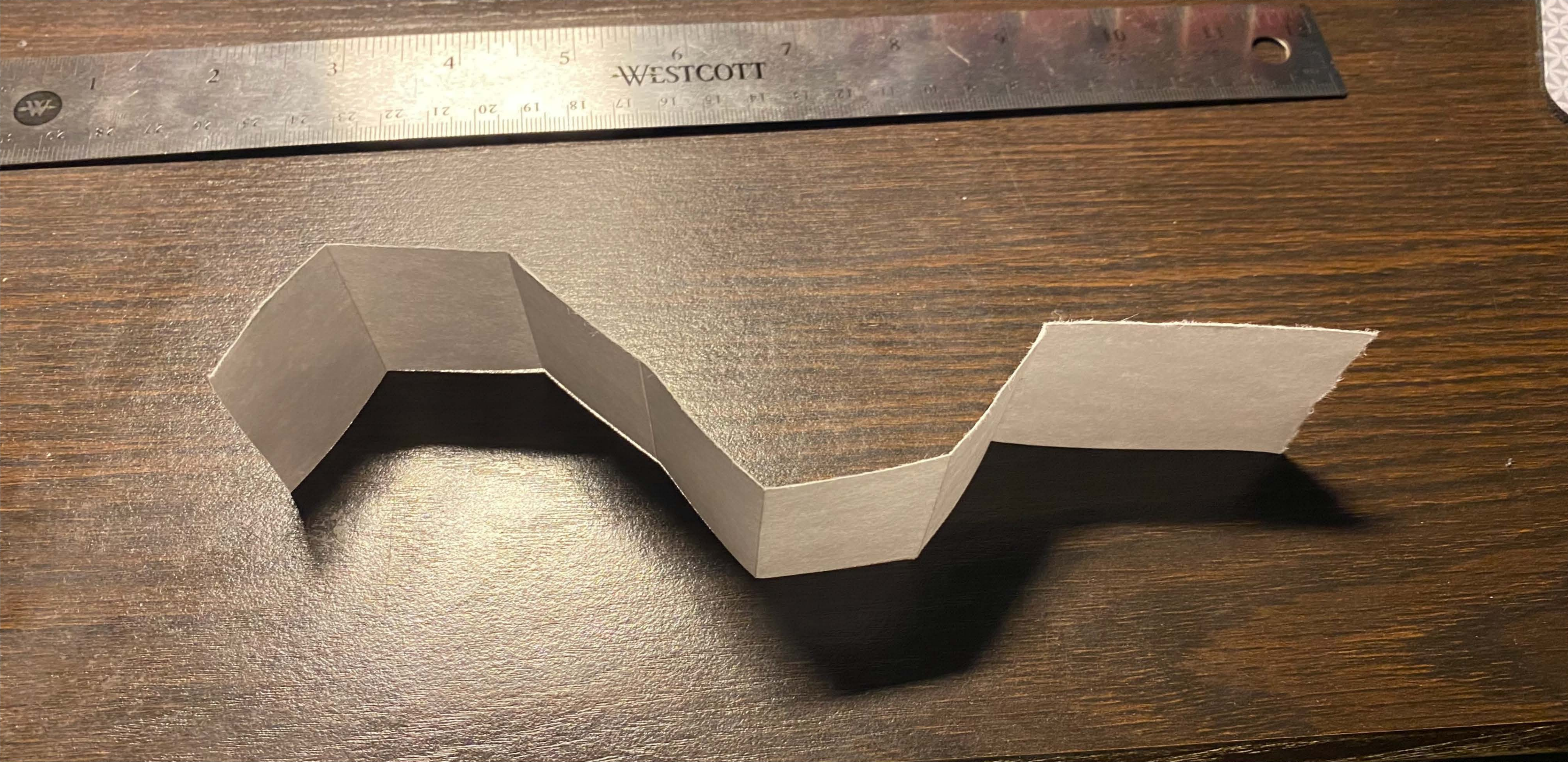
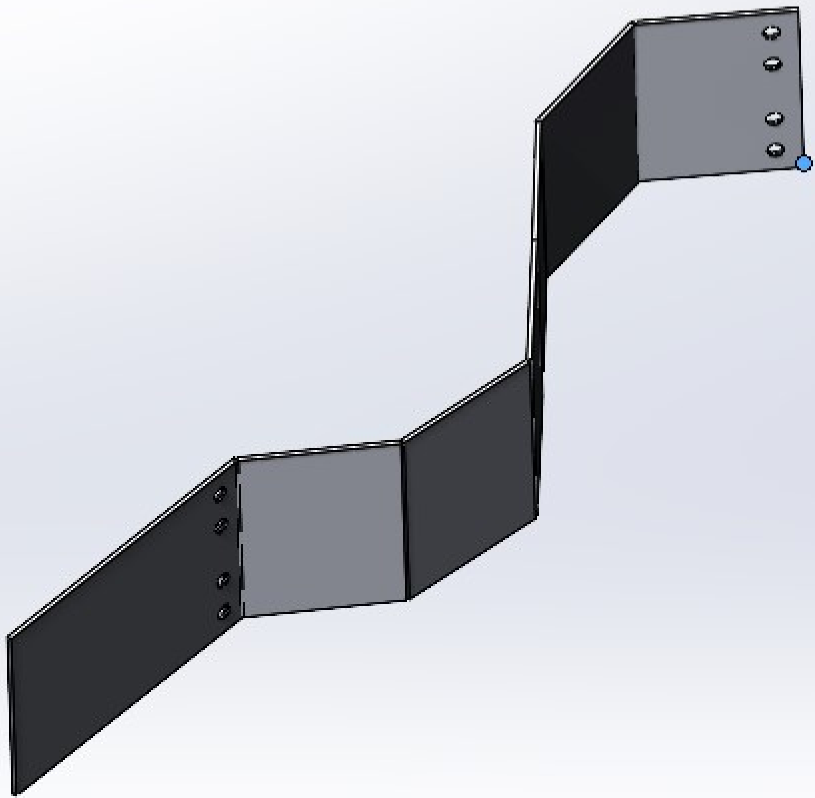
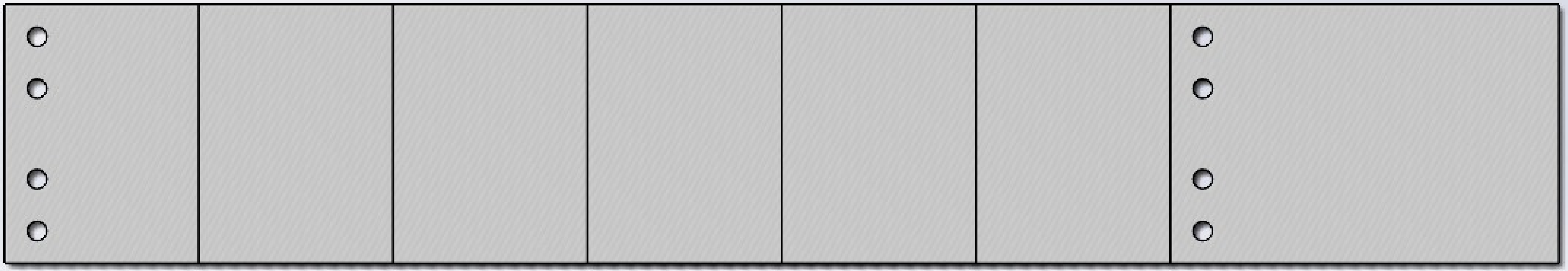
Paper Prototypes


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
```

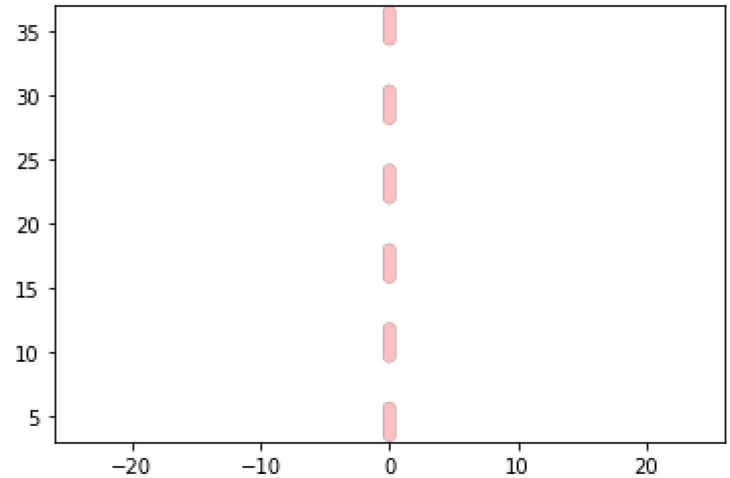
In [14]:
```
user_path = os.path.abspath(os.path.expanduser('~'))
user_path
```

Out[14]: 'C:\\Users\\aakwa'

1 Layer Robot

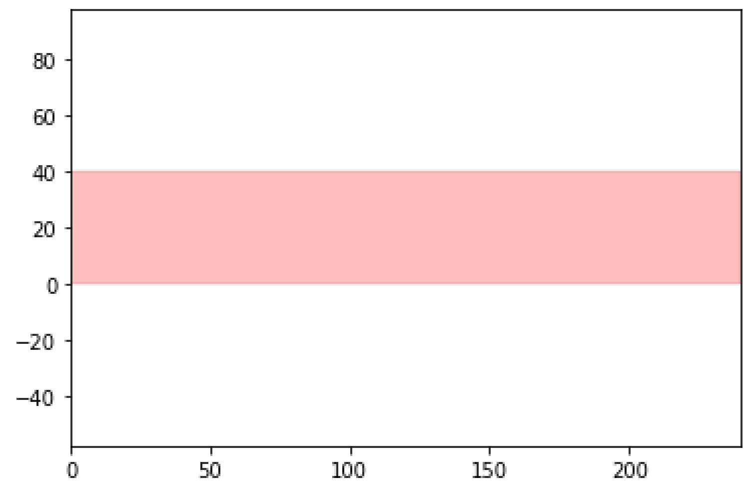
In [68]:
```
l = 240
h = 40
seg = 30

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()
```



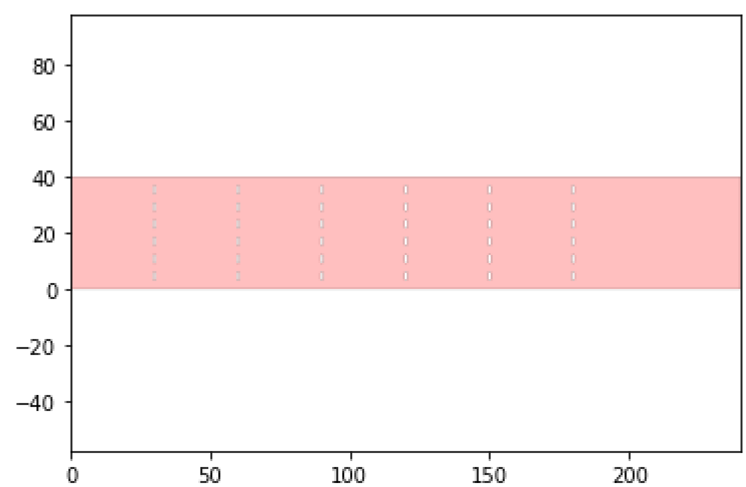
In [70]:

```
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]:

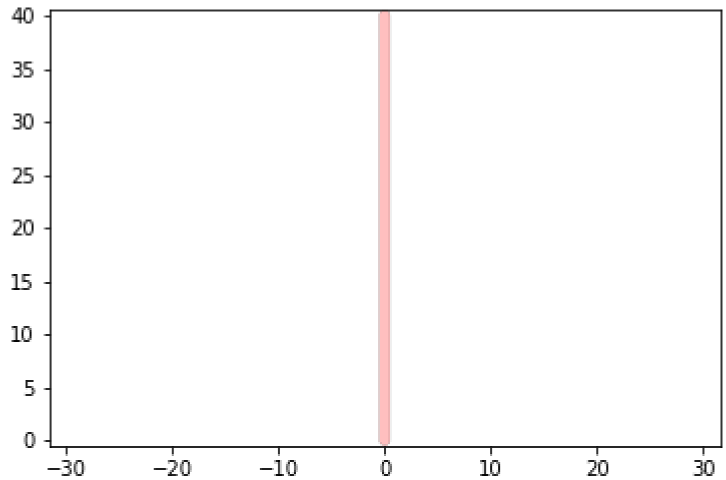
```
joint.export_dxf('Single_Layer')
```

For this design, we would use a single layer of cardstock with serrations to denote each segment of the spine. The serrations will allow for the joints to be weaker than the stiff segments. In order to manufacture this single layer robot, we only need to use a vinyl cutter to generate this pattern. This is because there are no individual components that will be floating in the design so only a vinyl cutter is necessary.

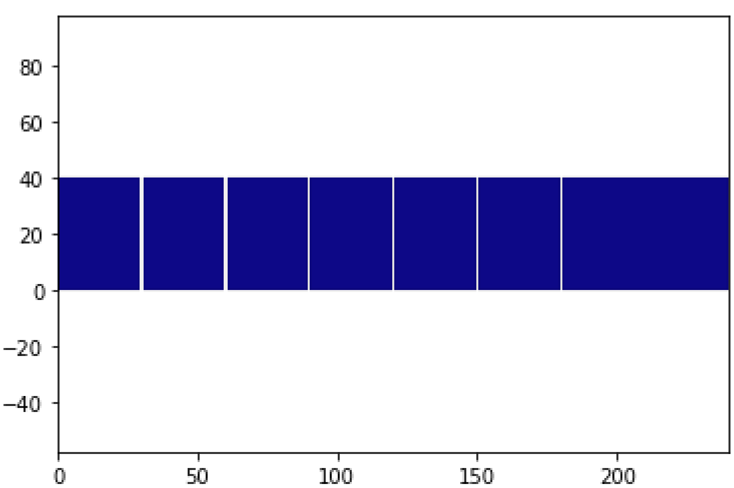
5 Layer Robot

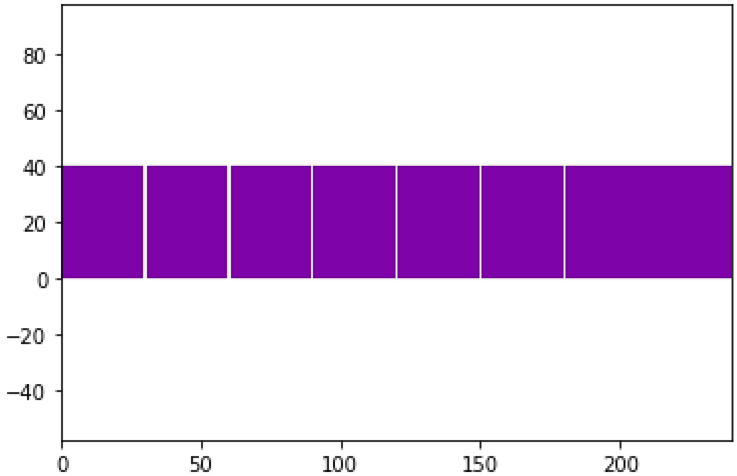
In [77]:
```
line = Layer(sg.LineString(((h,0),(0,0))))
line<<=radius
```

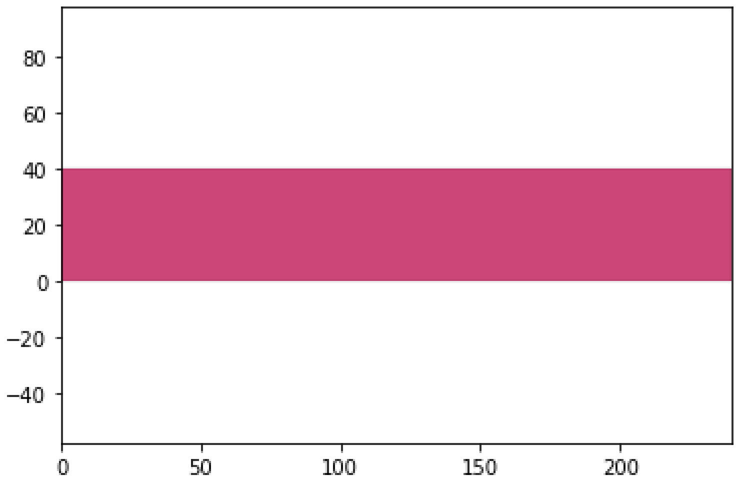
In [78]:
```
line = line.rotate(90)
line.plot()
```

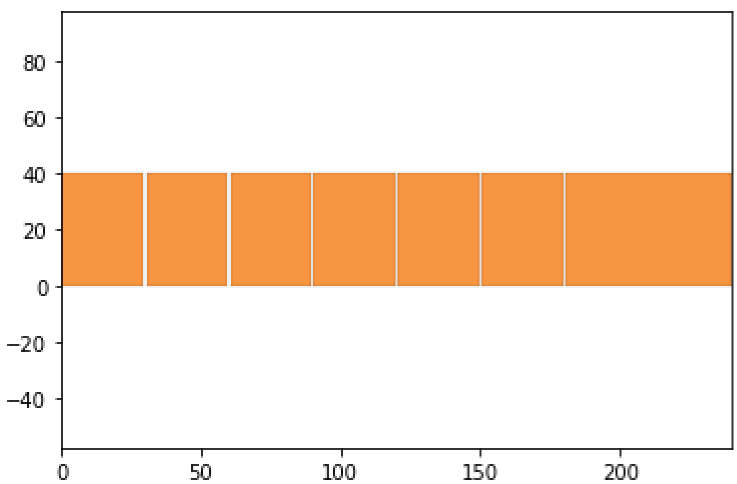


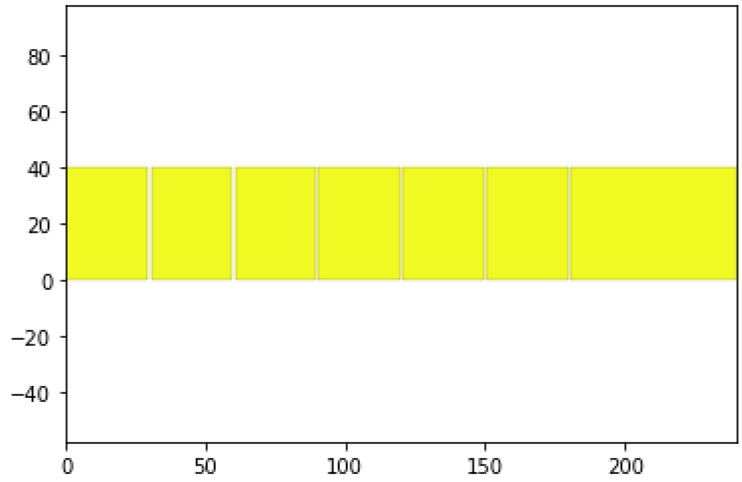
In [81]:
```
multilayer_hinge = Laminate(line,line,Layer(),line,line)
multilayer_body = Laminate(body,body,body,body,body)
joint5 = multilayer_body-multilayer_hinge.translate(seg*1,0)-multilayer_hinge.translate

joint5.plot_layers()
```



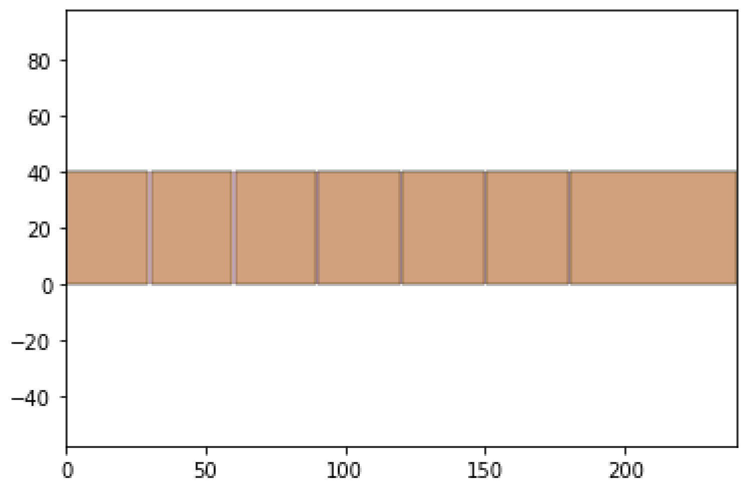

80
60
40
20
0
−20
−40
0
50
100
150
200


80
60
40
20
0
−20
−40
0
50
100
150
200


80
60
40
20
0
−20
−40
0
50
100
150
200



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



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

For this design we will use a stiff material such as cardstock and for the flexible material we plan on using a polycarbonate sheet. The reason for this is because we want to have the joints very flexible and the segments relatively stiff. In order to achieve this laminate design we would need to use a laser cutter in order to get all the layers to match.

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
```

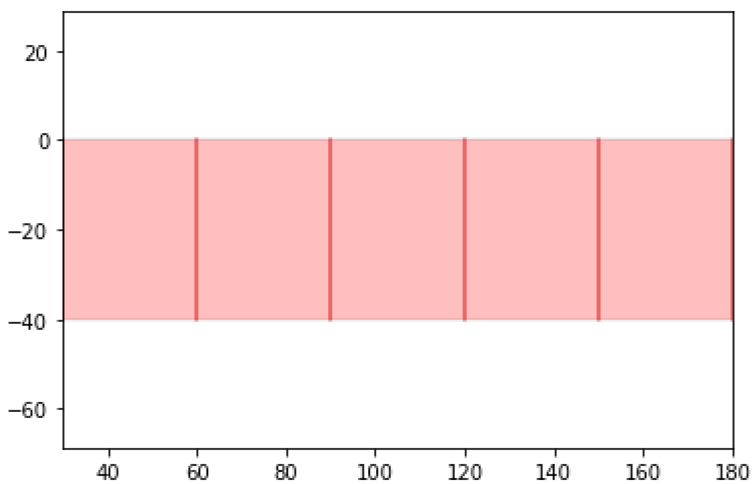
```
round_digits = 2
prescale=1000
jig_diameter = 5
support_width = 1
kerf = .05
jig_hole_spacing=20
is_adhesive = [False,True,False,True,False]
arc_approx = 10
```

In [25]:

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

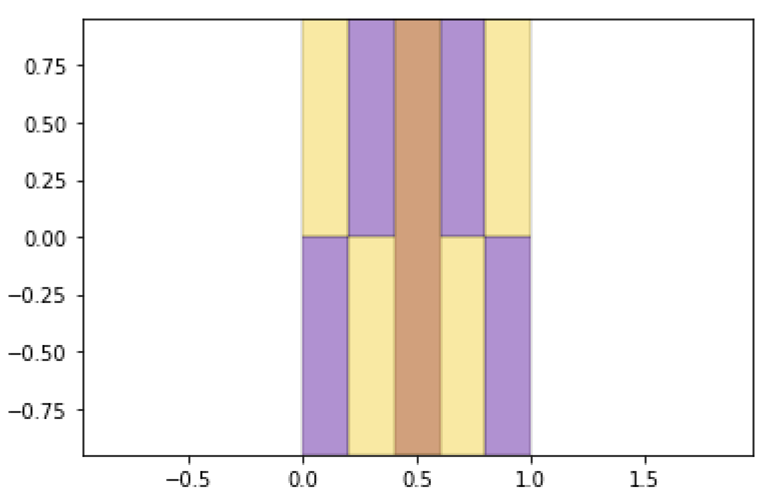
Out[25]:

```
(<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>])
```



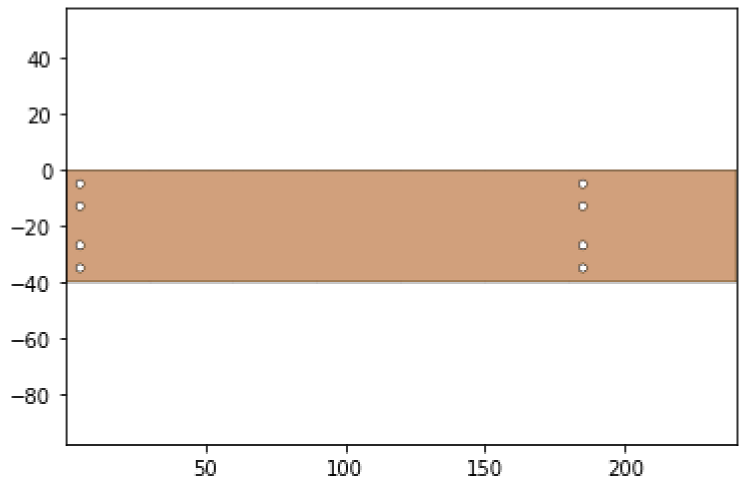
In [26]:

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

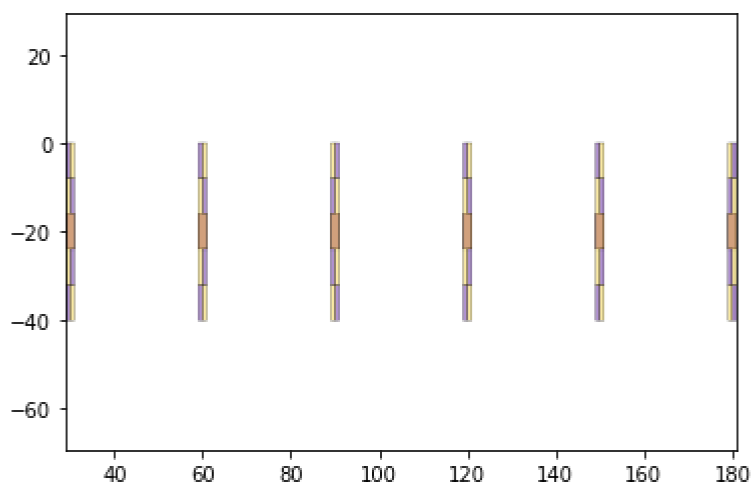


In [27]:
```
NUMLAYERS = len(hinge)
```

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()
```

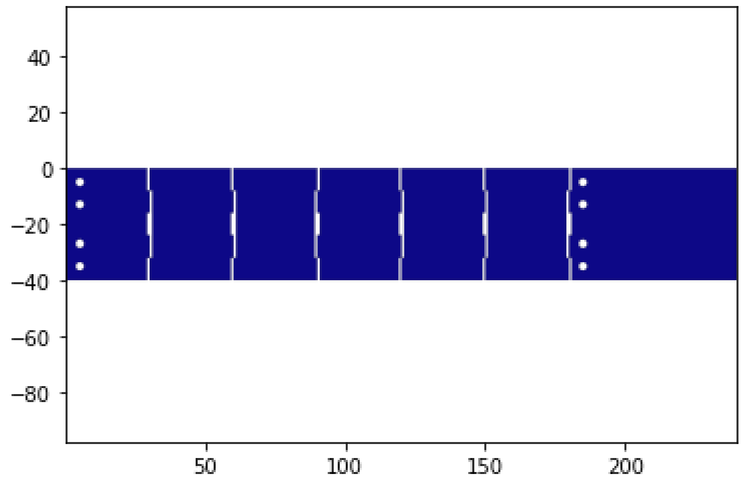
In [31]:
```
holes = get_holes(output_file_name,'holes',NUMLAYERS)
#holes.plot()
```

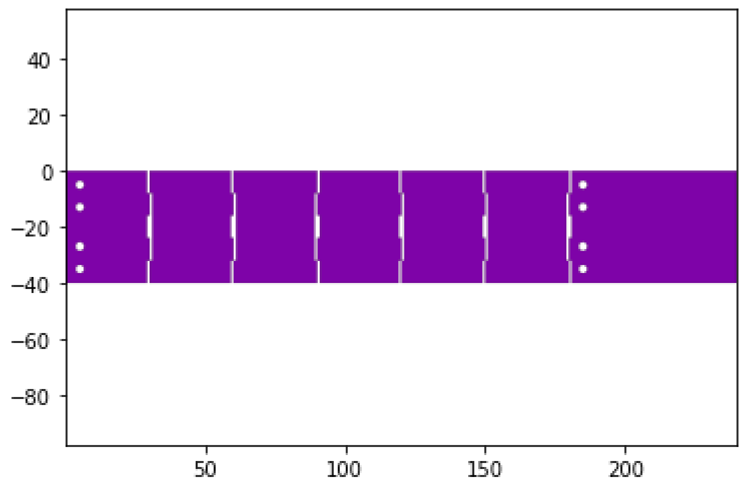
In [32]:
```
hole,dummy = foldable_robotics.manufacturing.calc_hole(joint_lines,w)
hole = hole.to_laminate(NUMLAYERS)
hole<<=.2
hole.plot()
```

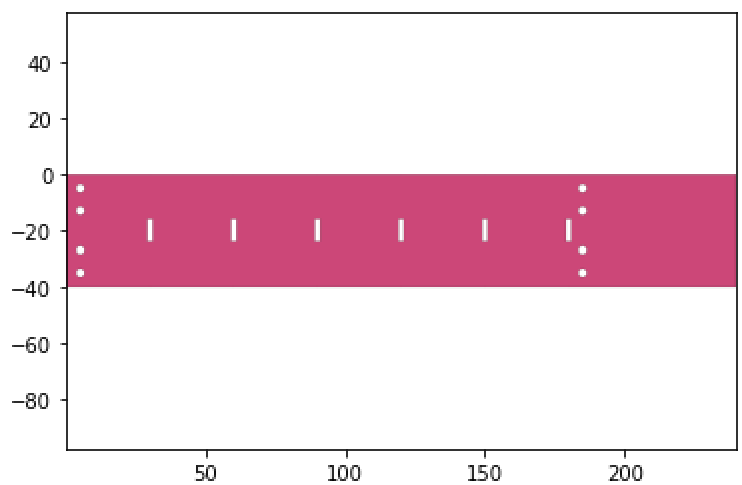
```
('zero-size array to reduction operation minimum which has no identity',)
<Figure size 432x288 with 0 Axes>
```

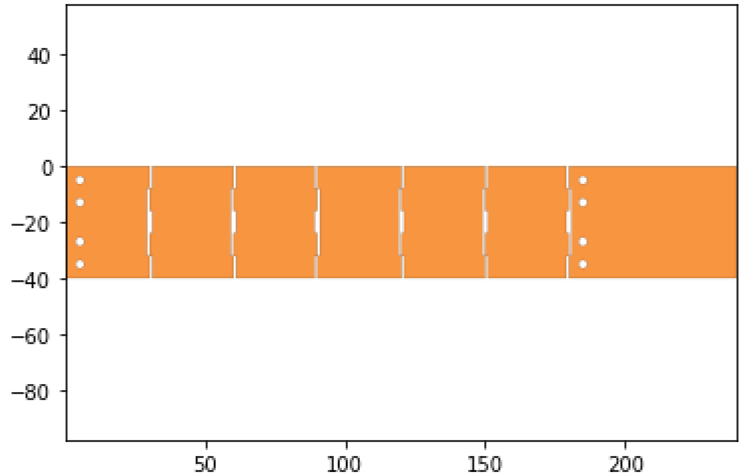
In [53]:

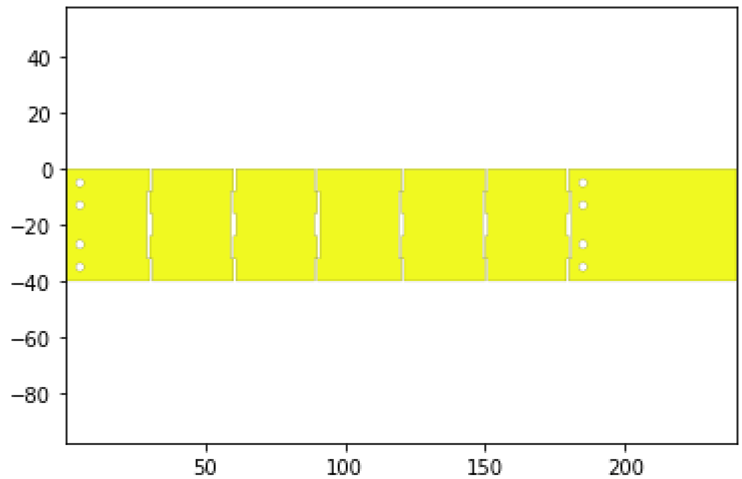
```
design2 = body- hole - joints - cuts - holes
design2.plot_layers()
```



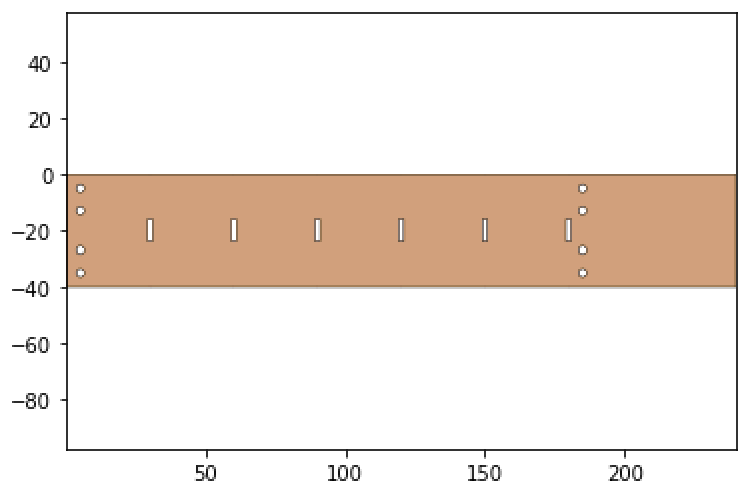




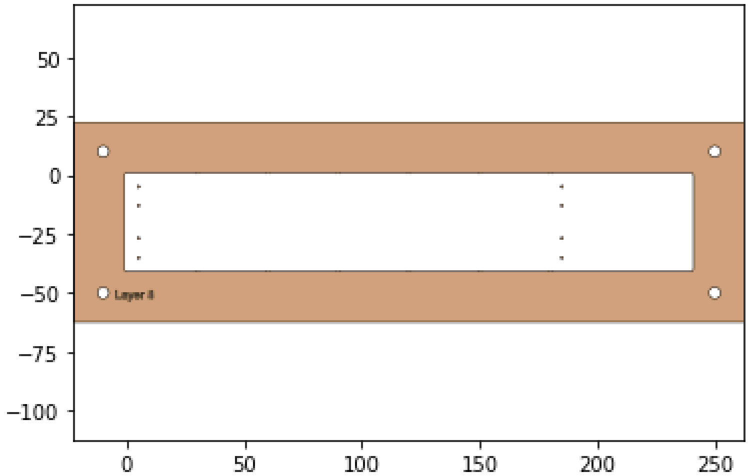




In [34]:
```
keepout =  foldable_robotics.manufacturing.keepout_laser(design2)
keepout.plot()
```

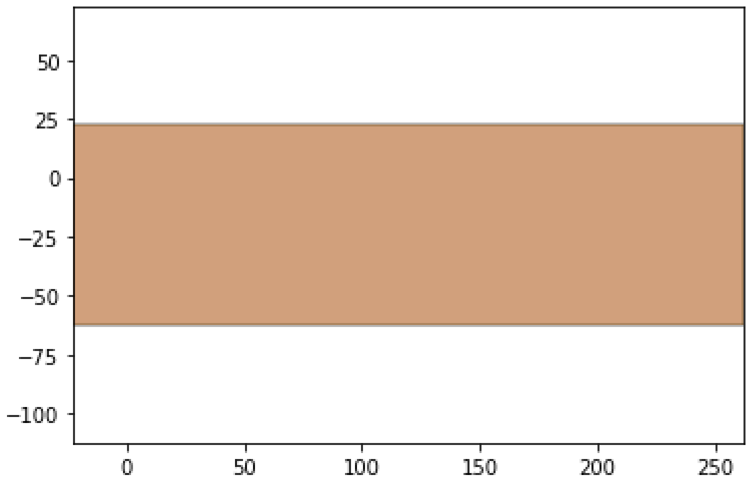


In [35]:
```
web,sheet=build_web(design2,keepout,support_width,jig_diameter,jig_hole_spacing,is_adhe
web.plot()
```



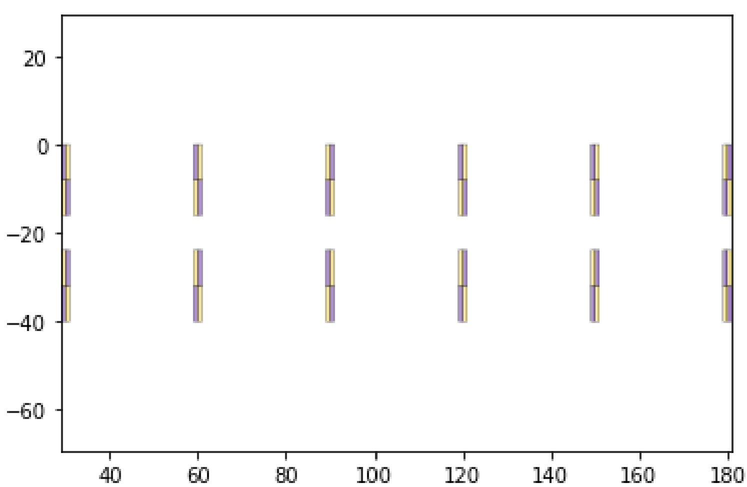
In [36]:

```
sheet.plot()
```



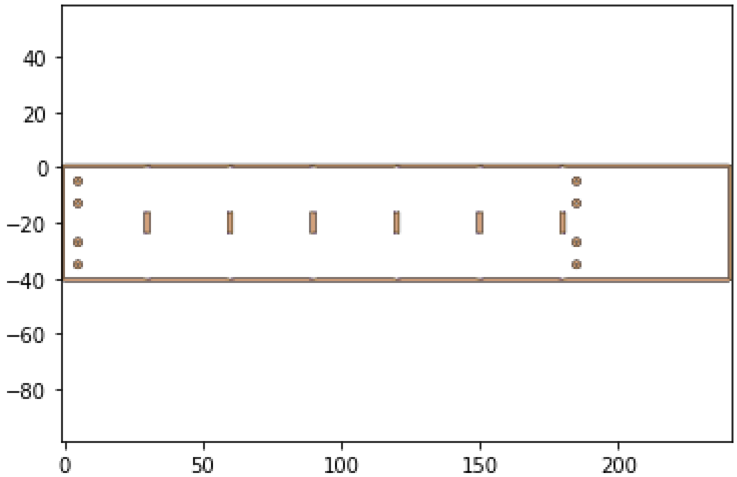
In [37]:

```
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()
```



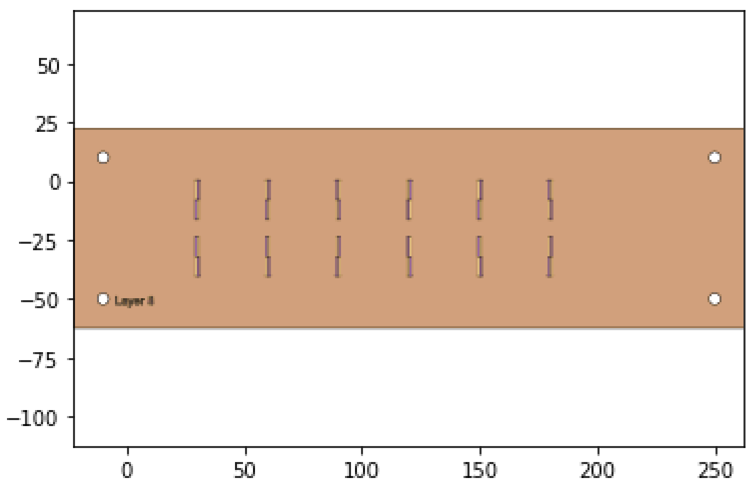
In [38]:

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



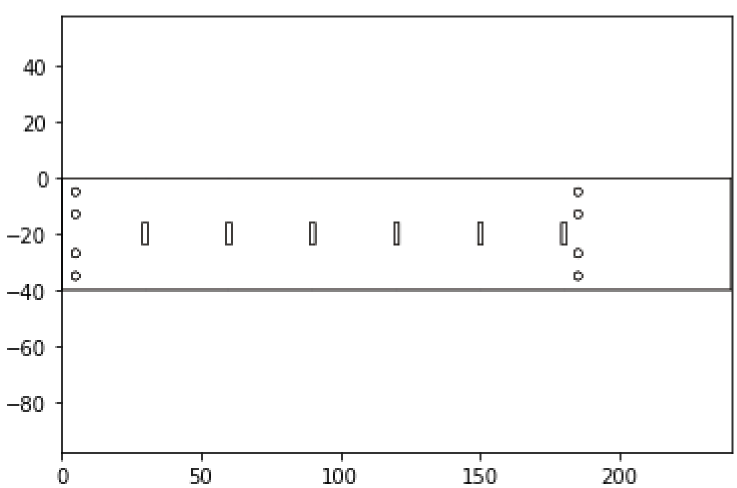
In [39]:

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

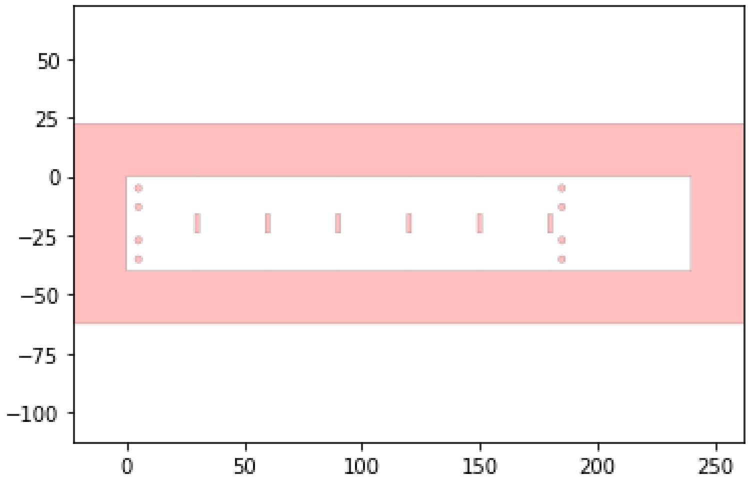


In [40]:

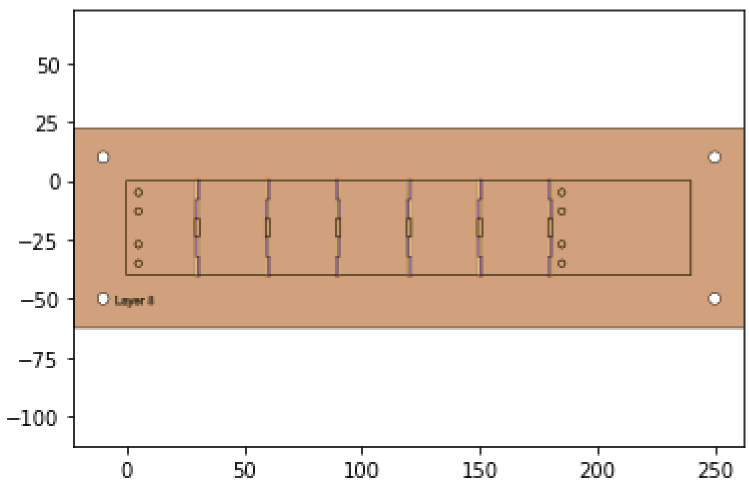
```
#cut_line = keepout<<kerf
cut_material = (keepout<<kerf)-keepout
cut_material.plot()
```



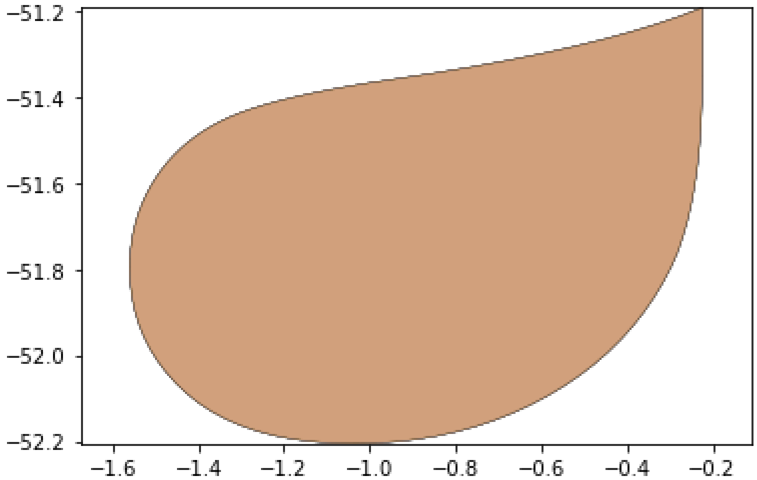
In [41]:
```
final_cut = sheet - keepout
final_cut = final_cut[0]
final_cut.plot()
```

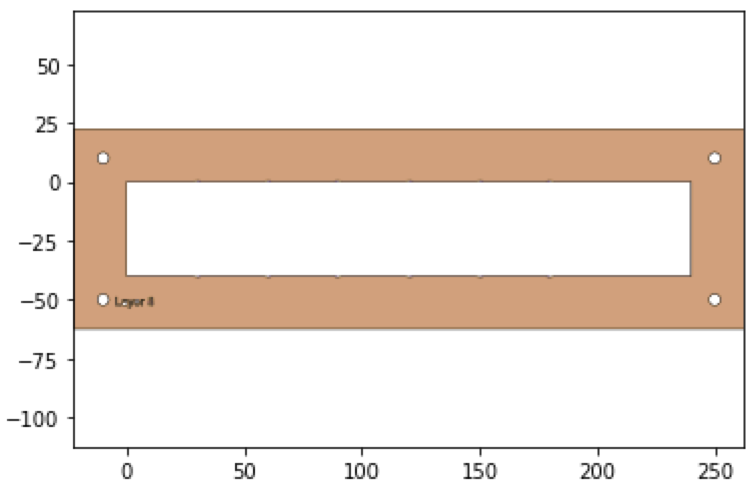


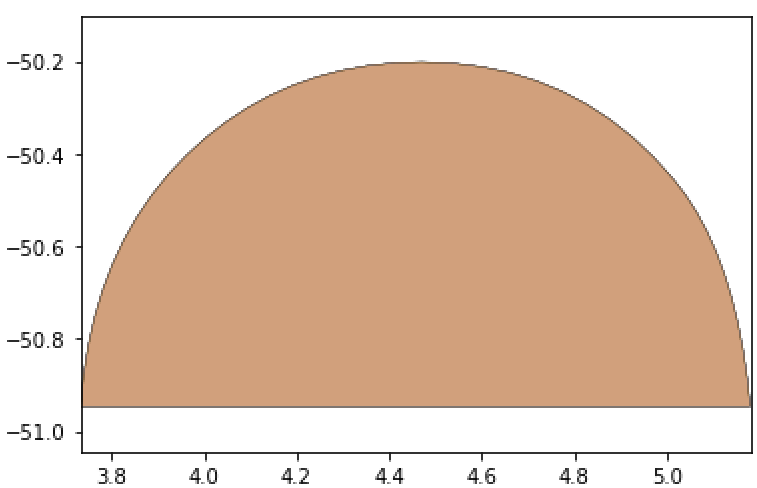
In [42]:
```
remaining_material = supported_design-cut_material
remaining_material.plot()
```

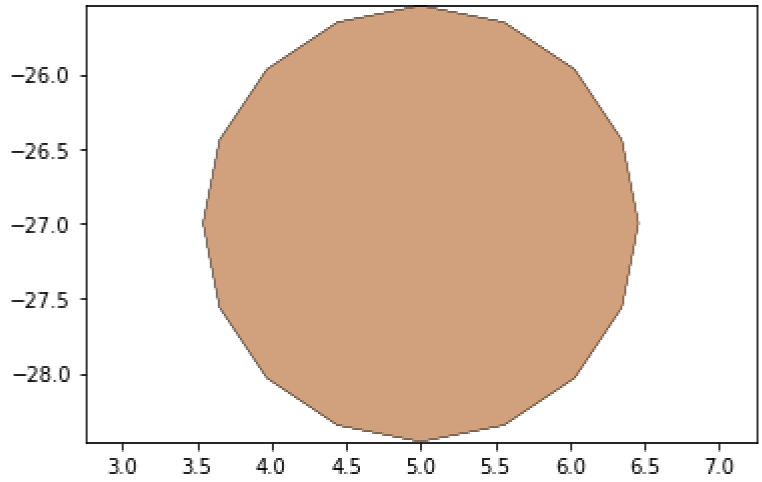


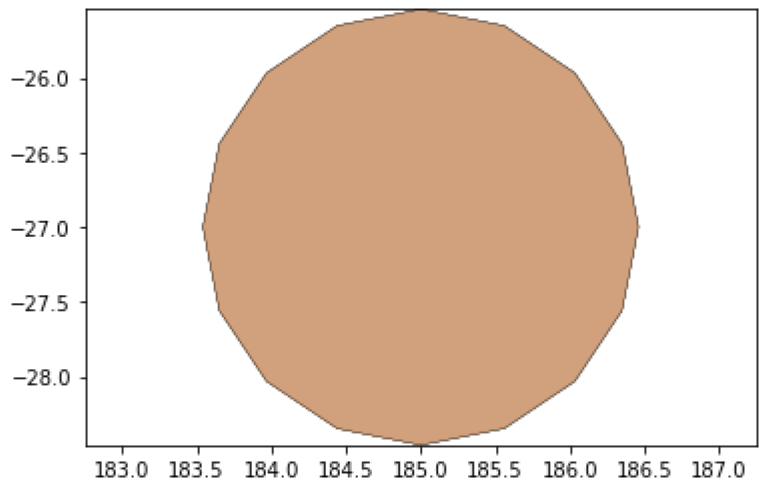
In [43]:
```
remaining_parts = foldable_robotics.manufacturing.find_connected(remaining_material,is_
for item in remaining_parts:
    item.plot(new=True)
```

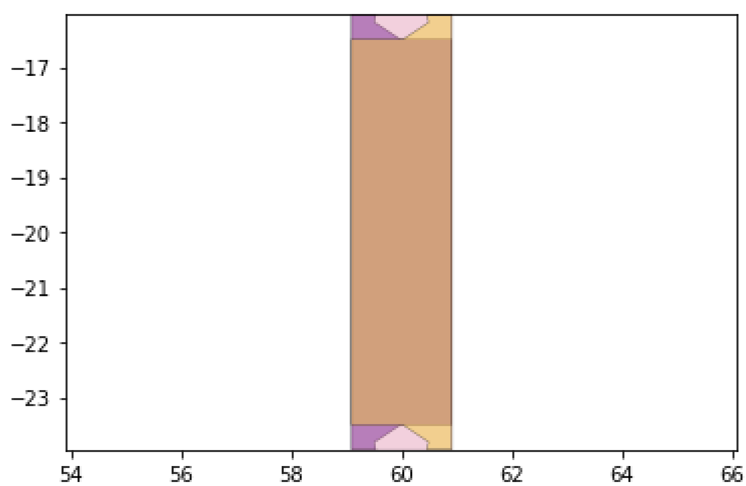

−51.2
−51.4
−51.6
−51.8
−52.0
−52.2
−1.6 −1.4 −1.2 −1.0 −0.8 −0.6 −0.4 −0.2

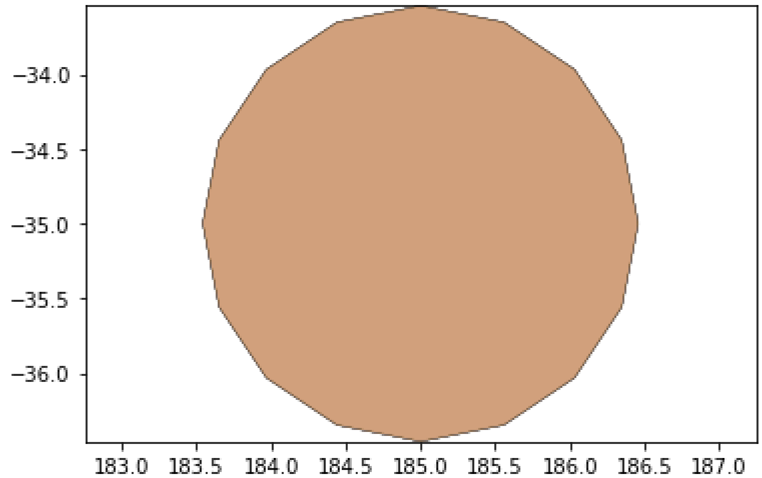

50
25
0
−25
−50
−75
−100
0 50 100 150 200 250

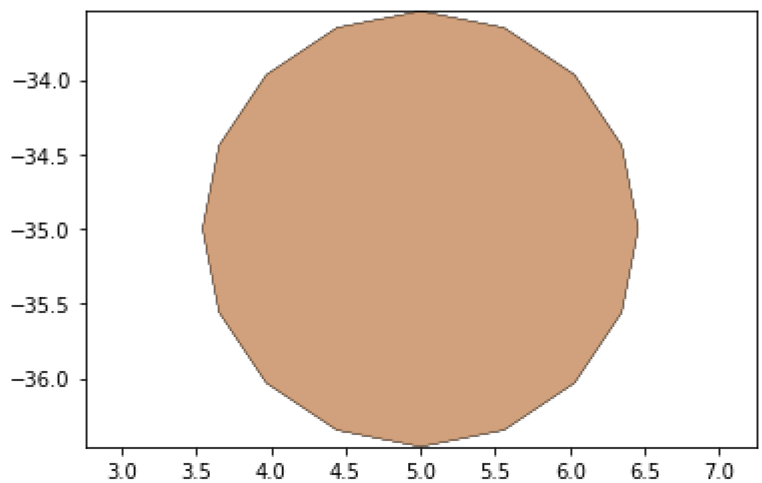

−50.2
−50.4
−50.6
−50.8
−51.0
3.8 4.0 4.2 4.4 4.6 4.8 5.0

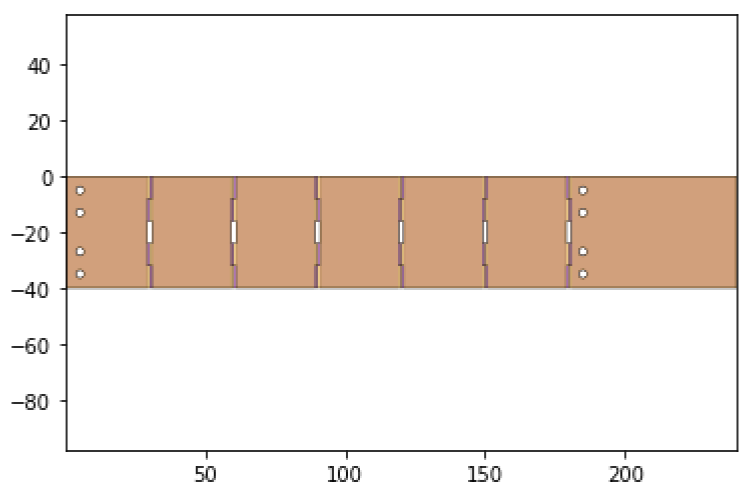

−26.0
−26.5
−27.0
−27.5
−28.0
3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0

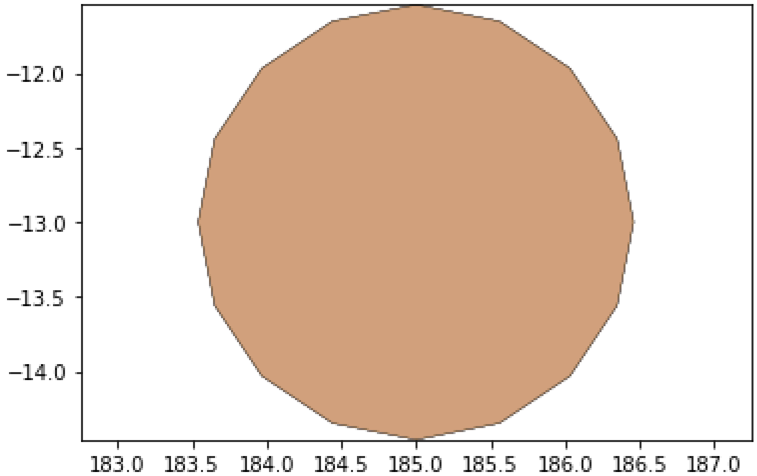

−26.0
−26.5
−27.0
−27.5
−28.0
183.0 183.5 184.0 184.5 185.0 185.5 186.0 186.5 187.0

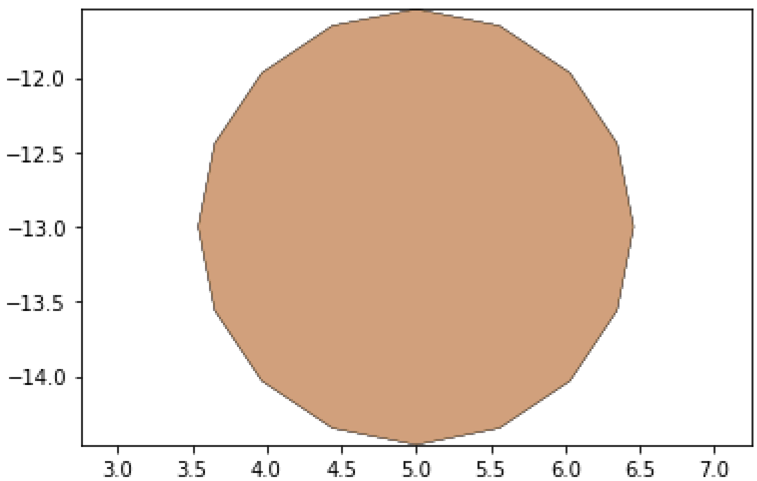

−17
−18
−19
−20
−21
−22
−23
54 56 58 60 62 64 66

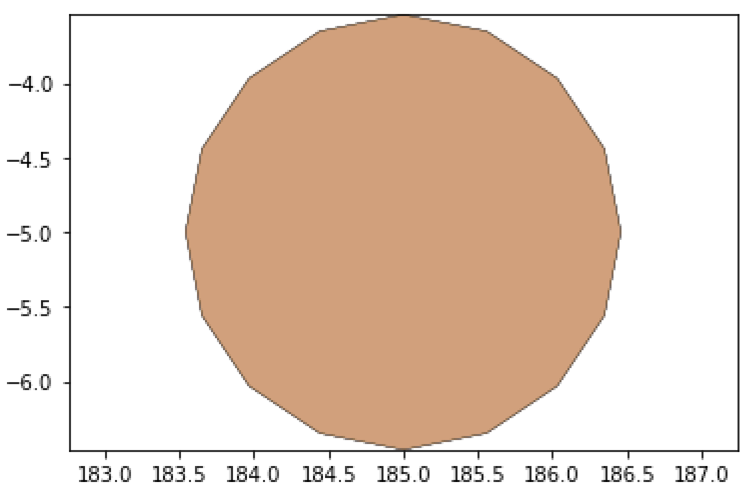

−34.0
−34.5
−35.0
−35.5
−36.0
183.0 183.5 184.0 184.5 185.0 185.5 186.0 186.5 187.0

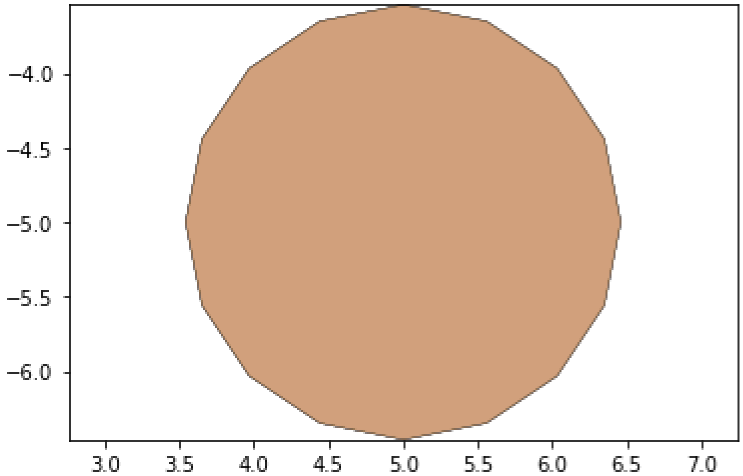

−34.0
−34.5
−35.0
−35.5
−36.0
3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0

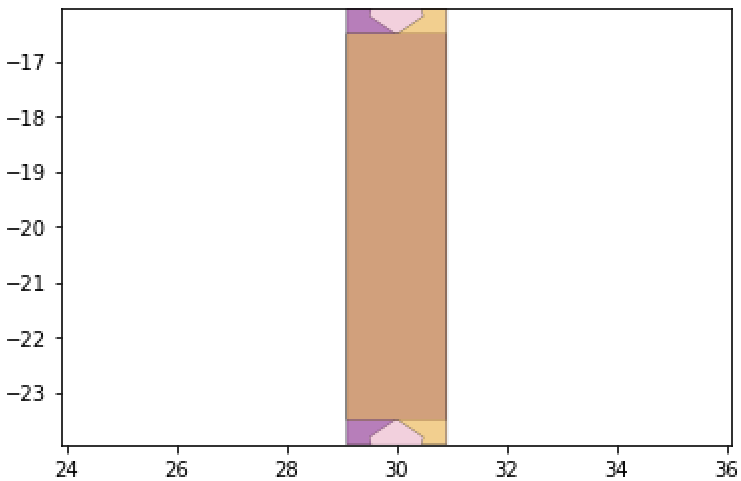

40
20
0
−20
−40
−60
−80
50 100 150 200

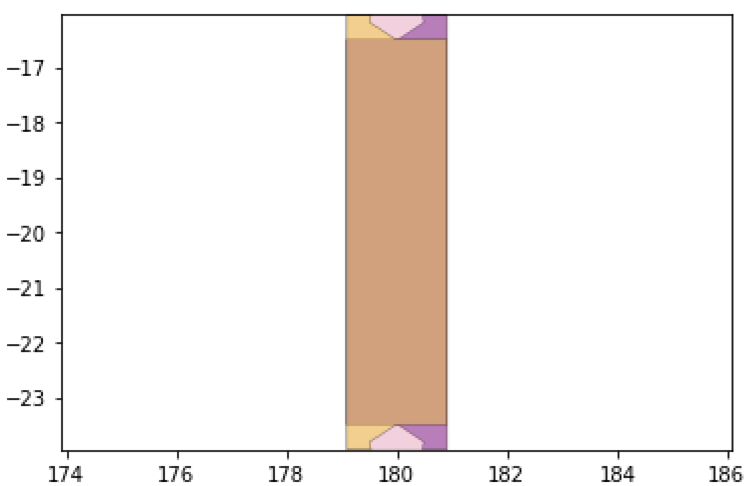

−12.0
−12.5
−13.0
−13.5
−14.0
183.0 183.5 184.0 184.5 185.0 185.5 186.0 186.5 187.0

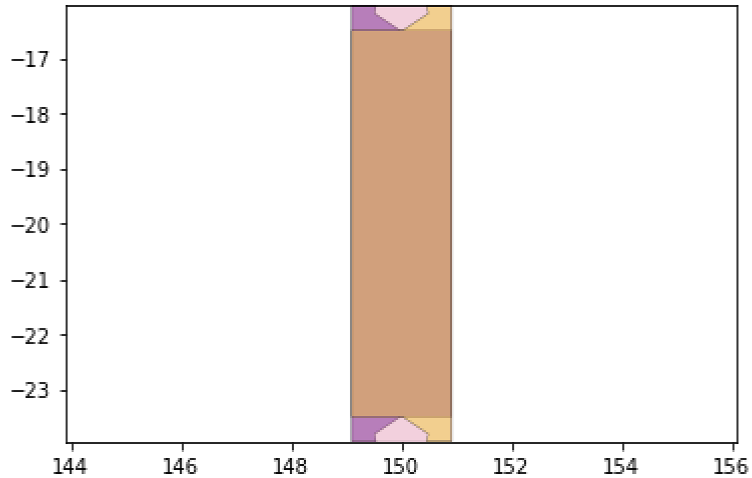

−12.0
−12.5
−13.0
−13.5
−14.0
3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0

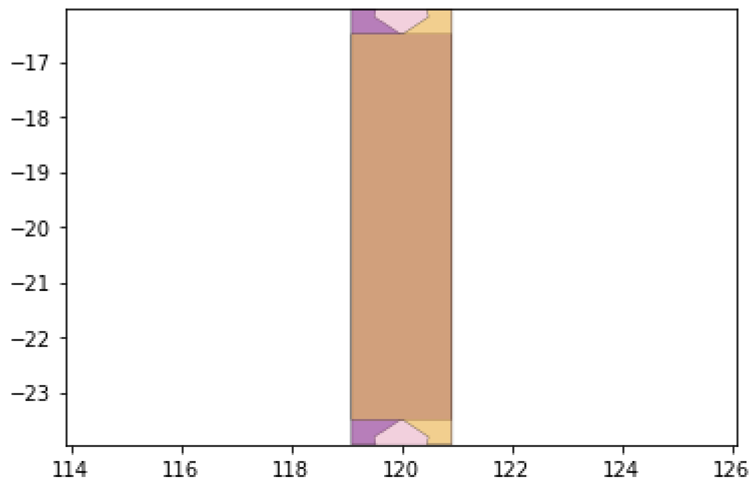

−4.0
−4.5
−5.0
−5.5
−6.0
183.0 183.5 184.0 184.5 185.0 185.5 186.0 186.5 187.0

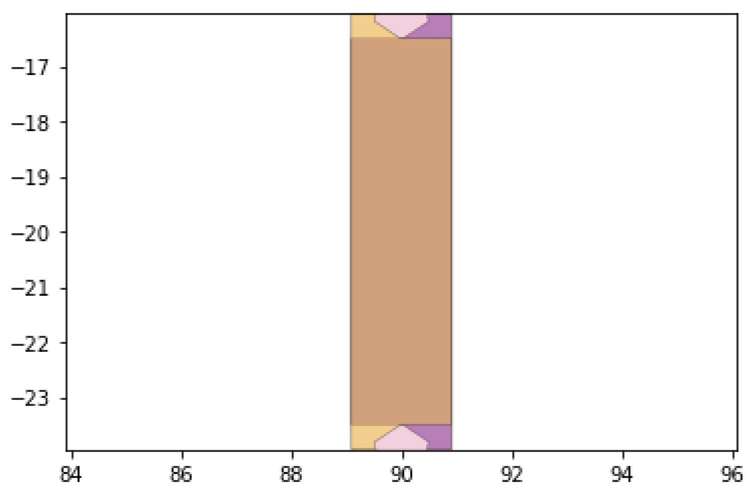

−4.0
−4.5
−5.0
−5.5
−6.0
3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0


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

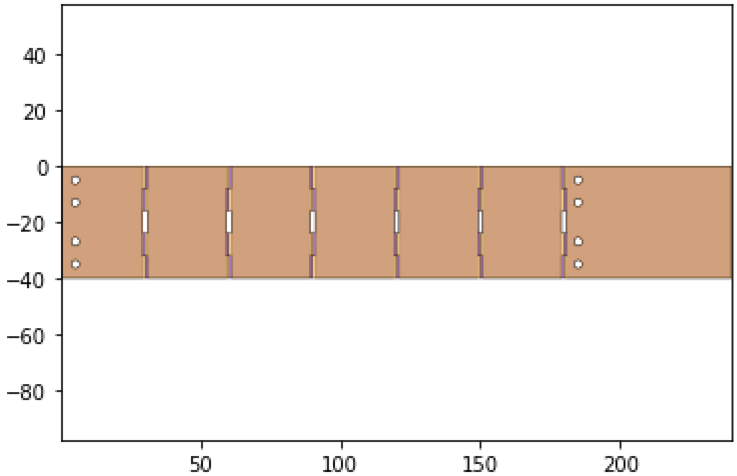

−17
−18
−19
−20
−21
−22
−23
174 176 178 180 182 184 186







In [44]:
```
d3=design2>>1
for item in remaining_parts:
    if not (item&d3).is_null():
        break
item.plot()
```



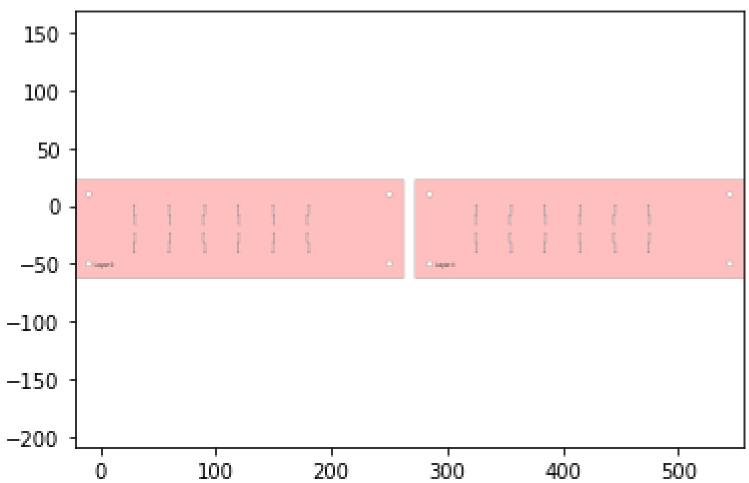
In [45]:

```
check = (item^design2)
check>>=1e-5
check.plot()
```

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

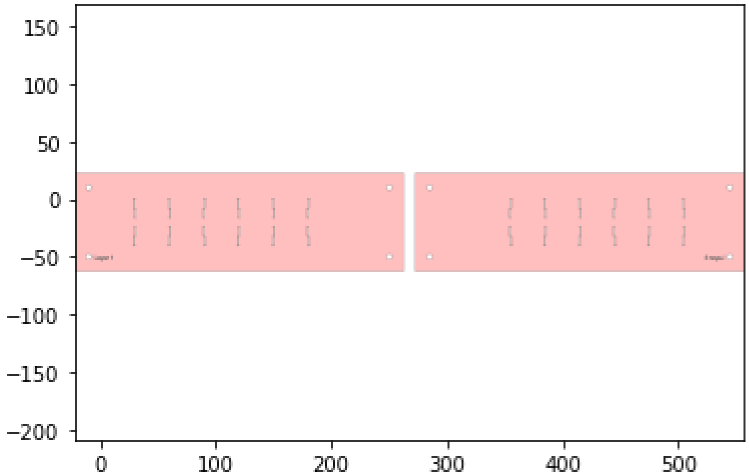
In [46]:

```
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 [ ]: