1) = U;
              P = P + 1;
            end
        end
        StoreCell{I}(Temp_Ind(1:end),:) = [];
        Temp_Ind = [];
        P = 1;
    end
    StoreCell = StoreCell(~cellfun('isempty',StoreCell));
```

Cont…

- Rearranging and removing the duplicate lines

```
%   Deleting the duplicate line and merging the lines
    StoreCellInlinesTEMP = StoreCell;
    STORE_INDEX_COMP1 = [];
    STORE_INDEX_COMP2 = [];
    P = 1;
    N = 1;
    for U = 1:length(StoreCellInlinesTEMP)
        for Y = 1:length(StoreCellInlinesTEMP)
            if Y ~= U
                if length(StoreCellInlinesTEMP{U}) >= length(StoreCellInlinesTEMP{Y})
                    COMP1 = ismember(StoreCellInlinesTEMP{Y}(:,1:2),StoreCellInlinesTEMP{U}
                    COMP1 = sum(COMP1,2);
                    if mode(COMP1,1) == 2
                        O = Y;
                        STORE_INDEX_COMP1(P,:) = [U,O];
                        P = P + 1;
                    end
                    else
                        COMP2 = ismember(StoreCellInlinesTEMP{U}(:,1:2),StoreCellInlinesTEM
                        COMP2 = sum(COMP2,2);
                    if mode(COMP2,1) == 2
                        O = Y;
                        STORE_INDEX_COMP2(N,:) = [U,O];
                        N = N + 1;
                    end
                end
            end
        end
    end
    STORE_INDEX = [STORE_INDEX_COMP1; STORE_INDEX_COMP2];

    StoreCell_Temp = cell(length(StoreCell),1);
    for L = 1:length(STORE_INDEX)...

    StoreCell = StoreCell_Temp;

    StoreCell = StoreCell(~cellfun('isempty',StoreCell));
    for I = 1:length(StoreCell)       ...
```

Cont…



cont

- Other function calls

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%    Identifing Inlines for the bionic structure
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    [StoreCell] = filterdata(StoreCell);
    [StoreCellPolyOut, StoreCellDerPolyOut] = BeamFittingDer(StoreCell);
    BeamMatch(StoreCellPolyOut, StoreCellDerPolyOut, StoreCell);
```

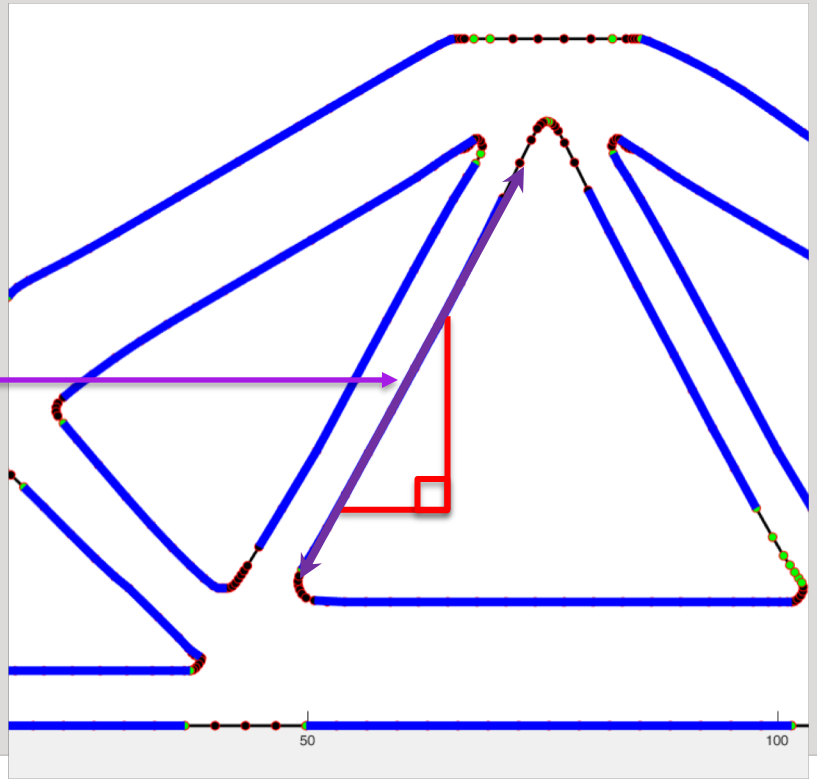
BeamFittingDer

- Getting the derivative for all the lines in the bionic shape

```
function [StoreCellPolyOut, StoreCellDerPolyOut] = BeamFittingDer(StoreCell)
    n = 1000;
    StoreCellPolyOut = cell(n,1);                                   % Cell Storing polyfit
%     PolyIn = cell(n,1);                                  % Cell Storing polyfit data o
    StoreCellDerPolyOut = cell(n,1);                                % Cell Storing polyfit
%     DerPolyIn = cell(n,1);                                % Cell Storing polyfit deriv
%      Identifying the outlines
    w = 1;
    for q = 1:length(StoreCell)        % curve fitting each beam to know beam length and
        x = StoreCell{q}(:,1);
        y = StoreCell{q}(:,2);
        if length(StoreCell{q}(:,1)) ==  1                          %dof = degree of f
            dof = 0;
        else
            dof = 1;                                                %length(StoreCellI
        end
        StoreCellPolyOut{w} = [StoreCellPolyOut{w}, polyfit( x, y, dof)];      %length(S
        StoreCellDerPolyOut{w} = [StoreCellDerPolyOut{w}, polyder(StoreCellPolyOut{w,1})
        w = w + 1;
    end

    StoreCellPolyOut = StoreCellPolyOut(~cellfun('isempty',StoreCellPolyOut));
    StoreCellDerPolyOut = StoreCellDerPolyOut(~cellfun('isempty',StoreCellDerPolyOut));

    clear dof n q StoreCell w x y;

end
```

Cont…

$$f'n = polyfit(StoreCell\{Line\}) = mx + b$$
$$m = slope\ of\ line$$



Cont…

- Other function calls

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%    Identifing Inlines for the bionic structure
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    [StoreCell] = filterdata(StoreCell);
    [StoreCellPolyOut, StoreCellDerPolyOut] = BeamFittingDer(StoreCell);
    BeamMatch(StoreCellPolyOut, StoreCellDerPolyOut, StoreCell);
```

indentifyBeam →BeamMatch

- Matching each to its partner and creating a beam
- Plotting a patch to show the area of the beam

BeamStoreInline

11x2 cell

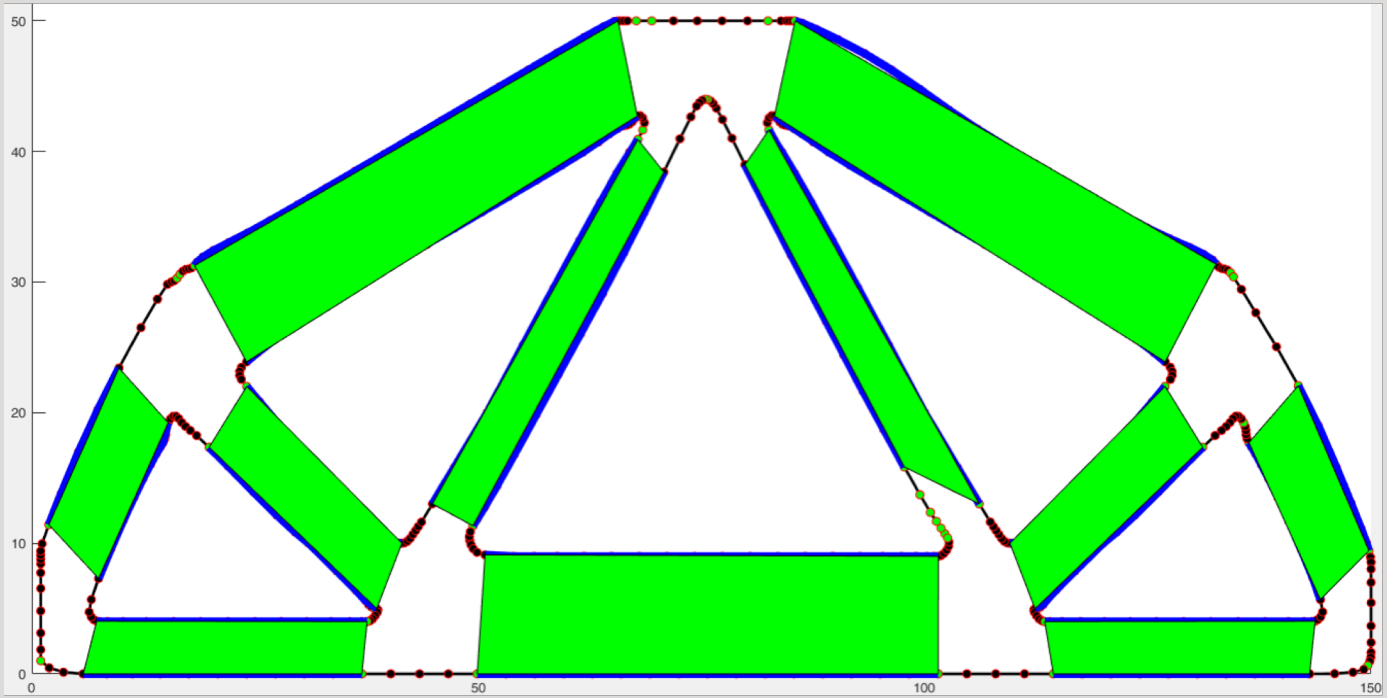
	1	2
1	5x3 double	10x3 double
2	21x3 double	17x3 double
3	20x3 double	18x3 double
4	7x3 double	10x3 double
5	10x3 double	15x3 double
6	17x3 double	19x3 double
7	11x3 double	15x3 double
8	12x3 double	9x3 double
9	13x3 double	10x3 double
10	11x3 double	6x3 double
11	13x3 double	11x3 double

```
%   For All Lines!!

    for p = 1:length(StoreCell)
        if StoreCell{p}(1,1) > StoreCell{p}(end,1)
            StoreCell{p} = flip(StoreCell{p});
        end
    end

    [CenterStoreCell] = CenterPoints(StoreCell);
    count=1;
    while size(StoreCell,1)>1   % Selects 1 Outline to compare with various inline
        A = CenterStoreCell(1,:);
        OuterBeamInline = StoreCell{1};
        StoreCell{1}=[];
        StoreCell = StoreCell(~cellfun('isempty',StoreCell));
        ader=StoreCellDerPolyOut{1};
        StoreCellDerPolyOut{1}=[];
        StoreCellDerPolyOut = StoreCellDerPolyOut(~cellfun('isempty',StoreCellDerP
        CenterStoreCell(1,:)=[];
        B = CenterStoreCell();
        distancesInline = sqrt(sum(bsxfun(@minus, B, A).^2,2));            % compu
        [~,ClosestBeamIndex] = min(distancesInline);                %get index min va

        if abs(ader - (StoreCellDerPolyOut{ClosestBeamIndex})) <= Der_Tol   % check
            InnerBeamInline = StoreCell{ClosestBeamIndex};
            BeamStoreInline{count,1} = OuterBeamInline;
            BeamStoreInline{count,2} = InnerBeamInline;
            PatchCoorXInline(count,:) = [BeamStoreInline{count,1}(1,1), BeamStoreIn
            PatchCoorYInline(count,:) = [BeamStoreInline{count,1}(1,2), BeamStoreIn
            patch(PatchCoorXInline(count,:),PatchCoorYInline(count,:),'green');
            StoreCell{ClosestBeamIndex}=[];
            StoreCell = StoreCell(~cellfun('isempty',StoreCell));
            StoreCellDerPolyOut{ClosestBeamIndex}=[];
            StoreCellDerPolyOut = StoreCellDerPolyOut(~cellfun('isempty',StoreCell
            CenterStoreCell(ClosestBeamIndex,:)=[];
        end
        count=count+1;
    end

end
```

indentifyBeam →BeamMatch → CenterPoints

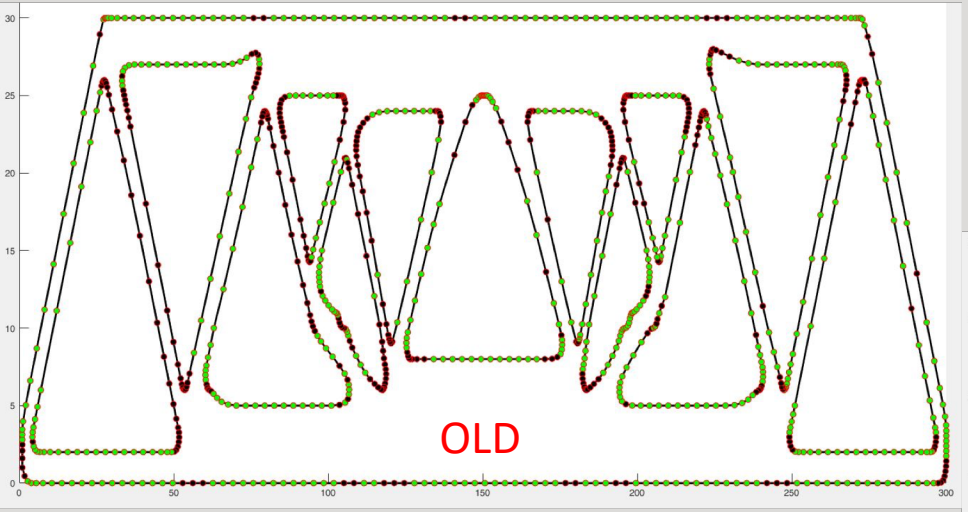
- Finds the center points for all the lines to match the closest line

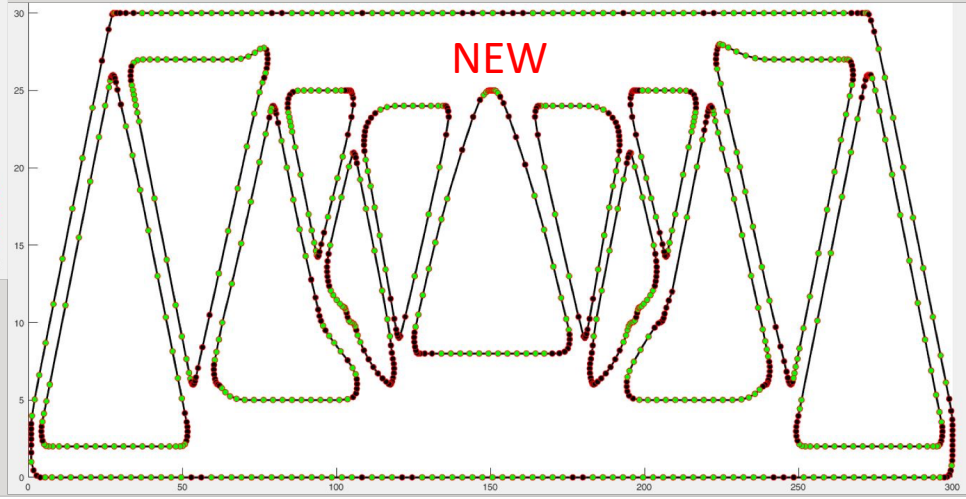
Cont…



Post Processing

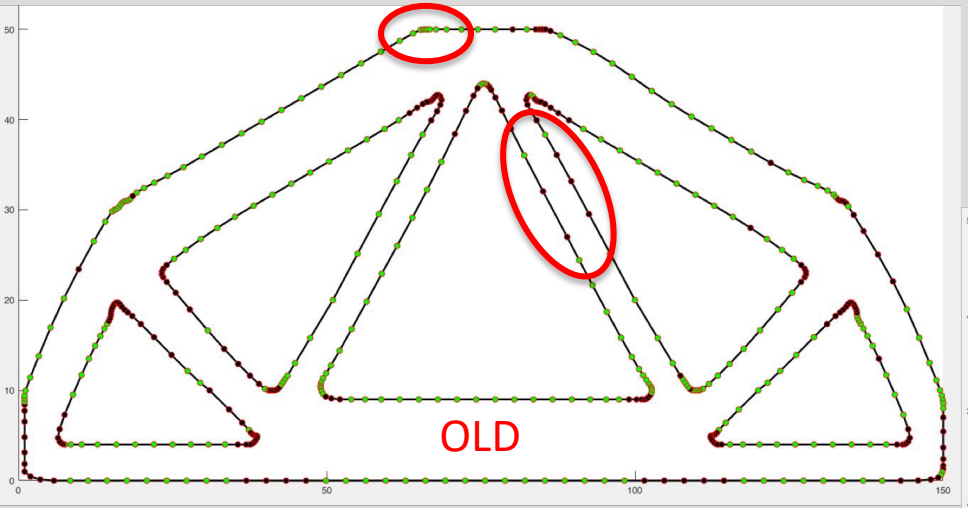
Method 1 vs Method 2 – Points Detection

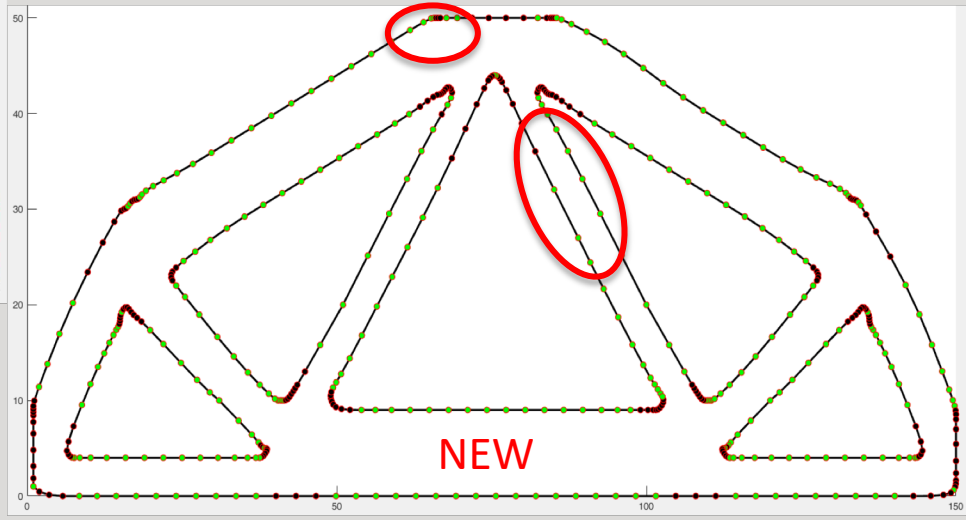




Example 1: Structure 1

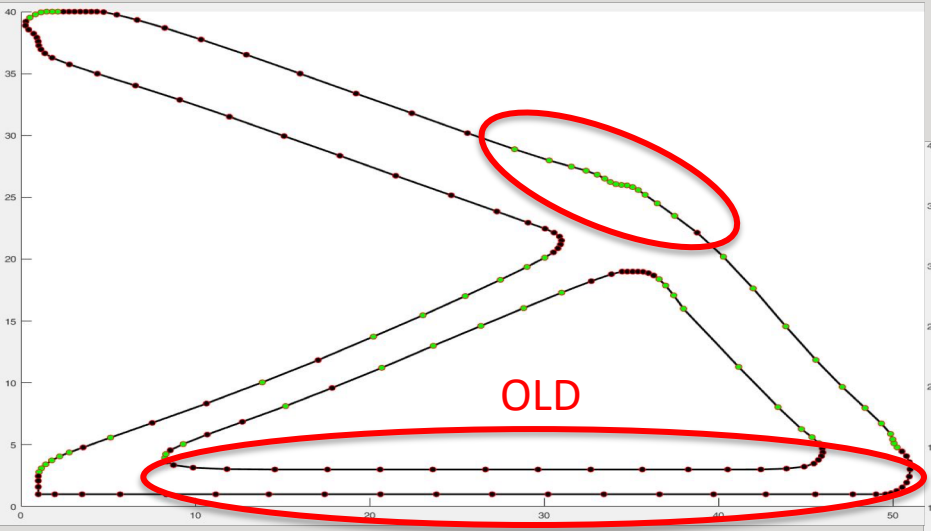
Method 1 vs Method 2 – Points Detection

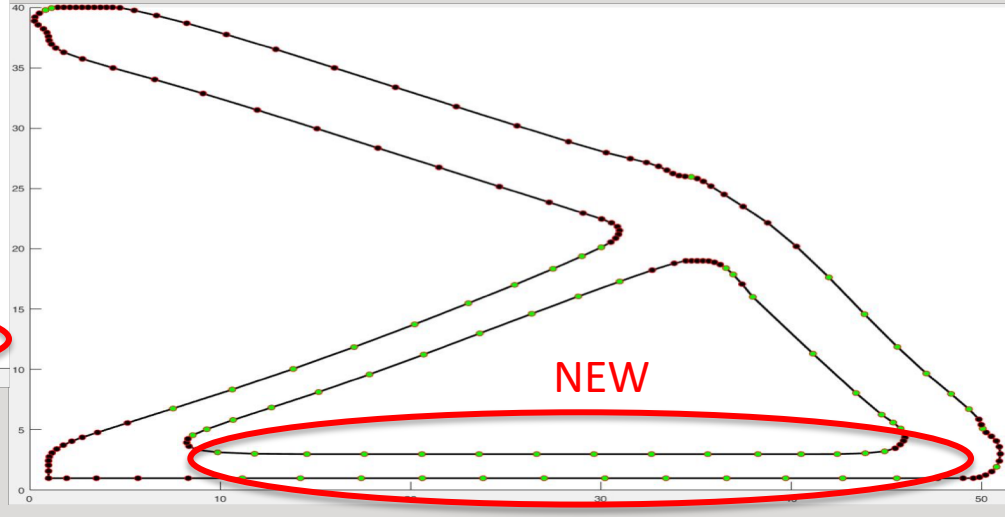




Example 2: Structure 2

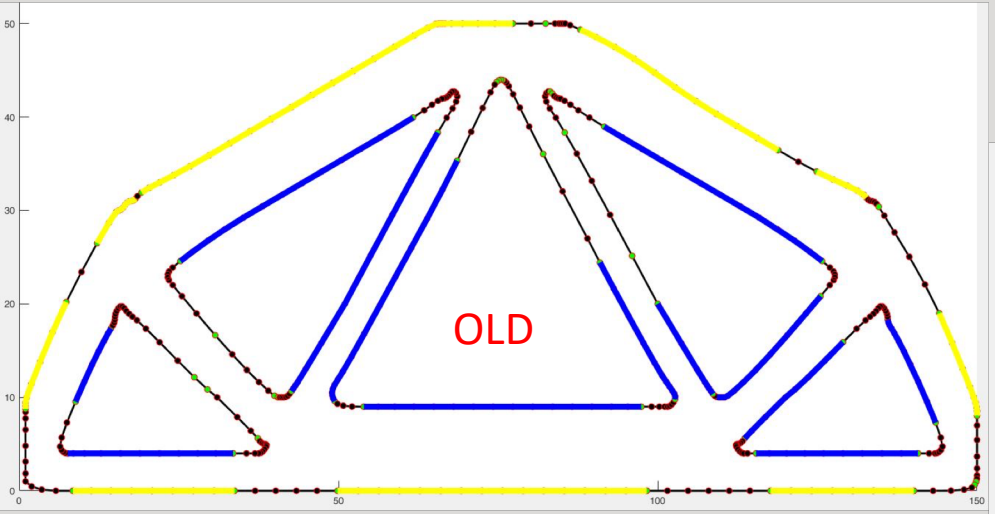
Method 1 vs Method 2 – Points Detection

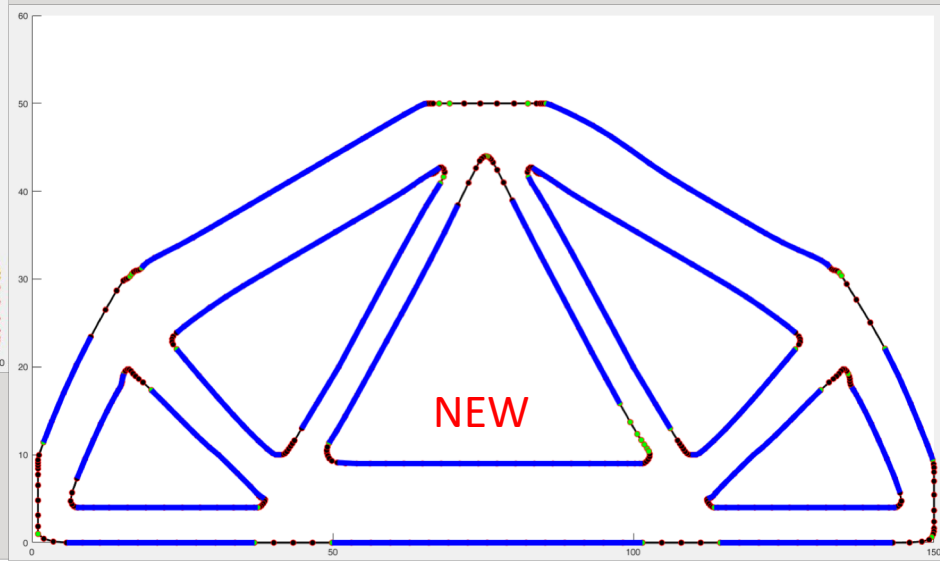




Example 4: Structure 4

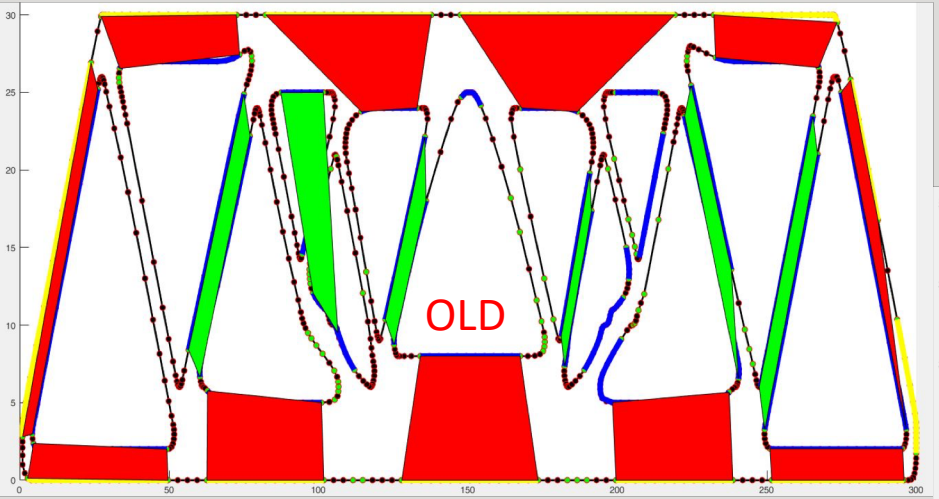
Method 1 vs Method 2 - Lines

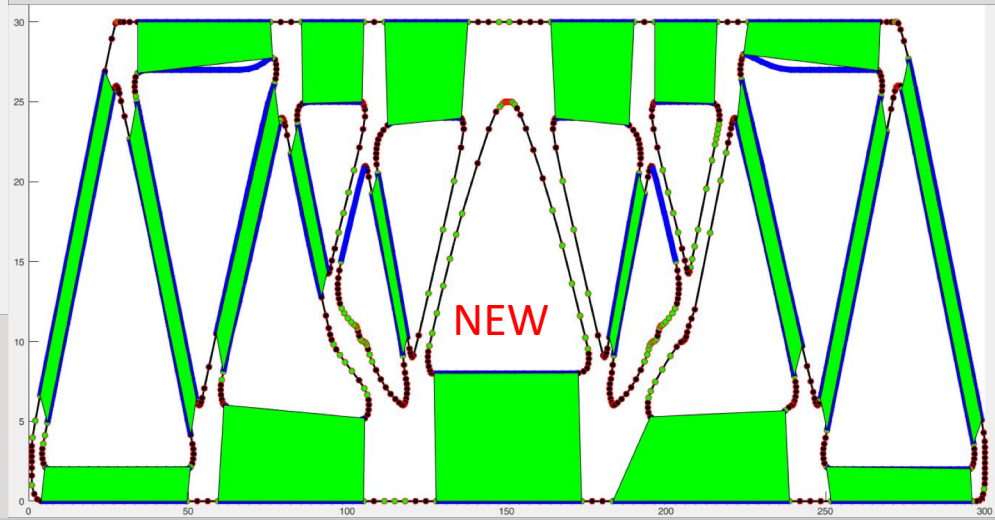




Example 2: Structure 2

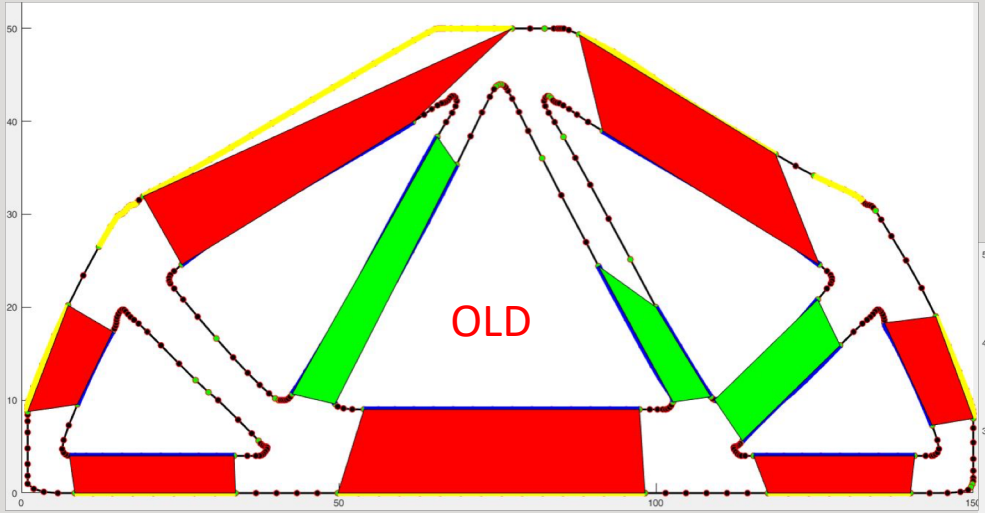
Method 1 vs Method 2 - Patch

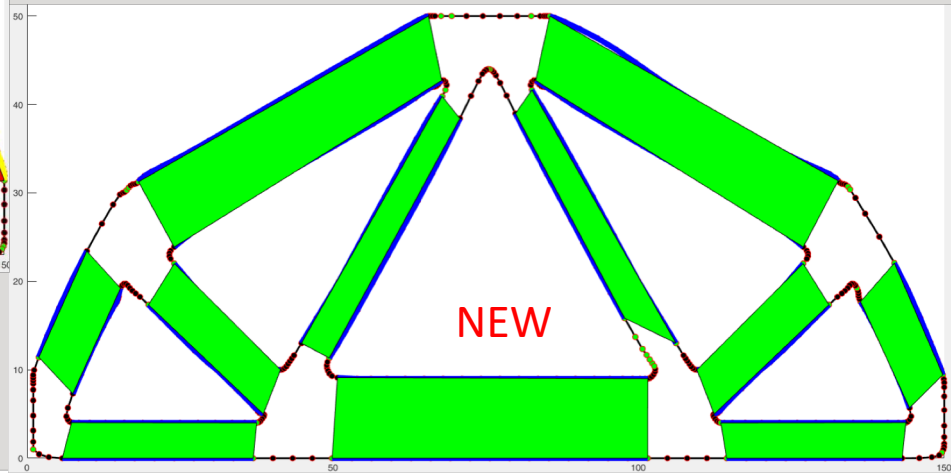




Example 1: Structure 1

Method 1 vs Method 2 - Patch





Example 2: Structure 2

Method 1 vs Method 2 – Run Time

Structure Number	Method 1 (OLD)	Method 2 (NEW)
1	15.912 s	14.568 s
2	6.959 s	5.041 s
3	Does Not Work (DNW)	5.168 s
4	DNW	1.074 s
5	DNW	12.234 s

Conclusion

Conclusion

- The NURBS mesh derivative method yields better results
- To get better results and better runtime
  - Tweaking the polynomial and having a better curve fitting parameter
  - Optimizing the tolerance for each structure

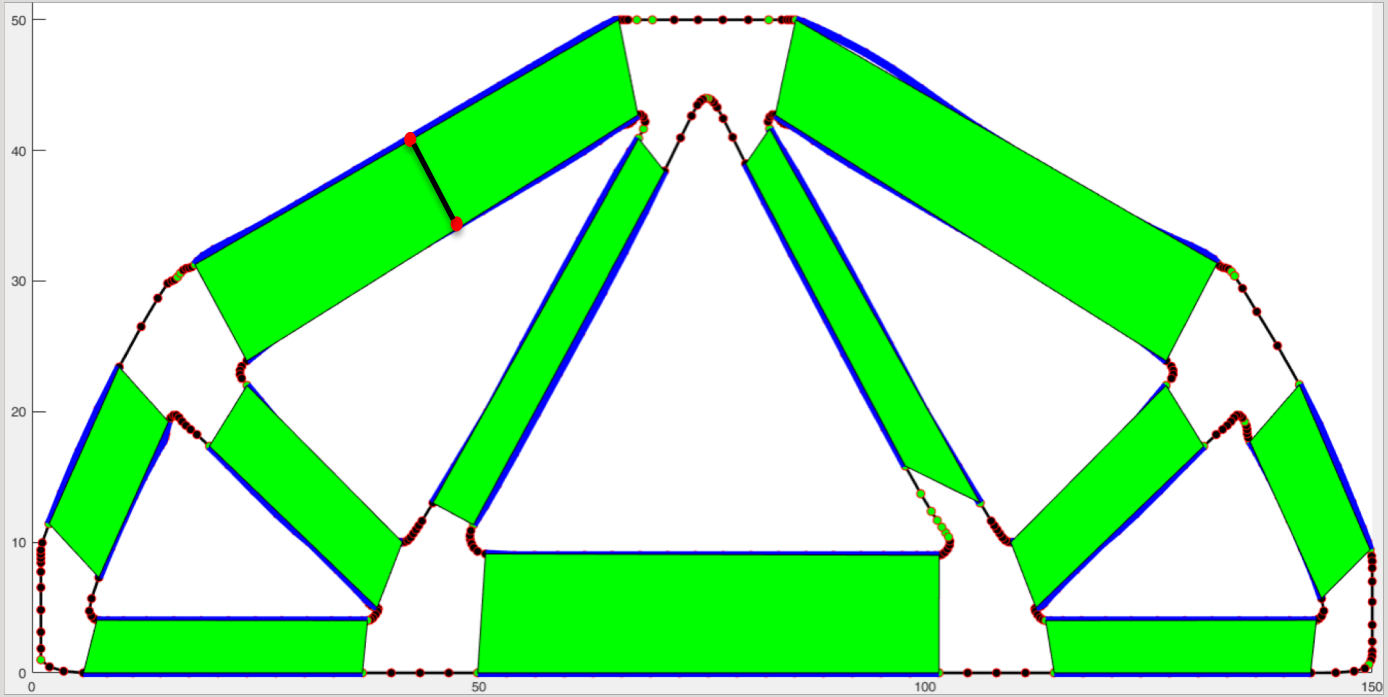
Future Plans

Future Plans

- Look for new storage array for faster process
  - Identifybeam function
- Figure out a new way to compare lines to itself
- New way to compare derivatives and construct polynomial better

- Start simulating the structure on the FEM code
- Start to delete elements
  - Compare the thickness and store elements to delete
  - Ham Code

Element Deletion



BeamStoreInline

11x2 cell

	1	2
1	5x3 double	10x3 double
2	21x3 double	17x3 double
3	20x3 double	18x3 double
4	7x3 double	10x3 double
5	10x3 double	15x3 double
6	17x3 double	19x3 double
7	11x3 double	15x3 double
8	12x3 double	9x3 double
9	13x3 double	10x3 double
10	11x3 double	6x3 double
11	13x3 double	11x3 double

Questions?

References

- Hydrogen Fuel Cells – PEM

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Thank You!

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