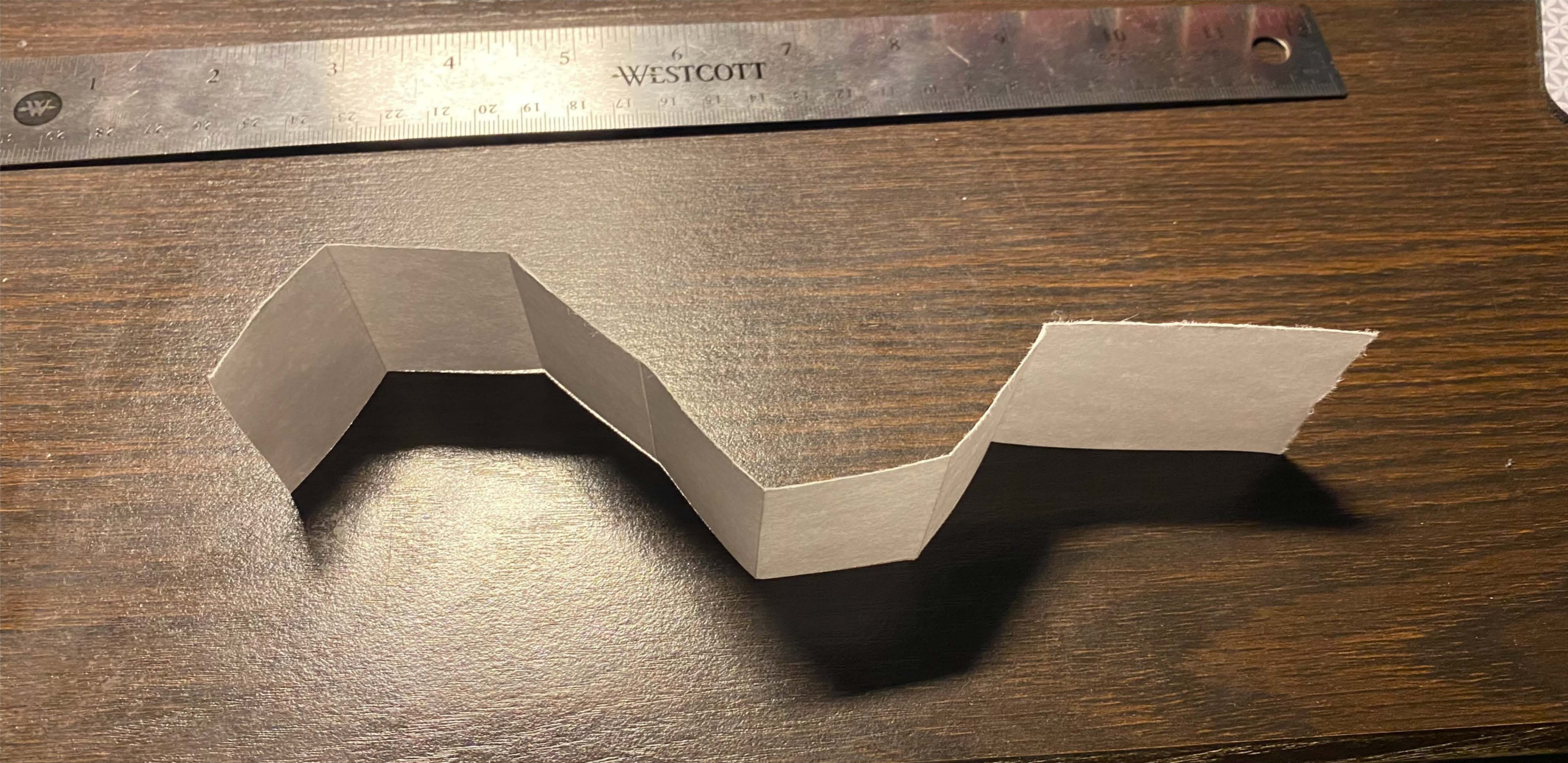
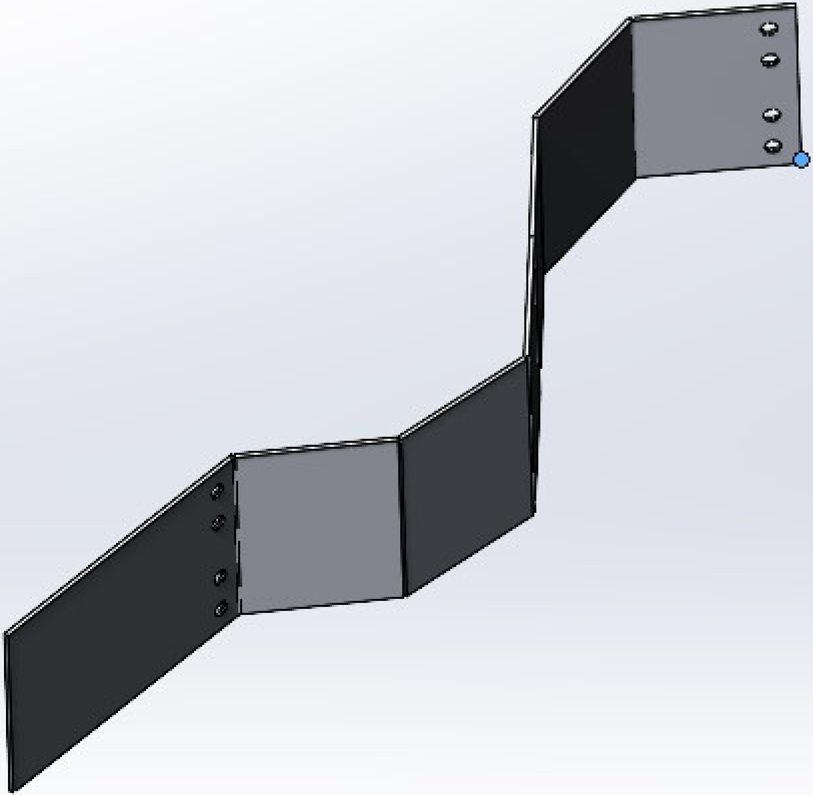
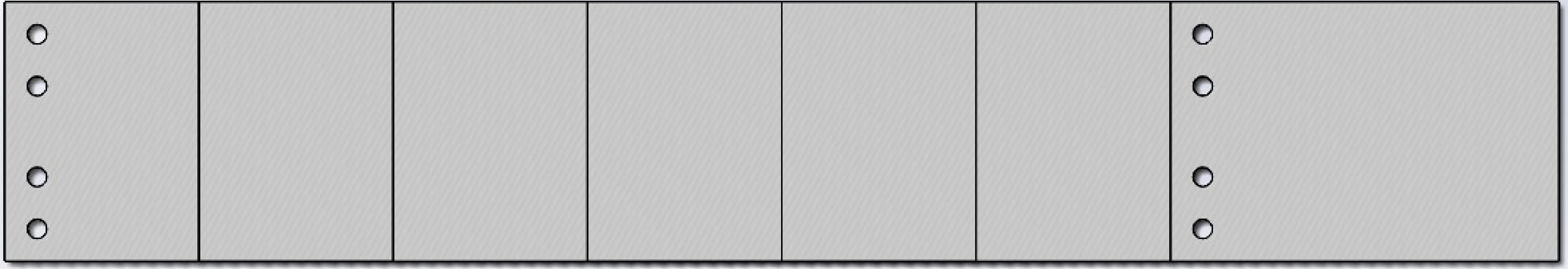
Paper Prototypes


WESTCOTT

Solidwork Model





Python Script

In [1]:

```
%matplotlib inline
```

In [2]:

```
import shapely.geometry as sg
from foldable_robotics.layer import Layer
from foldable_robotics.laminate import Laminate
import numpy

import foldable_robotics
import foldable_robotics.dxf
import numpy
import shapely.geometry as sg
from foldable_robotics.layer import Layer
from foldable_robotics.laminate import Laminate
import foldable_robotics.manufacturing
import foldable_robotics.parts.castellated_hinge1
import idealab_tools.plot_tris
from math import pi, sin,cos,tan
import idealab_tools.text_to_polygons
foldable_robotics.display_height=200
foldable_robotics.line_width=.5

from foldable_robotics.layer import Layer
from foldable_robotics.laminate import Laminate
import foldable_robotics
import foldable_robotics.dxf
import foldable_robotics.manufacturing
import foldable_robotics.parts.castellated_hinge1
foldable_robotics.display_height=200
foldable_robotics.line_width=.5
#import workflow_support as ws

import os
import foldable_robotics.solidworks_support
```

In [3]:

```
def get_bodies(filename, layername, num_layers):
    body = foldable_robotics.dxf.read_lwpolylines(filename,layer=layername, arc_approx

    bodies = [Layer(sg.Polygon(item)) for item in body]
    body = bodies.pop(0)
    for item in bodies:
        body ^= item
    body = body.to_laminate(num_layers)
    return body
```

In [4]:

```
def get_hinge_lines(filename,layername):
    hinge_lines1 = foldable_robotics.dxf.read_lines(filename,layer=layername)
    hinge_lines2 = foldable_robotics.dxf.read_lwpolylines(filename,layer=layername)
    hinge_lines3 = []
    for points in hinge_lines2:
        hinge_lines3.append(points[:2])
    hinge_lines = hinge_lines1 +hinge_lines3
    return hinge_lines
```

In [5]:

```
def hinge_lines_to_hinges(hinge_lines,hinge):
    lam = Layer().to_laminate(len(hinge))
    all_hinges = []
    for p3,p4 in hinge_lines:
        all_hinges.append(hinge.map_line_stretch((0,0),(1,0),p3,p4))
    all_hinges = lam.unary_union(*all_hinges)
    return all_hinges
```

In [6]:

```
def get_cuts(filename,layername,thickness,num_layers):
    cut_lines = foldable_robotics.dxf.read_lines(filename,layer=layername)
    cut_lines += foldable_robotics.dxf.read_lwpolylines(filename,layer=layername, arc_a

    cuts = []
    for item in cut_lines:
        cuts.append(Layer(sg.LineString(item)))
    cuts = Layer().unary_union(*cuts)
    cuts<<=thickness/2
    cuts = cuts.to_laminate(num_layers)
    return cuts
```

In [7]:

```
def get_holes(filename, layername,num_layers):
    holes = foldable_robotics.dxf.read_circles(filename,layer='holes')

    holes2 = []
    for center, radius in holes:
        holes2.append(sg.Point(*center).buffer(radius))
    holes_layer = Layer(*holes2)
    holes_lam = holes_layer.to_laminate(num_layers)
    return holes_lam
```

In [8]:

```
def hinge_width_calculator(desired_degrees,thickness):
    theta = (180-desired_degrees)*pi/180
    w=thickness/tan(theta)
    return w
```

In [9]:

```
def polys_to_layer(l1):
    l1 = [sg.Polygon(item) for item in l1]
    l11 = Layer(l1.pop(0))
    for item in l1:
        l11 ^= Layer(item)
    return l11
```

In [10]:

```
def output_pdf(filename,design2,x,y,layers_separate = True):
    design2 = design2.translate(x,y)
    design2=design2.scale(1/25.4,1/25.4)
    design2=design2.scale(foldable_robotics.pdf.ppi,foldable_robotics.pdf.ppi)
    if isinstance(design2,Laminate):
        if not layers_separate:
            p=foldable_robotics.pdf.Page(filename+'.pdf')
            for d in design2:
    #        d = design2[0]
                for item in d.exteriors()+d.interiors():
                    p.draw_poly(item)
            p.close()
        else:
            for ii,d in enumerate(design2):
                p=foldable_robotics.pdf.Page(filename+'{0:03f}.pdf'.format(ii))
                for item in d.exteriors()+d.interiors():
                    p.draw_poly(item)
                p.close()

    elif isinstance(design2,Layer):
        p=foldable_robotics.pdf.Page(filename+'.pdf')
        for item in design2.exteriors()+design2.interiors():
            p.draw_poly(item)
        p.close()
```

In [11]:

```
def build_layer_numbers(num_layers, text_size = None, prop=None):
    text_size = text_size or 1
    prop = prop or {'family':'Arial','size':text_size}
    layer_ids = []
    for ii in range(num_layers):

        l = idealab_tools.text_to_polygons.text_to_polygons('Layer '+str(ii),prop=prop)
        layer_ids.append(l)

    layer_ids = [polys_to_layer(item) for item in layer_ids]
    layer_id = Laminate(*layer_ids)
    return layer_id
```

In [12]:

```
def build_web(design2,keepout,support_width,jig_diameter,jig_hole_spacing,is_adhesive):
    num_layers = len(design2)

    layer_id = build_layer_numbers(num_layers,text_size=jig_diameter)

    design_outer = foldable_robotics.manufacturing.unary_union(design2)
    bb1= (design_outer<<jig_hole_spacing/2).bounding_box()
    (x1,y1),p2 = bb1.bounding_box_coords()
    w,h = bb1.get_dimensions()
    w2 = round(w/jig_hole_spacing)*jig_hole_spacing
    h2 = round(h/jig_hole_spacing)*jig_hole_spacing

    points = []
    points.append(sg.Point(x1,y1))
    points.append(sg.Point(x1+w2,y1))
    points.append(sg.Point(x1,y1+h2))
    points.append(sg.Point(x1+w2,y1+h2))

    layer_id = layer_id.translate(x1+jig_diameter,y1-jig_diameter/2)
    placement_holes2 = Layer(*points)
    placement_holes2<<=(jig_diameter/2)
    sheet = (placement_holes2<<10).bounding_box()
    placement_holes2=placement_holes2.to_laminate(num_layers)
    sheet=sheet.to_laminate(num_layers)

    removable_scrap = calculate_removable_scrap(design2,sheet,support_width,is_adhesive

    web = (removable_scrap-placement_holes2)-layer_id
    return web,sheet
```

In [13]:

```
def calculate_removable_scrap(design,sheet,width,is_adhesive):
    '''this computes all removable scrap given a sheet, a design, and a clearance width
    all_scrap = sheet-design

    ru = foldable_robotics.manufacturing.not_removable_up(design,is_adhesive)
    rd = foldable_robotics.manufacturing.not_removable_down(design,is_adhesive)

    removable_scrap_up = all_scrap-(ru<<width)
    removable_scrap_down = all_scrap-(rd<<width)

    removable_scrap = removable_scrap_up|removable_scrap_down
    return removable_scrap
```

In [14]:

```
user_path = os.path.abspath(os.path.expanduser('~'))
user_path
```

Out[14]:

```
'C:\\Users\\aakwa'
```

1 Layer Robot

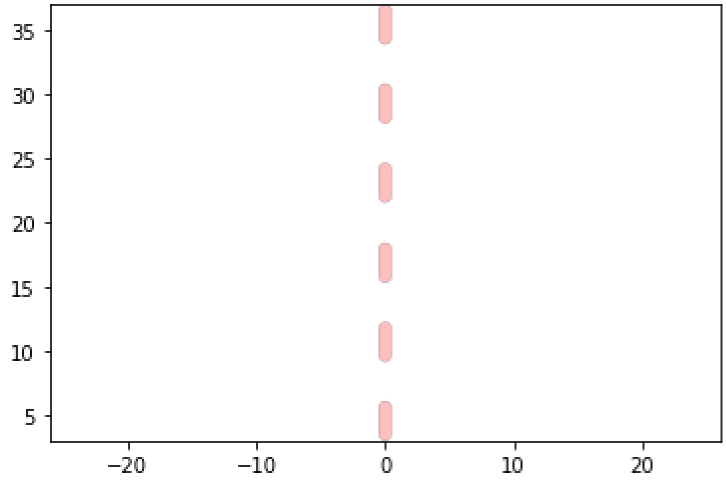
In [68]:

```
l = 240
h = 40
seg = 30

radius = .5
num_perforations = 6
num_segments = num_perforations*2+1
num_points = num_segments+1
a=numpy.r_[0:h:num_points*1j]
lines = []
for ii in range(int(len(a)/2)-1):
    p1 = sg.Point(a[2*ii+1]+radius,0)
    p2 = sg.Point(a[2*ii+2]-radius,0)
    lines.append(sg.LineString((p1,p2)))
hinge = Layer(*lines)
hinge<<=radius
```

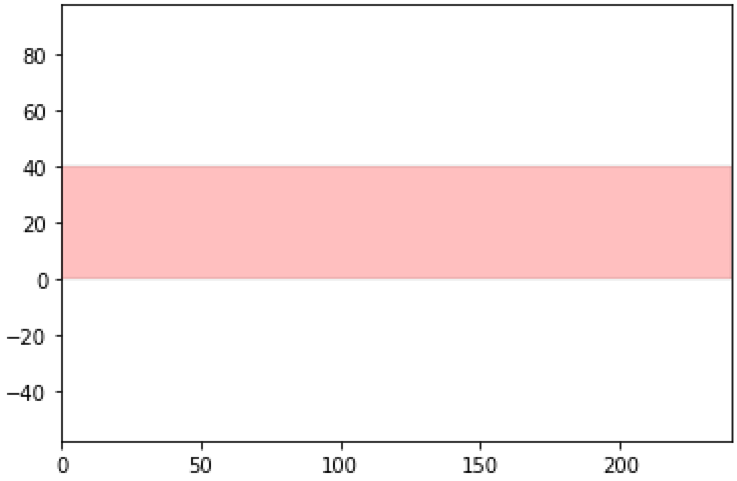
In [69]:

```
hinge = hinge.rotate(90)
hinge.plot()
```



In [70]:

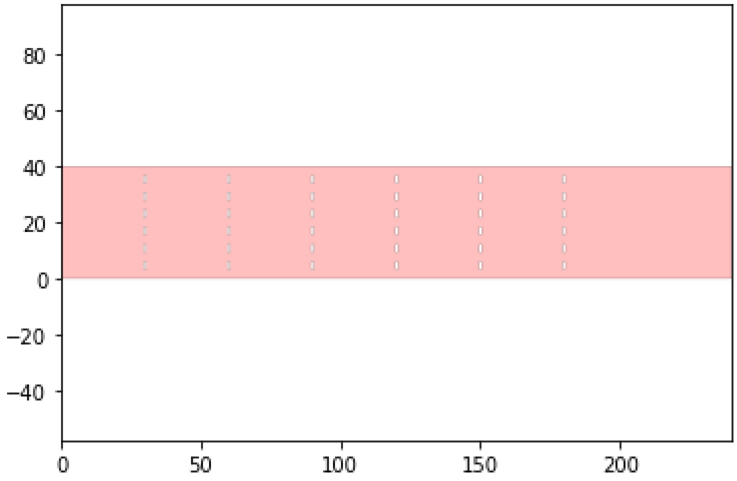
```
body = Layer(sg.Polygon([[0,0],[l,0],[l,h],[0,h]]))
body.plot()
```



In [71]:

```
joint = body-hinge.translate(seg,0)-hinge.translate(seg*2,0)-hinge.translate(seg*3,0)-h

joint.plot()
```



In [72]:

```
joint.export_dxf('Single_Layer')
```

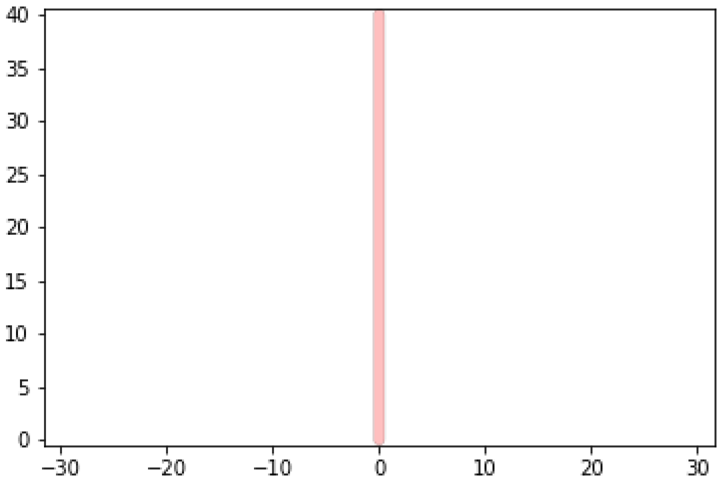
5 Layer Robot

In [77]:

```
line = Layer(sg.LineString(((h,0),(0,0))))
line<<=radius
```

In [78]:

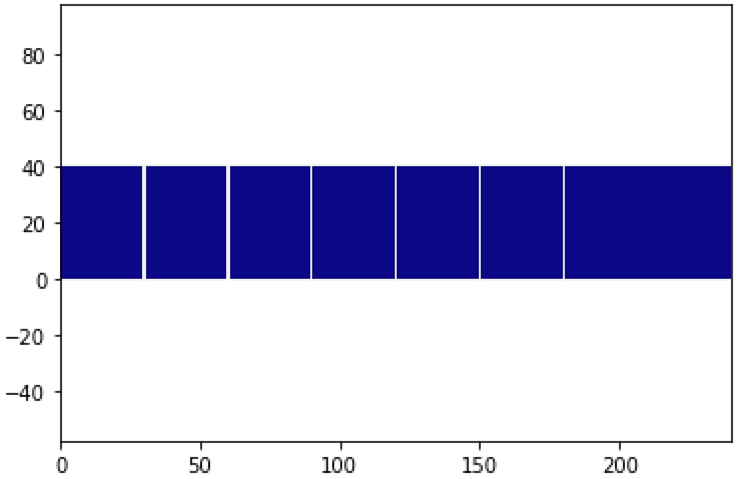
```
line = line.rotate(90)
line.plot()
```

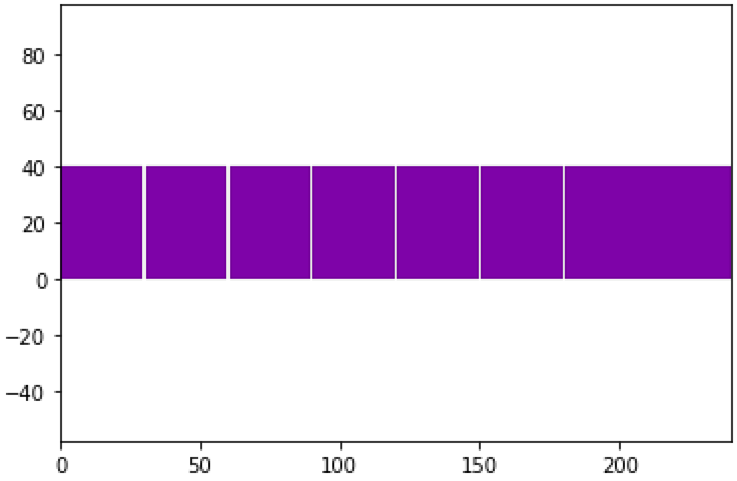


In [81]:

```
multilayer_hinge = Laminate(line,line,Layer(),line,line)
multilayer_body = Laminate(body,body,body,body,body)
joint5 = multilayer_body-multilayer_hinge.translate(seg*1,0)-multilayer_hinge.translate

joint5.plot_layers()
```




80
60
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0
−20
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0
50
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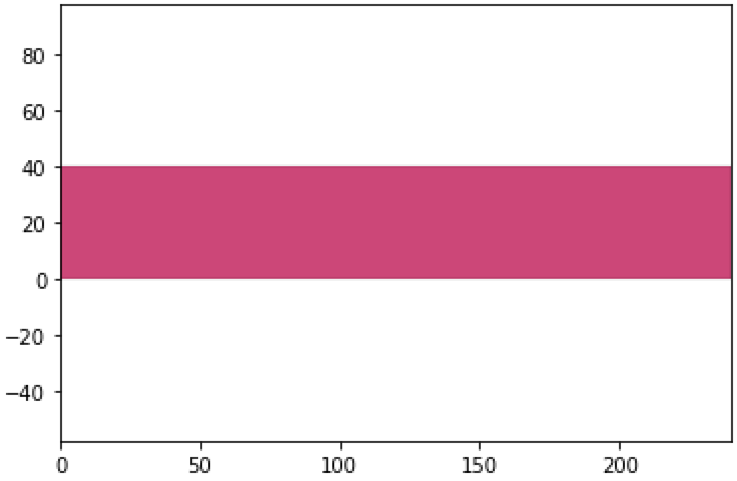
150
200


80
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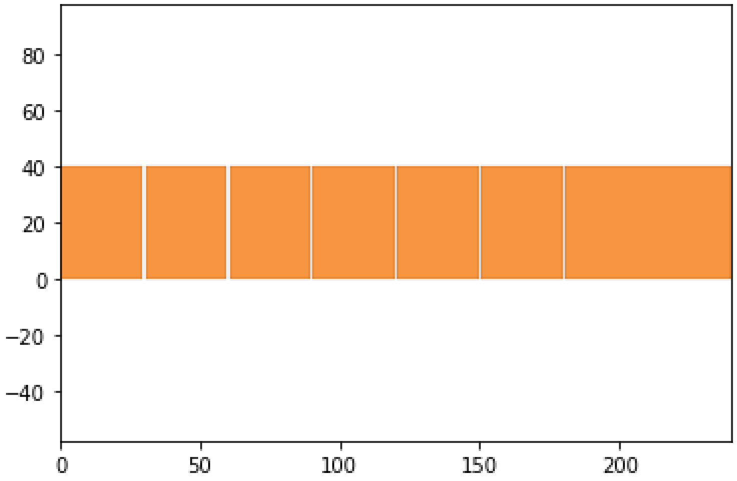
80
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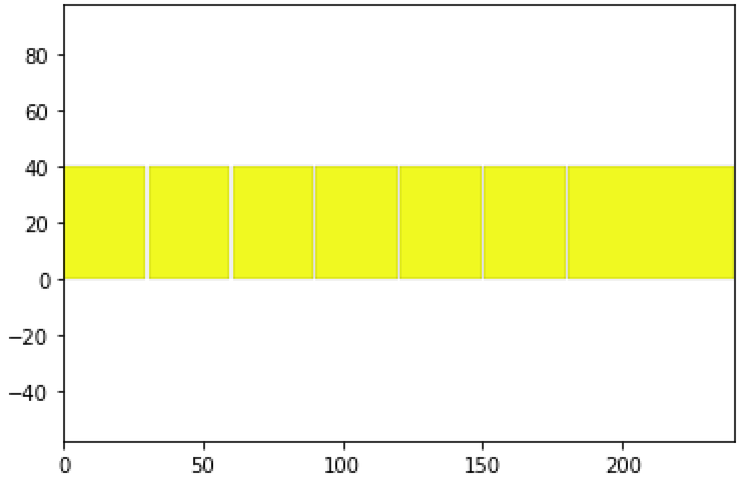
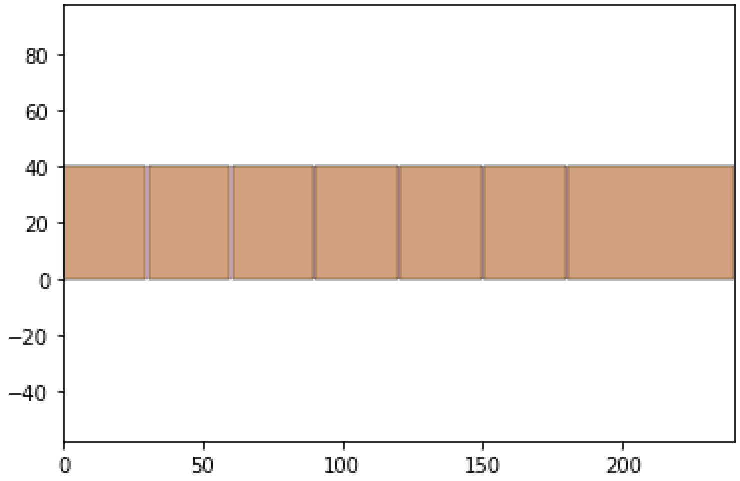
200



```
In [76]: joint5.plot()
```



```
In [82]: joint5.export_dxf('5_Layer')
```

5-Layer Manufacturing Design

```
In [23]: folder = 'C:/Users/aakwa/Dropbox (ASU)/Term 8/EGR 557/Solidworks Model/'
         input_filename = folder+'Full_Spine - Sheet1_Drawing View1.yaml'
         output_file_name = 'design.dxf'
```

```
In [24]: round_digits = 5
         prescale=1000
         body_prebuffer=-.01
         joint_tolerance = 1e-5

         round_digits = 2
         prescale=1000
         jig_diameter = 5
         support_width = 1
         kerf = .05
         jig_hole_spacing=20
```

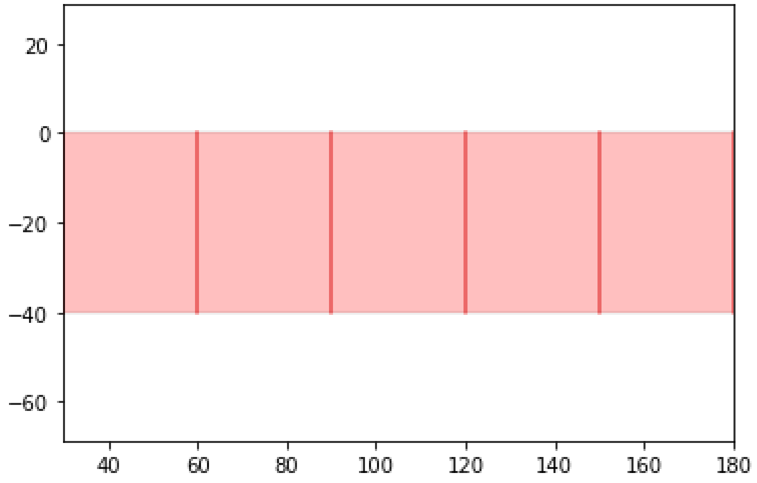
```
is_adhesive = [False,True,False,True,False]
arc_approx = 10
```

In [25]:

```
foldable_robotics.solidworks_support.process(input_filename,output_file_name,prescale,r
```

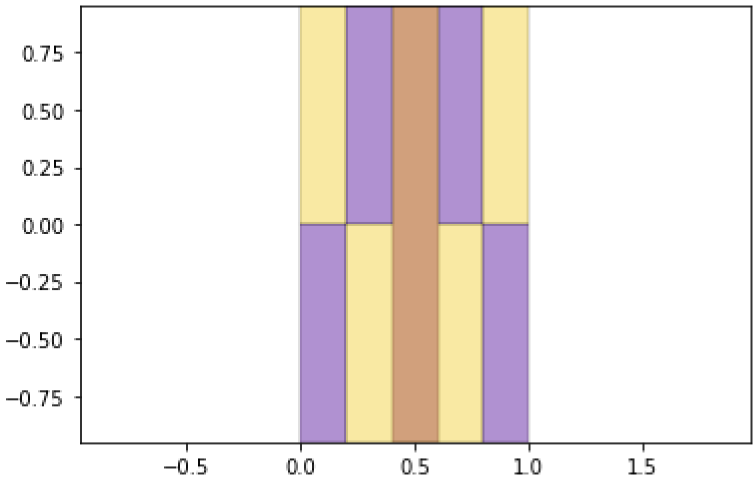
Out[25]:

```
(<foldable_robotics.layer.Layer at 0x254fb332d60>,
 <foldable_robotics.layer.Layer at 0x254fb65e5e0>,
 [<foldable_robotics.solidworks_support.Component at 0x254fb65e040>,
  <foldable_robotics.solidworks_support.Component at 0x254fb65e580>,
  <foldable_robotics.solidworks_support.Component at 0x254fb65e700>,
  <foldable_robotics.solidworks_support.Component at 0x254fb65e880>,
  <foldable_robotics.solidworks_support.Component at 0x254fb65e100>,
  <foldable_robotics.solidworks_support.Component at 0x254fb65e820>,
  <foldable_robotics.solidworks_support.Component at 0x254fb65e550>])
```



In [26]:

```
hinge = foldable_robotics.parts.castellated_hinge1.generate()
w=hinge_width_calculator(150,1.1)
hinge = hinge.scale(1,w)
hinge.plot()
```



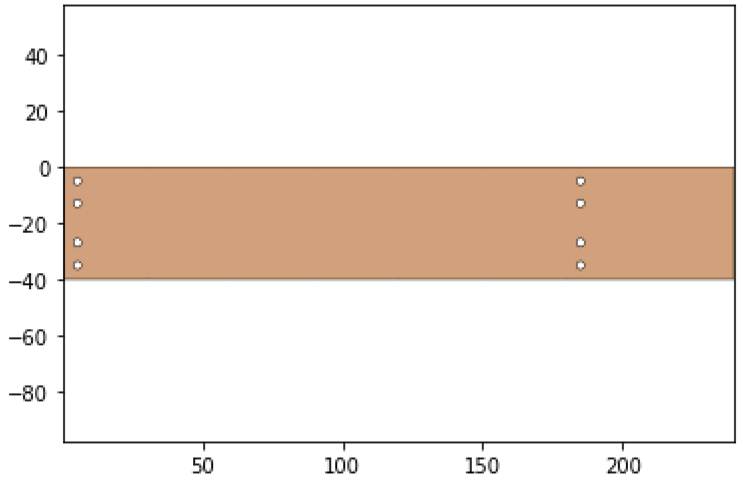
In [27]:

```
NUMLAYERS = len(hinge)
```

In [28]:

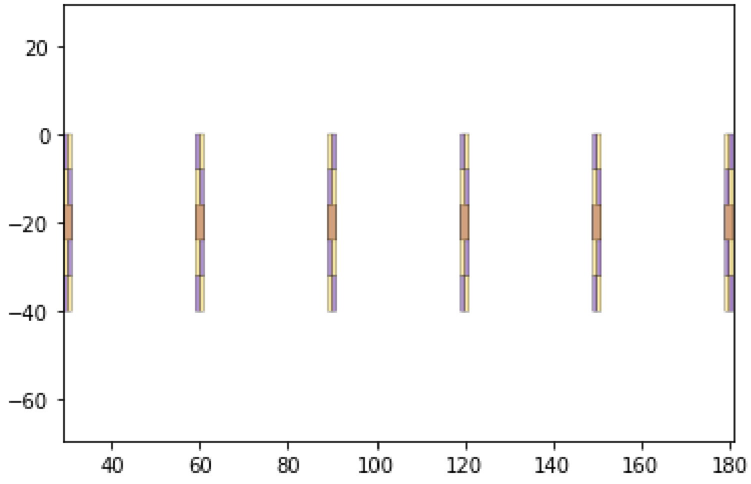
```
body = get_bodies(output_file_name,'body',NUMLAYERS)
body = foldable_robotics.manufacturing.cleanup(body,.02)
```

```
body.plot()
```



In [29]:

```
joint_lines= get_hinge_lines(output_file_name,'joints')
joints = hinge_lines_to_hinges(joint_lines,hinge)
joints = foldable_robotics.manufacturing.cleanup(joints,.02)
joints.plot()
```



In [30]:

```
cuts = get_cuts(output_file_name,'cuts',.02,NUMLAYERS)
#cuts.plot()
```

In [31]:

```
holes = get_holes(output_file_name,'holes',NUMLAYERS)
#holes.plot()
```

In [32]:

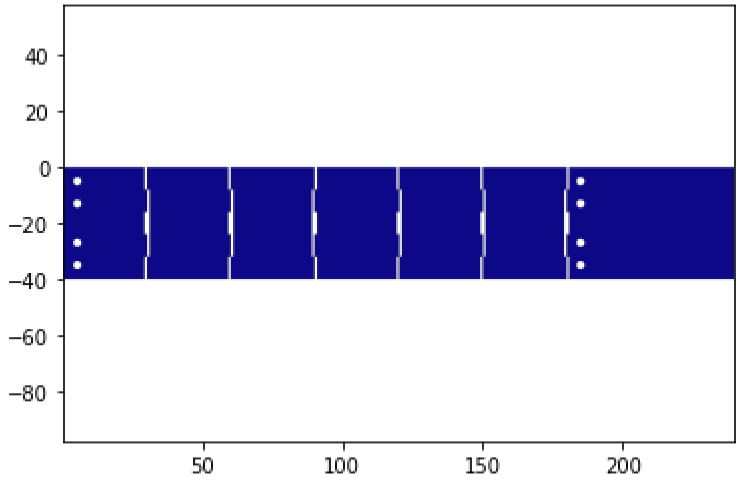
```
hole,dummy = foldable_robotics.manufacturing.calc_hole(joint_lines,w)
hole = hole.to_laminate(NUMLAYERS)
hole<<=.2
hole.plot()
```

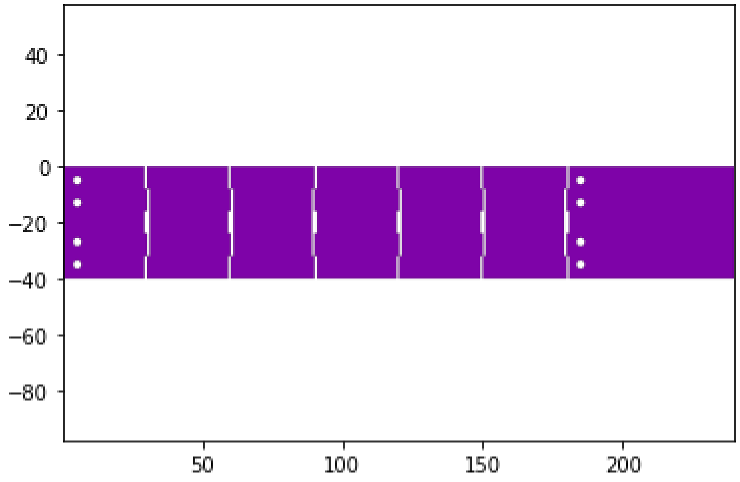
```
('zero-size array to reduction operation minimum which has no identity',)
<Figure size 432x288 with 0 Axes>
```

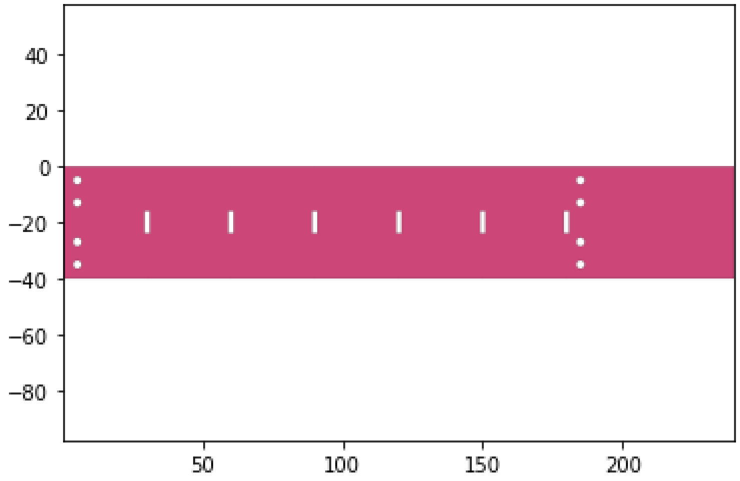
In [53]:

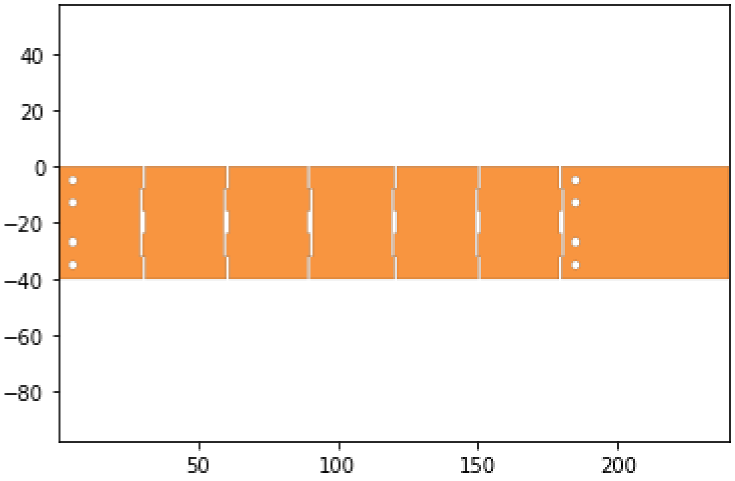
```
design2 = body- hole - joints - cuts - holes
```

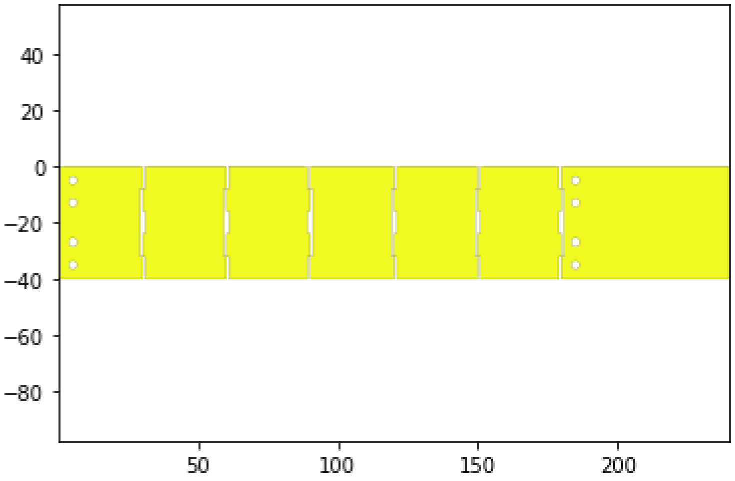
```
design2.plot_layers()
```





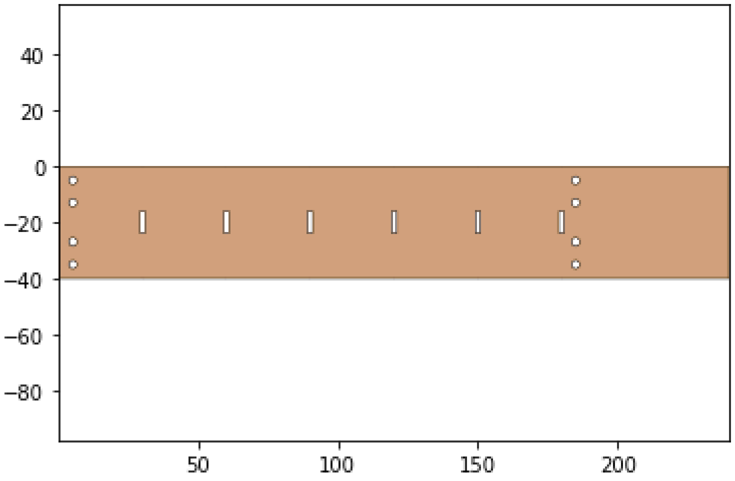






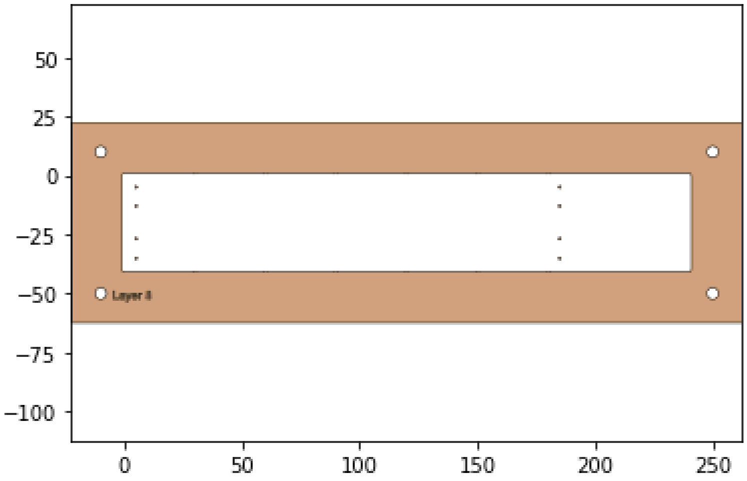
In [34]:

```
keepout =  foldable_robotics.manufacturing.keepout_laser(design2)
keepout.plot()
```



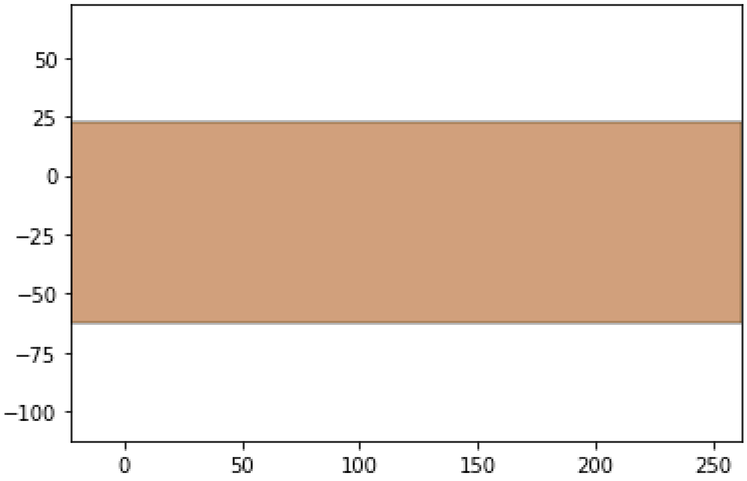
In [35]:

```
web,sheet=build_web(design2,keepout,support_width,jig_diameter,jig_hole_spacing,is_adhe
web.plot()
```



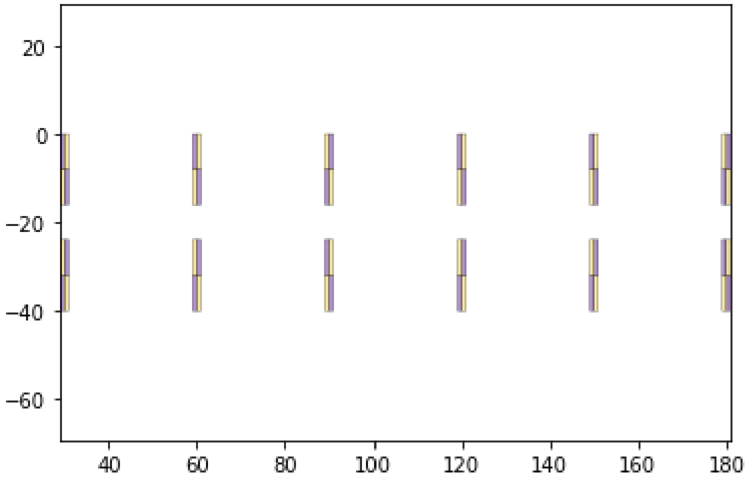
In [36]:

```
sheet.plot()
```



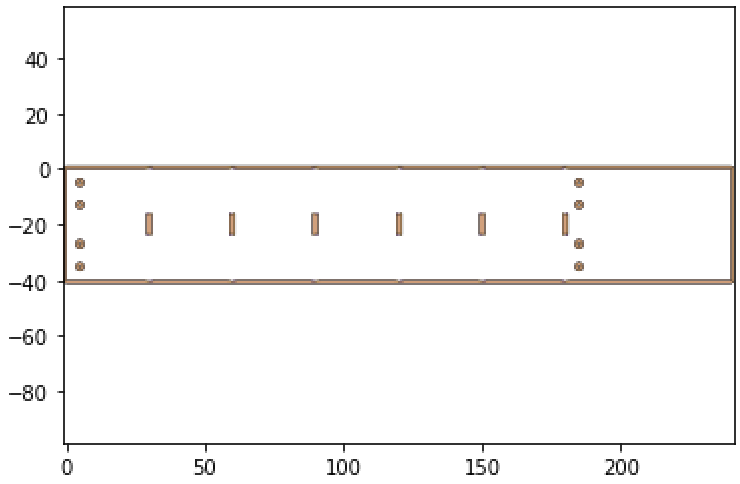
In [37]:

```
second_pass_scrap = sheet-keepout
first_pass_scrap = sheet - design2-second_pass_scrap
first_pass_scrap = foldable_robotics.manufacturing.cleanup(first_pass_scrap,.00001)
first_pass_scrap.plot()
```



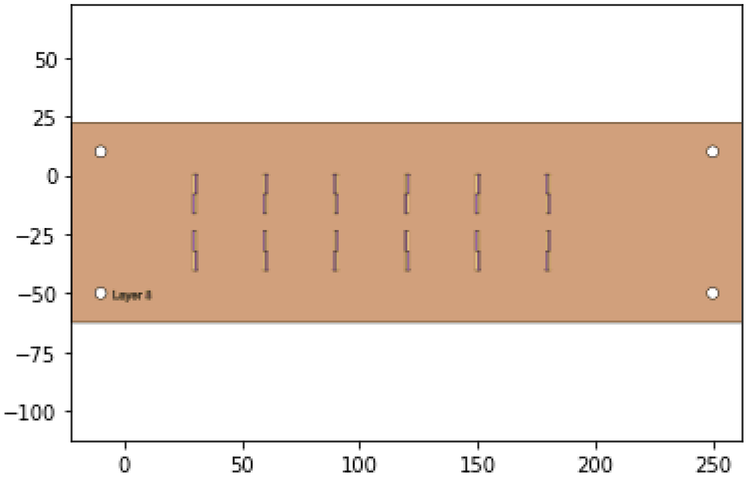
In [38]:

```
support = foldable_robotics.manufacturing.support(design2,foldable_robotics.manufacturi
support.plot()
```



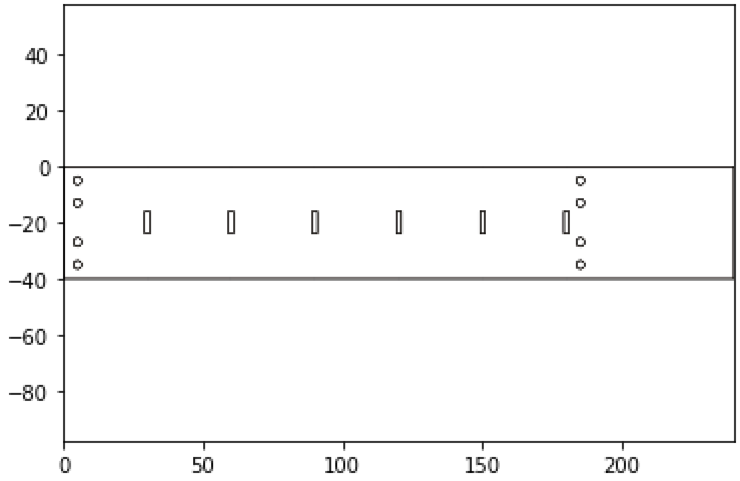
In [39]:

```
#Calculate the web by using only the material which can be cut, minus a gap determined
supported_design = web|design2|support
supported_design.plot()
```



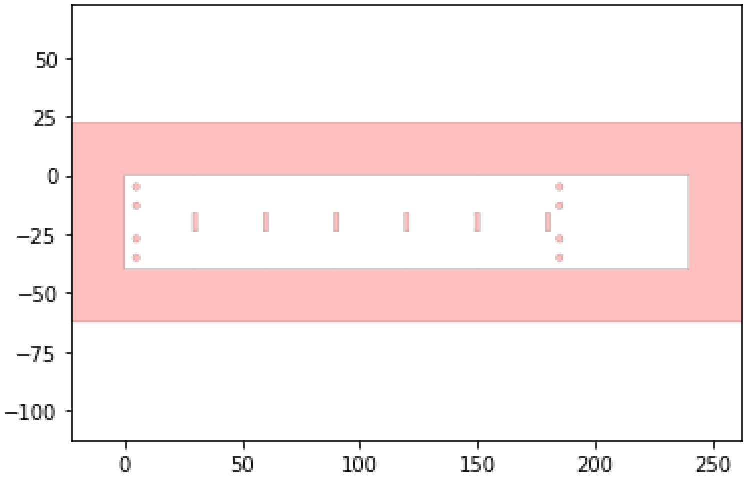
In [40]:

```
#cut_line = keepout<<kerf
cut_material = (keepout<<kerf)-keepout
cut_material.plot()
```



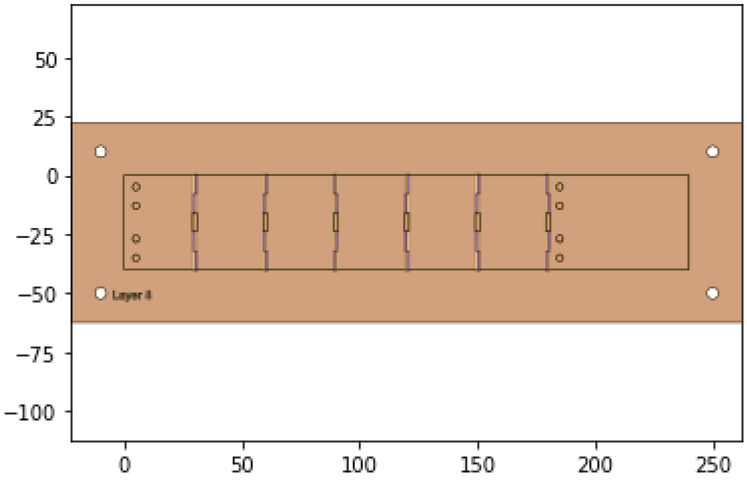
In [41]:

```
final_cut = sheet - keepout
final_cut = final_cut[0]
final_cut.plot()
```



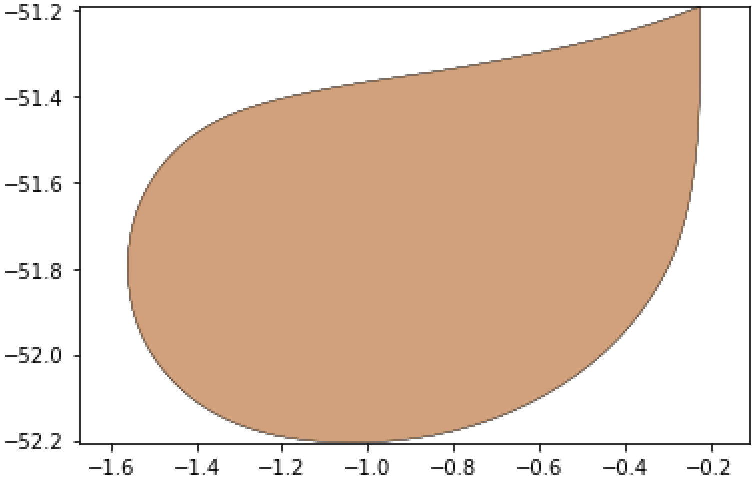
In [42]:

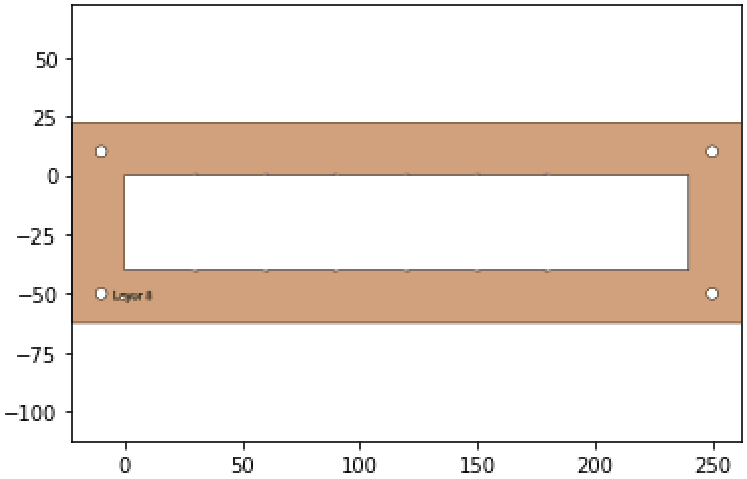
```
remaining_material = supported_design-cut_material
remaining_material.plot()
```

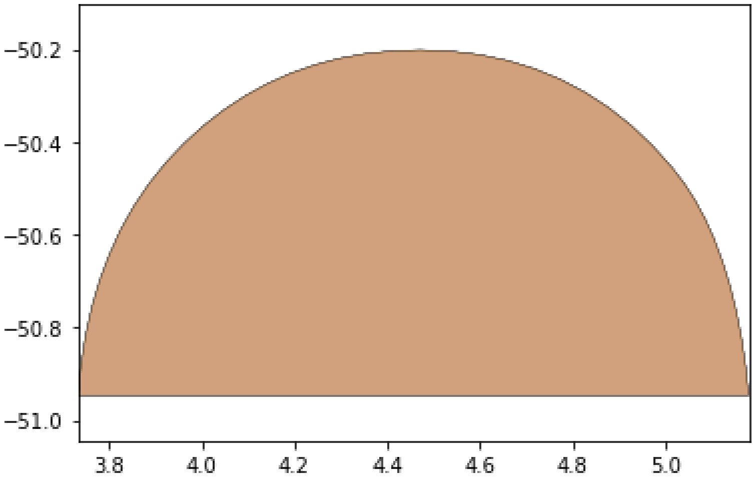


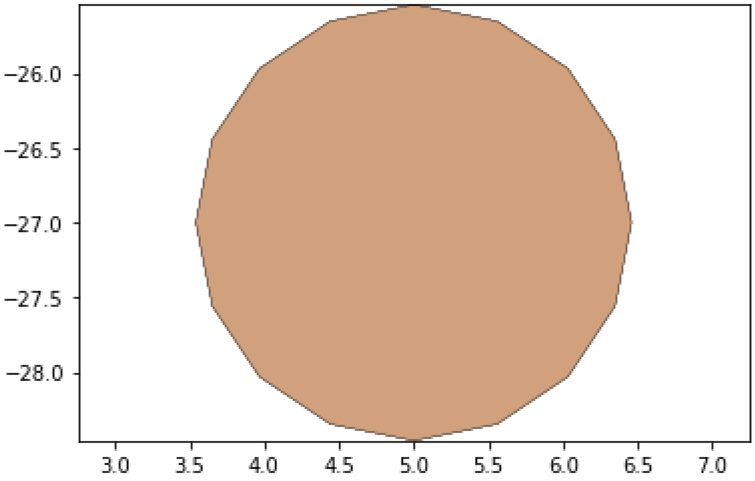
In [43]:

```
remaining_parts = foldable_robotics.manufacturing.find_connected(remaining_material,is_
for item in remaining_parts:
    item.plot(new=True)
```


−51.2
−51.4
−51.6
−51.8
−52.0
−52.2
−1.6
−1.4
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2


50
25
0
−25
−50
−75
−100
Layer 4
0
50
100
150
200
250


−50.2
−50.4
−50.6
−50.8
−51.0
3.8
4.0
4.2
4.4
4.6
4.8
5.0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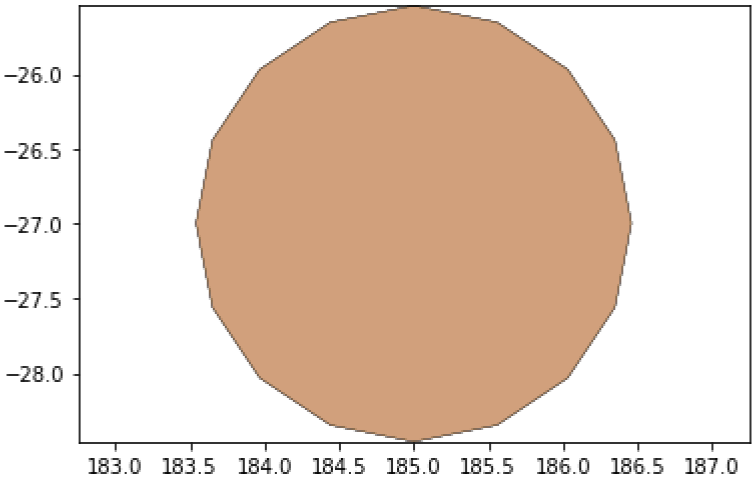
−26.5
−27.0
−27.5
−28.0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0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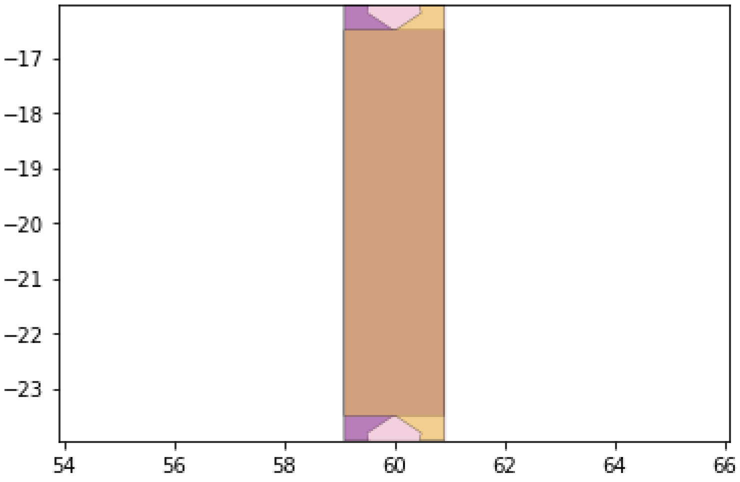
−26.5
−27.0
−27.5
−28.0
183.0
183.5
184.0
184.5
185.0
185.5
186.0
186.5
187.0


−17
−18
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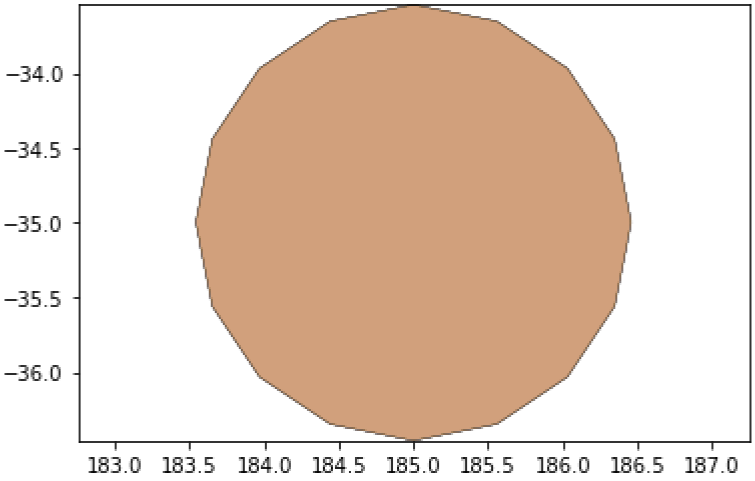
−20
−21
−22
−23
54
56
58
60
62
64
66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183.5
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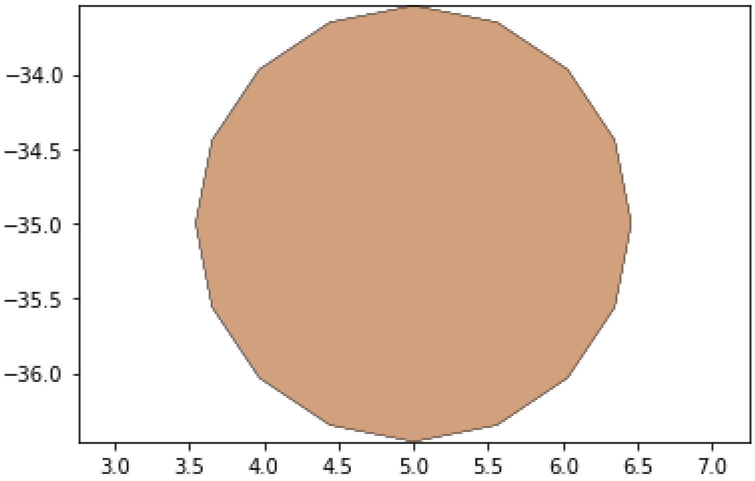
186.0
186.5
187.0


−34.0
−34.5
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3.0
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4.0
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6.5
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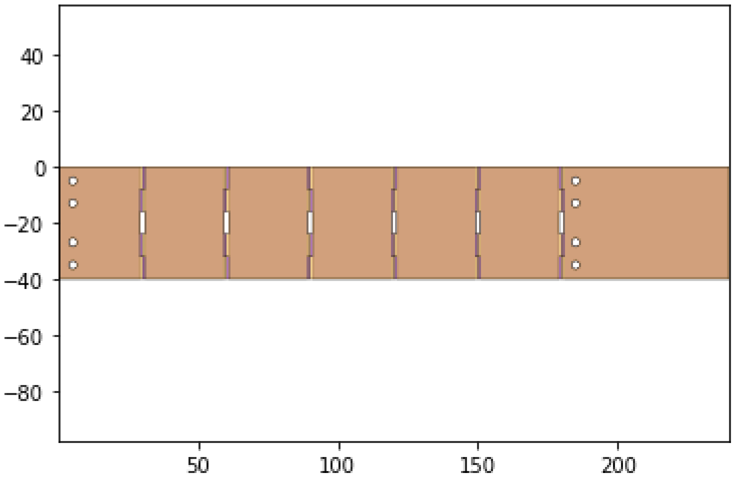
40
20
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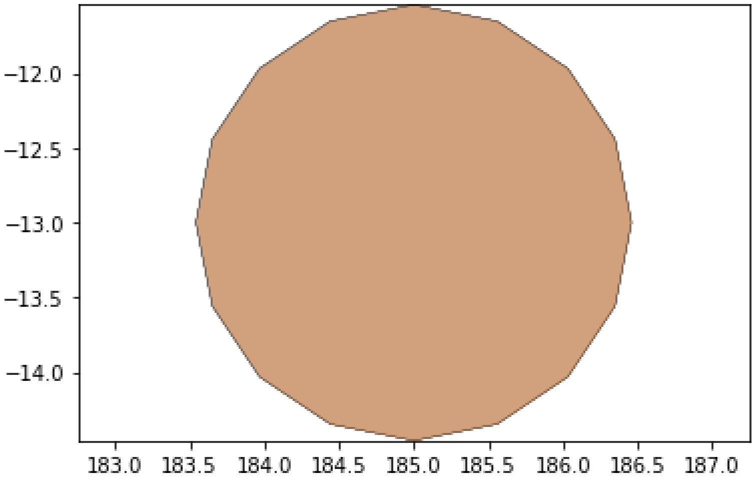
−40
−60
−80
50
100
150
200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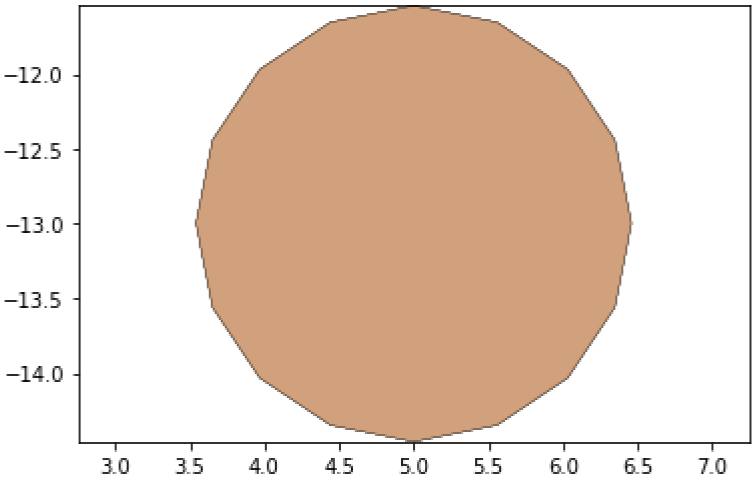
−14.0
183.0
183.5
184.0
184.5
185.0
185.5
186.0
186.5
187.0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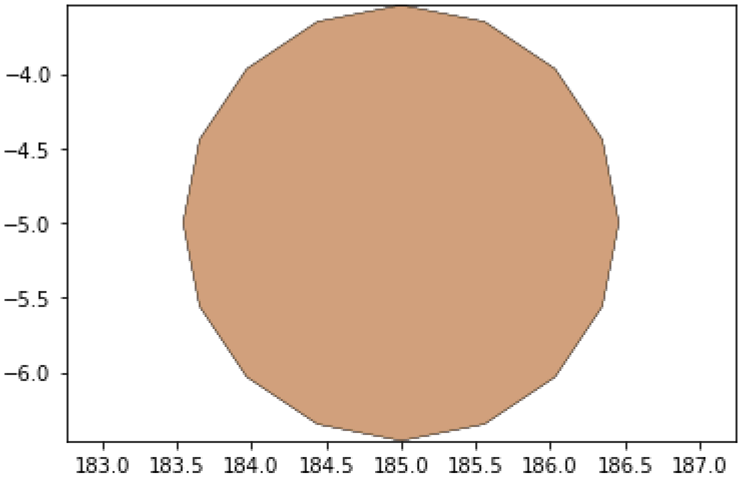
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0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183.0
183.5
184.0
184.5
185.0
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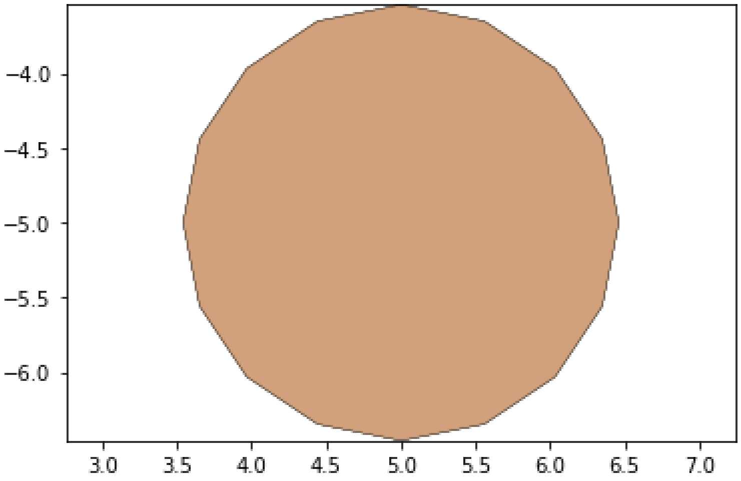
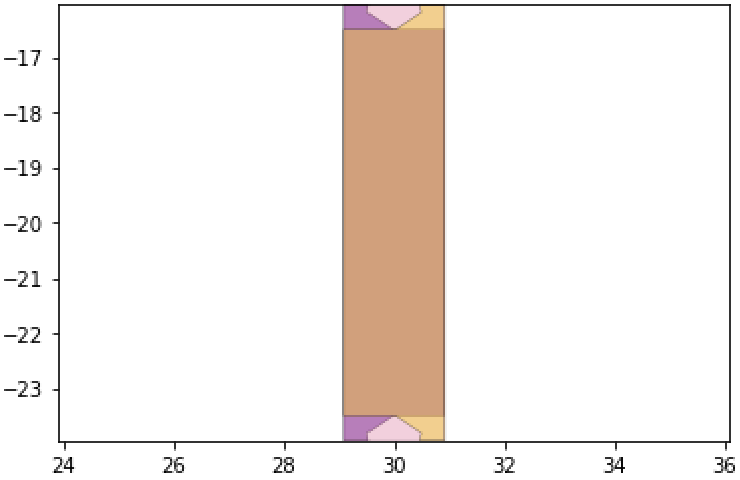
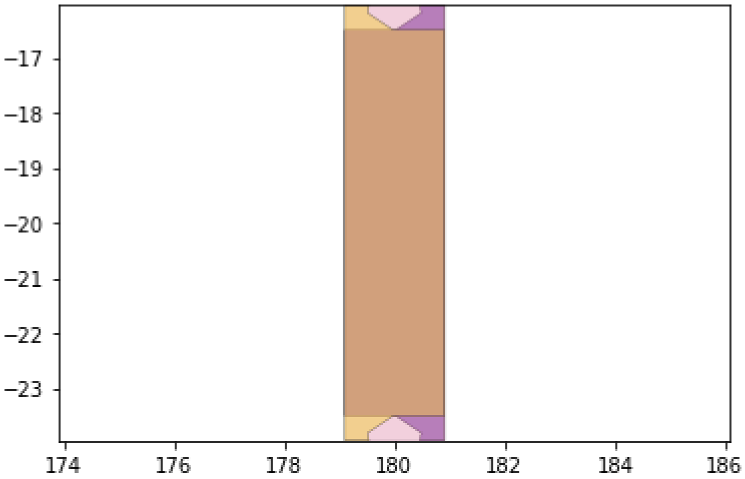
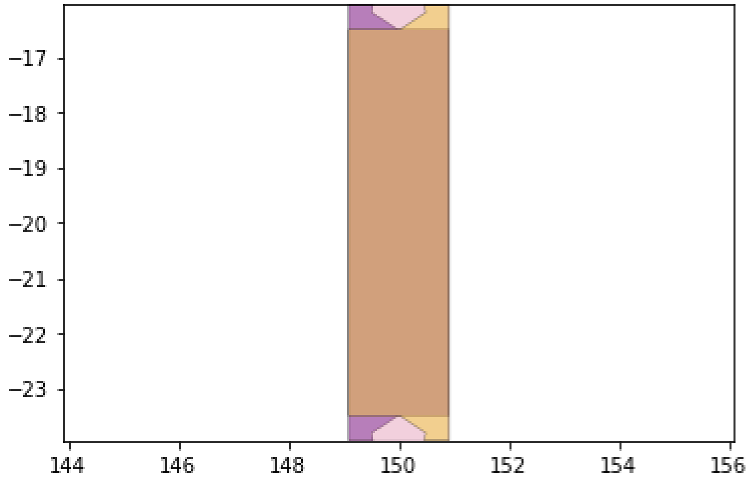
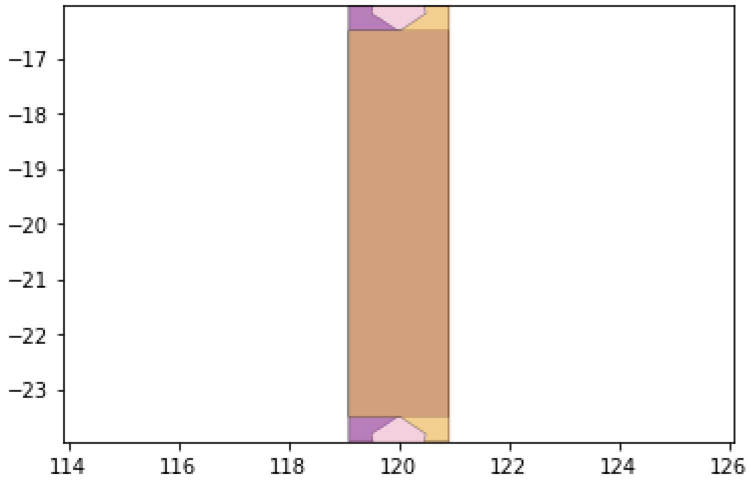
186.0
186.5
187.0

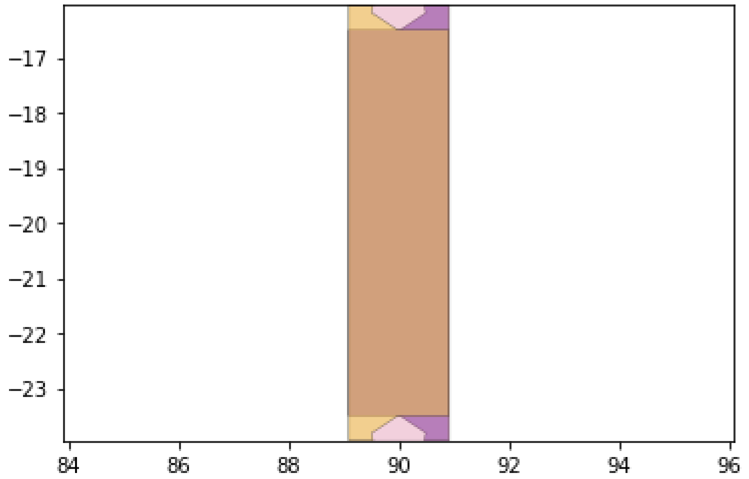

−4.0
−4.5
−5.0
−5.5
−6.0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0


−17
−18
−19
−20
−21
−22
−23
24
26
28
30
32
34
36


−17
−18
−19
−20
−21
−22
−23
174
176
178
180
182
184
186

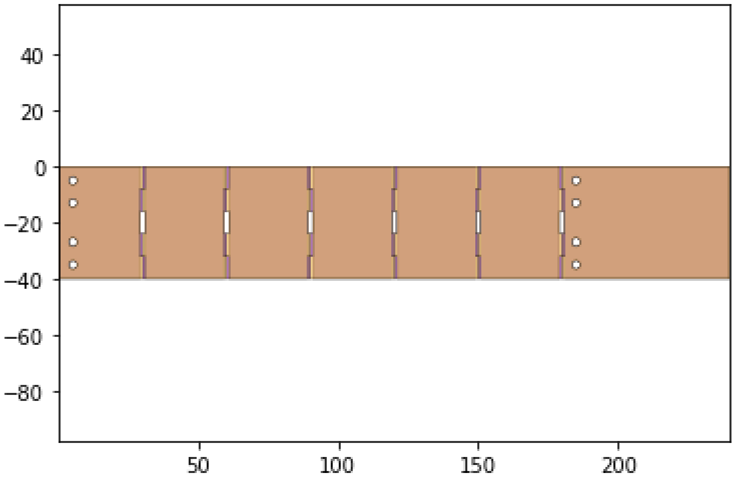






In [44]:

```
d3=design2>>1
for item in remaining_parts:
    if not (item&d3).is_null():
        break
item.plot()
```

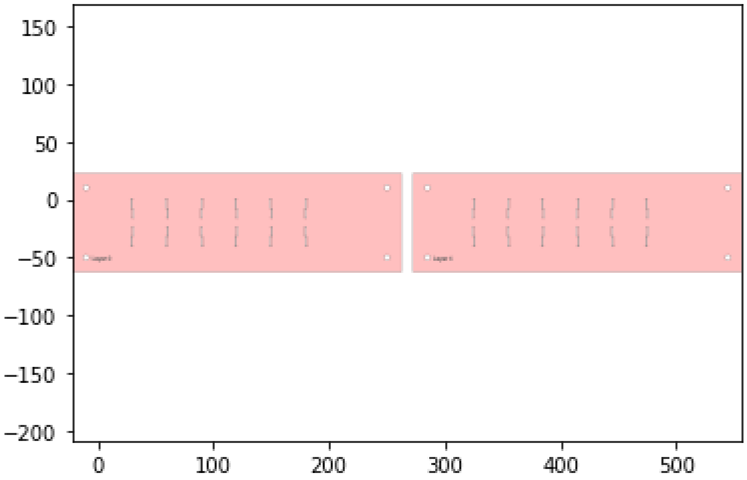


In [45]:
```
check = (item^design2)
check>>=1e-5
check.plot()
```

```
('zero-size array to reduction operation minimum which has no identity',)
```

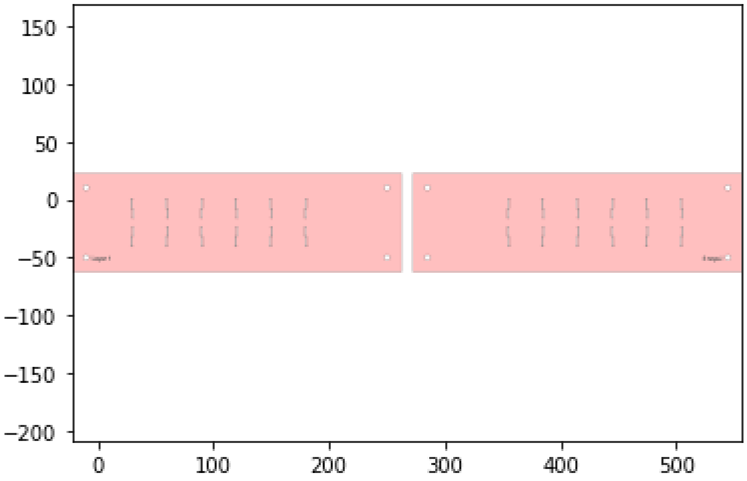
In [46]:
```
w,h = supported_design.get_dimensions()
p0,p1 = supported_design.bounding_box_coords()

rigid_layer = supported_design[0] | (supported_design[-1].translate(w+10,0))
rigid_layer.plot()
```



In [47]:
```
l4 = supported_design[3].scale(-1,1)
p2,p3 = l4.bounding_box_coords()
l4 = l4.translate(p0[0]-p2[0]+10+w,p0[1]-p2[1])

adhesive_layer = supported_design[1] | l4
adhesive_layer.plot()
```



In [48]:

```
first_pass = Laminate(rigid_layer,adhesive_layer,supported_design[2])
```

In [50]:

```
if check.is_null():
    first_pass.export_dxf('first_pass')
    final_cut.export_dxf('final_cut')
```

In [ ]: