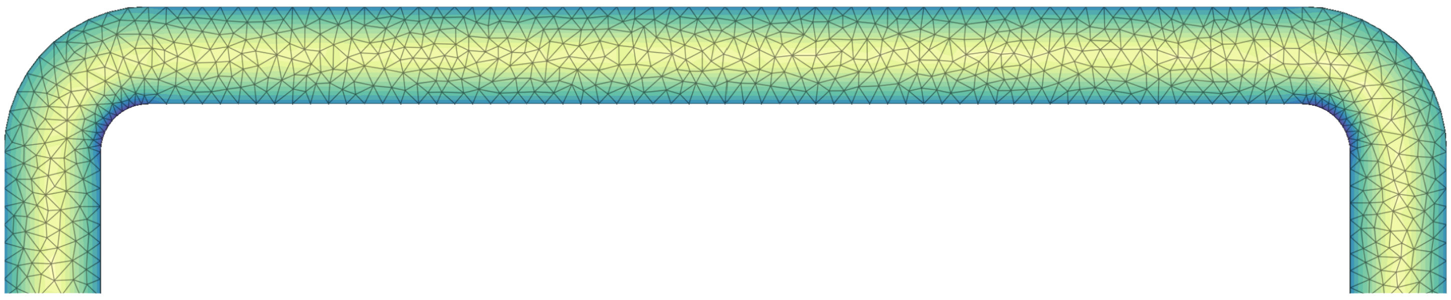
SectionProperties from DXF by finite mesh

https://pypi.org/project/sectionproperties/

https://sectionproperties.readthedocs.io/en/stable/examples.html



In [1]:
```
# %pip install sectionproperties
# if needed, uncomment line, install , restart

%matplotlib inline

## COLAB        (calculation=0.0) (plot=0.0) (interactive=0.5)
## VSCODE       (calculation=0.8) (plot=0.8) (interactive=0.5)
## JUPYTER LAB  (calculation=0.8) (plot=0.8) (interactive=0.5)
```

Import the appropriate classes. For example:

In [2]:
```
from sectionproperties.pre.geometry import Geometry
from sectionproperties.analysis.section import Section
```

1 Simple Example

Calculate section properties of a circle.

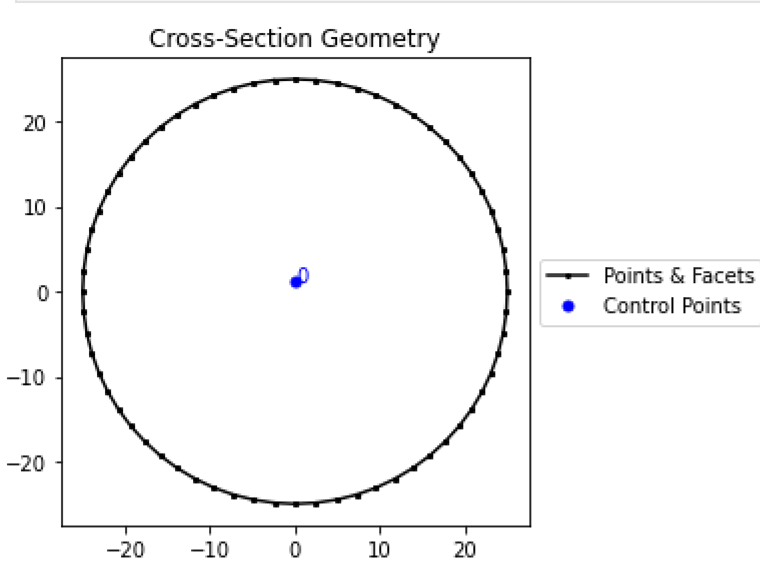
The following example calculates the geometric, warping and plastic properties of a 50 mm diameter circle. The circle is discretised with 64 points and a mesh size of 2.5 mm\ :sup: `2` .

The geometry and mesh are plotted, and the mesh information printed to the terminal before the analysis is carried out. Detailed time information is printed to the terminal during the cross-section analysis stage. Once the analysis is complete, the cross-section properties are printed to the terminal. The centroidal axis second moments of area and torsion constant are saved to variables and it is shown that, for a circle, the torsion constant is equal to the sum of the second moments of area.

In [3]:
```
# sphinx_gallery_thumbnail_number = 1

import sectionproperties.pre.library.primitive_sections as sections
from sectionproperties.analysis.section import Section
```

Create a 50 diameter circle discretised by 64 points

In [4]:
```
geometry = sections.circular_section(d=50, n=64)
geometry.plot_geometry()
```



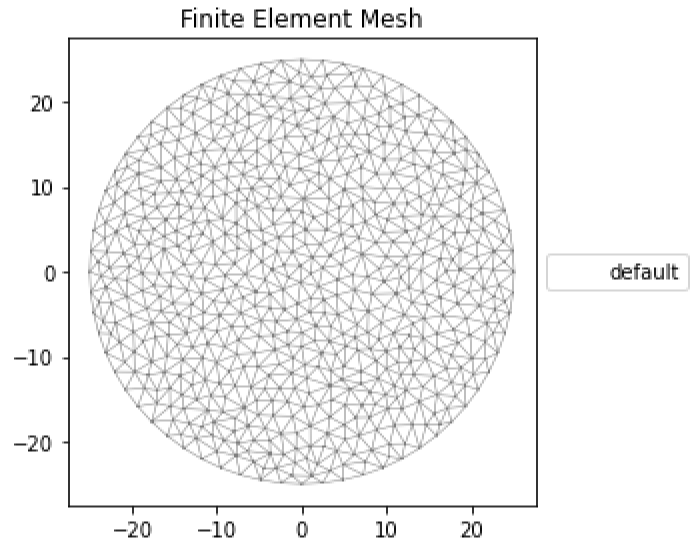
Out[4]:
```
<Axes: title={'center': 'Cross-Section Geometry'}>
```

Create a mesh with a mesh size of 2.5 and display information about it

In [5]:
```
geometry.create_mesh(mesh_sizes=[2.5])

section = Section(geometry, time_info=True)
section.display_mesh_info()
section.plot_mesh()
```

Mesh Statistics:

- **2557** nodes
- **1246** elements
- **1** region



Out[5]: <Axes: title={'center': 'Finite Element Mesh'}>

perform a geometric, warping and plastic analysis, displaying the time info

In [6]:
```
section.calculate_geometric_properties()
```

```
Output()
```

In [7]:
```
section.calculate_warping_properties()
```

```
Output()
```

In [8]:
```
section.calculate_plastic_properties()
```

```
Output()
```

Print the results to the terminal

In [9]:
```
section.display_results()
```

Section Properties

Property	Value
area	1.960343e+03
perimeter	1.570166e+02
qx	-1.296030e-11
qy	1.955325e-12
ixx_g	3.058119e+05
iyy_g	3.058119e+05
ixy_g	-1.551115e-11
cx	9.974402e-16
cy	-6.611241e-15
ixx_c	3.058119e+05
iyy_c	3.058119e+05
ixy_c	-1.551115e-11
zxx+	1.223248e+04
zxx-	1.223248e+04
zyy+	1.223248e+04
zyy-	1.223248e+04
rx	1.248996e+01
ry	1.248996e+01
i11_c	3.058119e+05
i22_c	3.058119e+05
phi	0.000000e+00
z11+	1.223248e+04
z11-	1.223248e+04
z22+	1.223248e+04
z22-	1.223248e+04
r11	1.248996e+01
r22	1.248996e+01
j	6.116238e+05
x_se	1.695293e-15
y_se	2.627651e-15
x1_se	6.978531e-16
y2_se	9.238892e-15
x_st	1.695293e-15
y_st	2.627651e-15
gamma	1.531487e-21
a_sx	1.680296e+03
a_sy	1.680296e+03
a_s11	1.680296e+03
a_s22	1.680296e+03
beta_x+	-1.343061e-14
beta_x-	1.343061e-14
beta_y+	1.038822e-15
beta_y-	-1.038822e-15
beta_11+	-1.343061e-14
beta_11-	1.343061e-14
beta_22+	1.038822e-15
beta_22-	-1.038822e-15
x_pc	9.974402e-16
y_pc	-6.611241e-15
x11_pc	9.974402e-16
y22_pc	-6.611241e-15
sxx	2.078317e+04
syy	2.078317e+04
s11	2.078317e+04
s22	2.078317e+04
sf_xx+	1.699016e+00
sf_xx-	1.699016e+00
sf_yy+	1.699016e+00
sf_yy-	1.699016e+00
sf_11+	1.699016e+00
sf_11-	1.699016e+00
sf_22+	1.699016e+00
sf_22-	1.699016e+00

Get and print the second moments of area and the torsion constant

In [10]:
```
(ixx_c, iyy_c, ixy_c) = section.get_ic()
j = section.get_j()
print("Ixx + Iyy = {0:.3f}".format(ixx_c + iyy_c))
print("J = {0:.3f}".format(j))
```

```
Ixx + Iyy = 611623.837
J = 611623.837
```

2 Creating a Nastran Section

https://sectionproperties.readthedocs.io/en/stable/gen/sectionproperties.pre.library.nastran_sections.html#

Calculate section properties of Nastran HAT1 section.

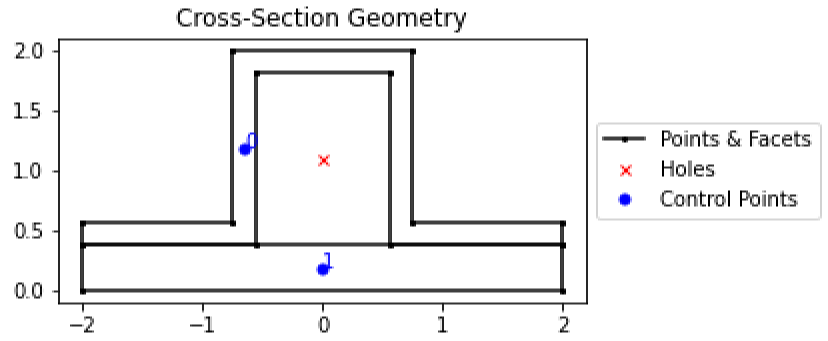
The following example demonstrates how to create a cross-section defined in a Nastran-based finite element analysis program. The following creates a HAT1 cross-section and calculates the geometric, warping and plastic properties. The HAT1 cross-section is meshed with a maximum elemental area of 0.005.

The geometry and mesh are plotted, and the mesh information printed to the terminal before the analysis is carried out. Detailed time information is printed to the terminal during the cross-section analysis stage. Once the analysis is complete, the cross-section properties are printed to the terminal. The centroidal axis second moments of area and torsion constant are saved to variables and it is shown that, for non-circular sections, the torsion constant is not equal to the sum of the second moments of area.

In [11]:
```python
# sphinx_gallery_thumbnail_number = 1

from typing import get_origin
import sectionproperties.pre.library.nastran_sections as nsections
from sectionproperties.analysis.section import Section
```

Create a HAT1 section

In [12]:
```python
geometry = nsections.nastran_hat1(dim_1=4.0, dim_2=2.0, dim_3=1.5, dim_4=0.1875, dim_5=0.375)
geometry.plot_geometry()  # plot the geometry
print(geometry.geom)
```



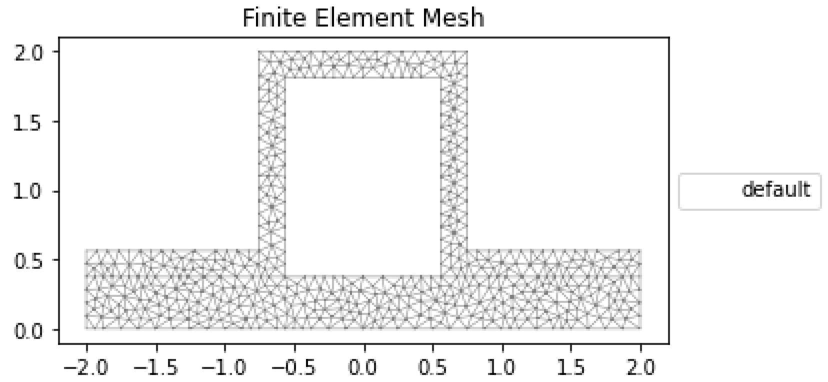

```
MULTIPOLYGON (((-2 0.375, -0.5625 0.375, -0.5625 1.8125, 0.5625 1.8125, 0.5625 0.375, 2 0.375, 2 0.5625, 0.75 0.5625, 0.75 2, -0.75 2, -0.75 0.5625, -2 0.5625, -2 0.375)), ((-2 0, 2 0, 2 0.375, -2 0.375, -2 0)))
```

Create a mesh with a maximum elemental area of 0.005

In [13]:
```python
geometry.create_mesh(mesh_sizes=[0.005])

section = Section(geometry, time_info=True)  # create a Section object
section.display_mesh_info()  # display the mesh information
section.plot_mesh()  # plot the generated mesh`
```

Mesh Statistics:

- **2038** nodes
- **926** elements
- **2** regions



Out[13]: `<Axes: title={'center': 'Finite Element Mesh'}>`

Perform a geometric, warping and plastic analysis, displaying the time info

In [14]:
```python
section.calculate_geometric_properties()
section.calculate_warping_properties()
section.calculate_plastic_properties()

section.display_results()
```

```
Output()
Output()
Output()
```

Section Properties

Property	Value
area	2.789062e+00
perimeter	1.200000e+01
qx	1.626709e+00
qy	-7.546047e-17
ixx_g	1.935211e+00
iyy_g	3.233734e+00
ixy_g	-4.371503e-16
cx	-2.705586e-17
cy	5.832458e-01
ixx_c	9.864400e-01
iyy_c	3.233734e+00
ixy_c	-3.931383e-16
zxx+	6.962676e-01
zxx-	1.691294e+00
zyy+	1.616867e+00
zyy-	1.616867e+00
rx	5.947113e-01
ry	1.076770e+00
i11_c	3.233734e+00
i22_c	9.864400e-01
phi	-9.000000e+01
z11+	1.616867e+00
z11-	1.616867e+00
z22+	1.691294e+00
z22-	6.962676e-01
r11	1.076770e+00
r22	5.947113e-01
j	9.878443e-01
x_se	4.822719e-05
y_se	4.674792e-01
x1_se	1.157666e-01
y2_se	4.822719e-05
x_st	4.822719e-05
y_st	4.674792e-01
gamma	1.160803e-01
a_sx	1.648312e+00
a_sy	6.979733e-01
a_s11	6.979733e-01
a_s22	1.648312e+00
beta_x+	-2.746928e-01
beta_x-	2.746928e-01
beta_y+	9.645438e-05
beta_y-	-9.645438e-05
beta_11+	9.645438e-05
beta_11-	-9.645438e-05
beta_22+	2.746928e-01
beta_22-	-2.746928e-01
x_pc	-2.705586e-17
y_pc	3.486328e-01
x11_pc	3.272102e-16
y22_pc	3.486328e-01
sxx	1.140530e+00
syy	2.603760e+00
s11	2.603760e+00
s22	1.140530e+00
sf_xx+	1.638062e+00
sf_xx-	6.743533e-01
sf_yy+	1.610373e+00
sf_yy-	1.610373e+00
sf_11+	1.610373e+00
sf_11-	1.610373e+00
sf_22+	6.743533e-01
sf_22-	1.638062e+00

Get the second moments of area and the torsion constant

In [15]:
```
(ixx_c, iyy_c, ixy_c) = section.get_ic()
j = section.get_j()
print("Ixx + Iyy = {0:.3f}".format(ixx_c + iyy_c))
print("J = {0:.3f}".format(j))
```

```
Ixx + Iyy = 4.220
J = 0.988
```

3 Creating Custom Geometry

Calculate section properties of a user-defined section from points and facets.

The following example demonstrates how geometry objects can be created from a list of points, facets, holes and control points. An straight angle section with a plate at its base is created from a list of points and facets. The bottom plate is assigned a separate control point meaning two discrete regions are created. Creating separate regions allows the user to control the mesh size in each region and assign material properties to different regions. The geometry is cleaned to remove the overlapping facet at the junction of the angle and the plate. A geometric, warping and plastic analysis is then carried out.

The geometry and mesh are plotted before the analysis is carried out. Once the analysis is complete, a plot of the various calculated centroids is generated.

In [16]:
```
# sphinx_gallery_thumbnail_number = 2
```

```python
from sectionproperties.pre.geometry import CompoundGeometry
from sectionproperties.analysis.section import Section
```

Define parameters for the angle section

In [17]:
```python
a = 1
b = 2
t = 0.1
```

Build the lists of points, facets, holes and control points

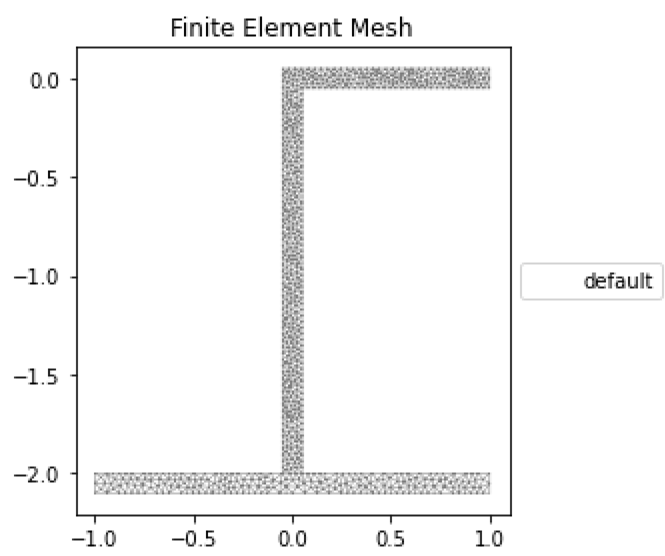
In [18]:
```python
points = [
    [-t / 2, -2 * a],
    [t / 2, -2 * a],
    [t / 2, -t / 2],
    [a, -t / 2],
    [a, t / 2],
    [-t / 2, t / 2],
    [-b / 2, -2 * a],
    [b / 2, -2 * a],
    [b / 2, -2 * a - t],
    [-b / 2, -2 * a - t],
]
facets = [
    [0, 1],
    [1, 2],
    [2, 3],
    [3, 4],
    [4, 5],
    [5, 0],
    [6, 7],
    [7, 8],
    [8, 9],
    [9, 6],
]
holes = []
control_points = [[0, 0], [0, -2 * a - t / 2]]
```

Because we have two separate geometry regions (as indicated by our control_points) we create a CompoundGeometry from points

In [19]:
```python
geometry = CompoundGeometry.from_points(points, facets, control_points, holes)
```

Create the mesh and section. For the mesh, use a smaller refinement for the angle region.

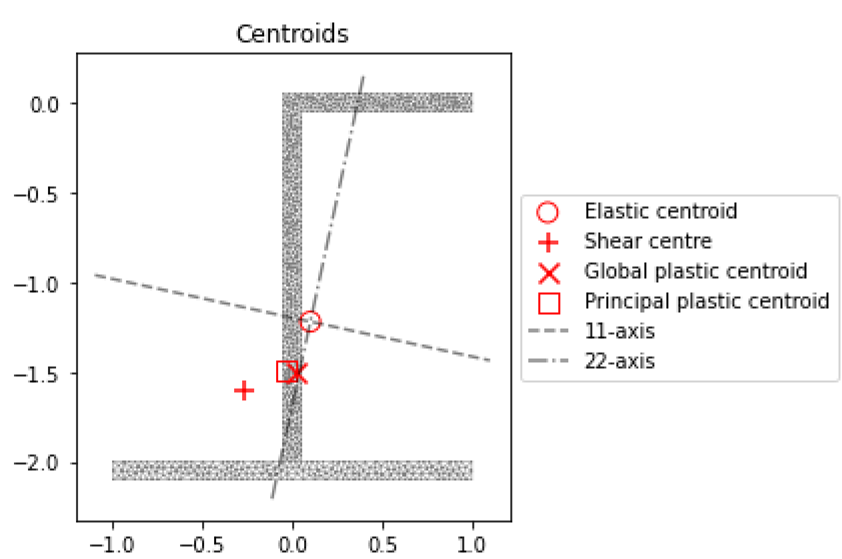
In [20]:
```python
geometry.create_mesh(mesh_sizes=[0.0005, 0.001])

section = Section(geometry)
section.plot_mesh()  # plot the generated mesh
```



Out[20]: <Axes: title={'center': 'Finite Element Mesh'}>

Perform a geometric, warping and plastic analysis

In [21]:
```python
section.calculate_geometric_properties()
section.calculate_warping_properties()
section.calculate_plastic_properties()

section.plot_centroids()
```



Out[21]: <Axes: title={'center': 'Centroids'}>

4 Creating a Built-Up Section

Merge two sections together into a single larger section.

The following example demonstrates how to combine multiple geometry objects into a single geometry object. A 150x100x6 RHS is modelled with a solid 50x50 triangular section on its top and a 100x100x6 angle section on its right side. The three geometry objects are combined together as a :class: `~sectionproperties.pre.geometry.CompoundGeometry` object using the `+` operator.

To manipulate individual geometries into the final shape, there are a variety of methods available to move and align. This example uses `.align_center()`, `.align_to()`, and `.shift_section()`.

The geometry and mesh are plotted, and the mesh information printed to the terminal before the analysis is carried out. Detailed time information is printed to the terminal during the cross-section analysis stage. Once the analysis is complete, the centroids are plotted.

In [22]:
```
# sphinx_gallery_thumbnail_number = 1

import sectionproperties.pre.library.steel_sections as steel_sections
from sectionproperties.pre.geometry import Geometry
from sectionproperties.analysis.section import Section
```

Create a 150x100x6 RHS

In [23]:
```
rhs = steel_sections.rectangular_hollow_section(d=150, b=100, t=6, r_out=15, n_r=8)
```

Create a triangular section from points, facets, and control points

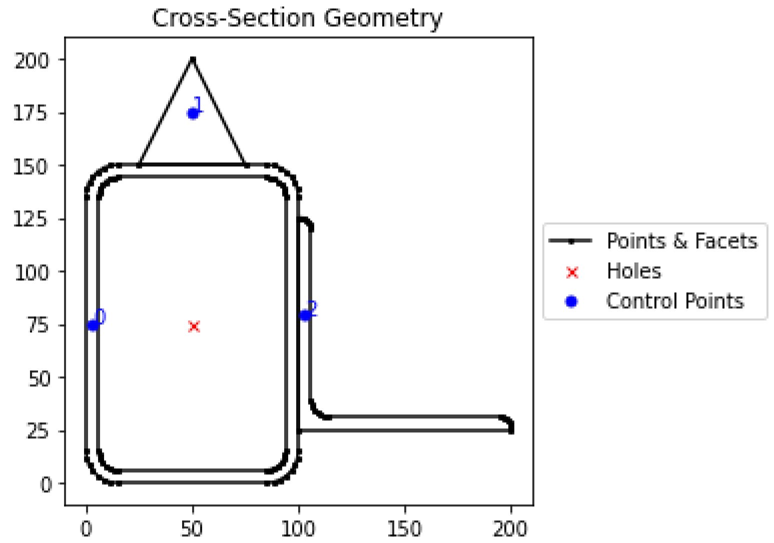
In [24]:
```
points = [[0, 0], [50, 0], [25, 50]]
facets = [[0, 1], [1, 2], [2, 0]]
control_points = [[25, 25]]
triangle = Geometry.from_points(points, facets, control_points)
triangle = triangle.align_center(rhs).align_to(rhs, on="top")
```

Create a 100x100x6 angle and position it on the right of the RHS

In [25]:
```
angle = steel_sections.angle_section(d=100, b=100, t=6, r_r=8, r_t=5, n_r=8)
angle = angle.shift_section(x_offset=100, y_offset=25)
```

Combine the sections into a CompoundGeometry with `+` operator

In [26]:
```
geometry = rhs + triangle + angle
geometry.plot_geometry()  # plot the geometry
```

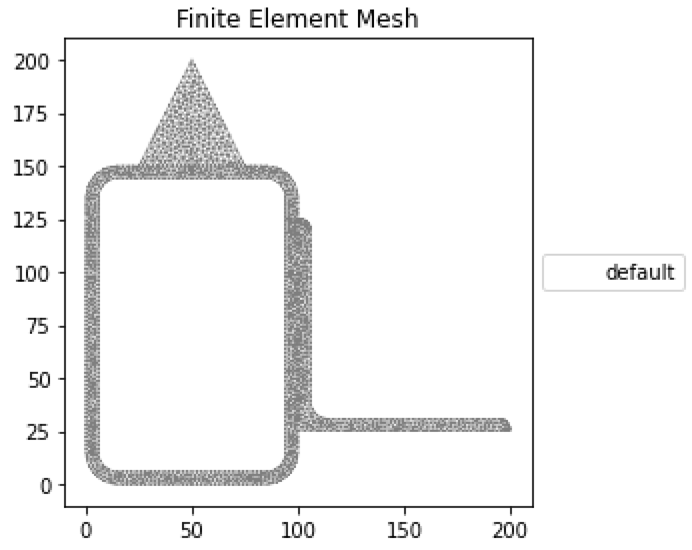


Out[26]: <Axes: title={'center': 'Cross-Section Geometry'}>

Create a mesh and section. For the mesh, use a mesh size of 2.5 for the RHS, 5 for the triangle and 3 for the angle.

In [27]:
```
geometry.create_mesh(mesh_sizes=[2.5, 5, 3])

section = Section(geometry, time_info=True)
section.display_mesh_info()  # display the mesh information
section.plot_mesh()  # plot the generated mesh
```

Mesh Statistics:
- **6020** nodes
- **2736** elements
- **3** regions

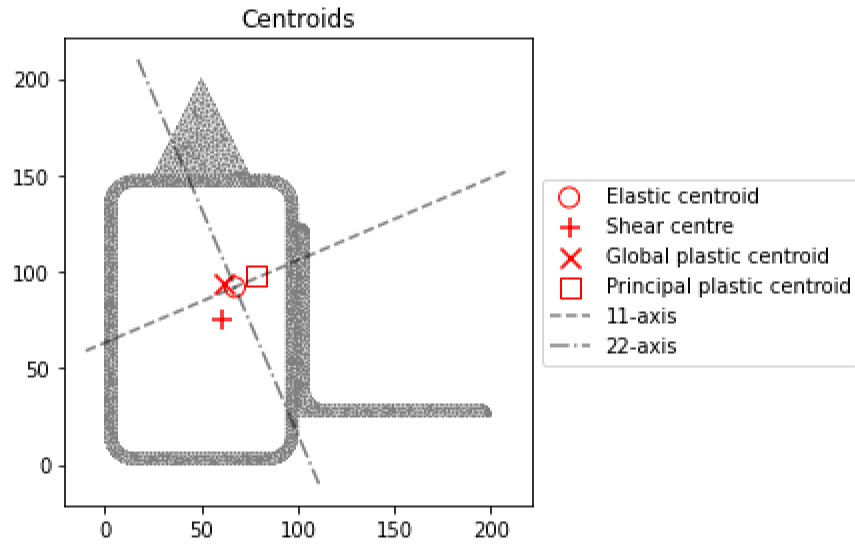


Out[27]: `<Axes: title={'center': 'Finite Element Mesh'}>`

Perform a geometric, warping and plastic analysis, displaying the time info and the iteration info for the plastic analysis

In [28]:
```
section.calculate_geometric_properties()
section.calculate_warping_properties()
section.calculate_plastic_properties(verbose=True)

# plot the centroids
section.plot_centroids()
```

```
Output()

Output()

Output()
d = -91.996268369166; f_norm = 1.0
d = 108.003731630834; f_norm = -1.0
d = 8.003731630833997; f_norm = -0.04433903442685115
d = 3.5610941851785247; f_norm = -0.013257745358062492
d = 1.6934563166381202; f_norm = -0.00019149964748535968
d = 1.666207547083575; f_norm = -8.635909458075013e-07
d = 1.6660841169311136; f_norm = -5.6994862781888e-11
d = 1.666082783889055; f_norm = 9.269146437289895e-09
---x-axis plastic centroid calculation converged at 1.66608e+00 in 7 iterations.
d = -67.409490017714; f_norm = 1.0
d = 132.590509982286; f_norm = -1.0
d = 32.590509982285994; f_norm = -0.546379783397773
d = -17.409490017714006; f_norm = 0.22681010830111303
d = -2.742322822682775; f_norm = -0.043022470763644426
d = -5.080875765477266; f_norm = -0.011205909614768165
d = -5.8657449981455345; f_norm = 0.0004252464243683582
d = -5.83704941245604; f_norm = -8.433780157994712e-06
d = -5.837607455591706; f_norm = -6.102942204925805e-09
d = -5.837610874395434; f_norm = 4.552923959027148e-08
---y-axis plastic centroid calculation converged at -5.83761e+00 in 9 iterations.
d = -106.16681282996599; f_norm = -1.0
d = 113.6728224117802; f_norm = 1.0
d = 3.753004790907113; f_norm = 0.03943689434659865
d = -0.588643873199187; f_norm = 0.0064103157486017455
d = -1.424880934386569; f_norm = 4.9126448280891056e-05
d = -1.431330697831833; f_norm = 6.360698720324061e-08
d = -1.4313390594740303; f_norm = 6.347923627862756e-13
d = -1.43134027514356; f_norm = -9.246865163494106e-09
---11-axis plastic centroid calculation converged at -1.43134e+00 in 7 iterations.
d = -96.43010376150585; f_norm = -1.0
d = 93.41518522403136; f_norm = 1.0
d = -1.507459268737236; f_norm = 0.24999344301692578
d = -26.819412050693646; f_norm = -0.5136606142451681
d = -9.793701141307244; f_norm = 0.06969393886809326
d = -12.614043035926302; f_norm = -0.015439988274398702
d = -12.10254254200654; f_norm = 0.0009283409099089009
d = -12.13155264001945; f_norm = 1.100285018307733e-05
d = -12.131900348758723; f_norm = -1.890117016569997e-10
d = -12.131893782808548; f_norm = 2.0758838935067447e-07
---22-axis plastic centroid calculation converged at -1.21319e+01 in 9 iterations.
```



Out[28]: `<Axes: title={'center': 'Centroids'}>`

5 Mirroring and Rotating Geometry

Mirror and rotate a cross section.

The following example demonstrates how geometry objects can be mirrored and rotated. A 200PFC and 150PFC are placed back-to-back by using the :func: `~sectionproperties.pre.geometry.Geometry.mirror_section` method and are rotated counter-clockwise by 30 degrees by using the :func: `~sectionproperties.pre.geometry.Geometry.rotate_section` method. The geometry is cleaned to ensure there are no overlapping facets along the junction between the two PFCs. A geometric, warping and plastic analysis is then carried out.

The geometry and mesh are plotted, and the mesh information printed to the terminal before the analysis is carried out. Detailed time information is printed to the terminal during the cross-section analysis stage and iteration information printed for the plastic analysis. Once the analysis is complete, a plot of the various calculated centroids is generated.

In [29]:
```
# sphinx_gallery_thumbnail_number = 1

import sectionproperties.pre.library.steel_sections as steel_sections
from sectionproperties.analysis.section import Section
```

Create a 200PFC and a 150PFC

In [30]:
```
pfc1 = steel_sections.channel_section(d=203, b=133, t_f=7.8, t_w=5.8, r=8.9, n_r=8)
pfc2 = steel_sections.channel_section(
    d=150, b=133, t_f=7.8, t_w=5.8, r=8.9, n_r=8
).shift_section(0, 26.5)
```

Mirror the 200 PFC about the y-axis

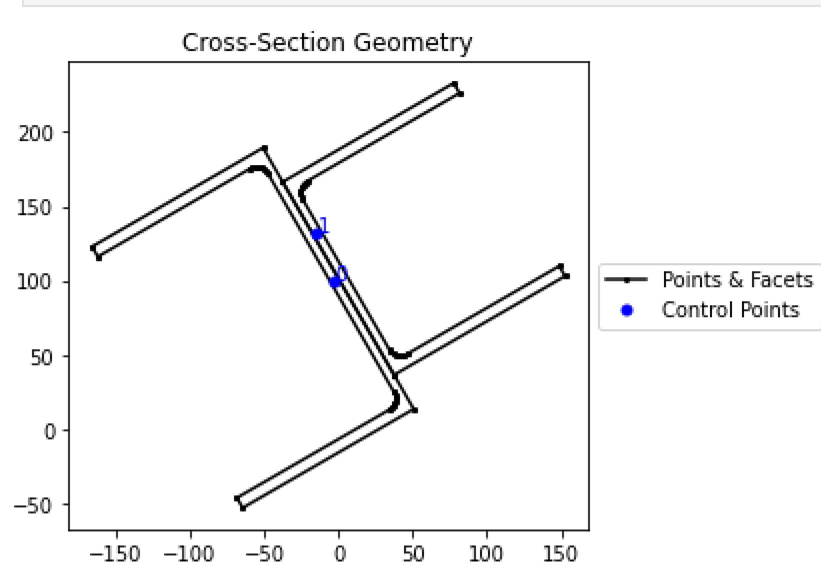
In [31]:
```
pfc1 = pfc1.mirror_section(axis="y", mirror_point=[0, 0])
```

Merge the pfc sections

In [32]:
```
geometry = ((pfc1 - pfc2) | pfc1) + pfc2
```

Rotate the geometry counter-clockwise by 30 degrees

In [33]:
```
geometry = geometry.rotate_section(angle=30)
geometry.plot_geometry()
```



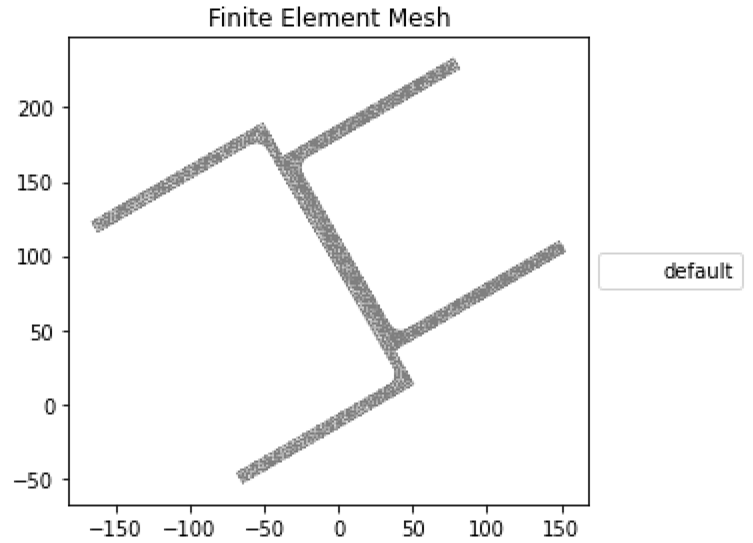
Out[33]: `<Axes: title={'center': 'Cross-Section Geometry'}>`

Create a mesh and section. For the mesh, use a mesh size of 5 for the 200PFC and 4 for the 150PFC

In [34]:
```
geometry.create_mesh(mesh_sizes=[5, 4])

section = Section(geometry, time_info=True)
section.display_mesh_info()  # display the mesh information
section.plot_mesh()  # plot the generated mesh
```

Mesh Statistics:
- **4850** nodes
- **2157** elements

- 2 regions

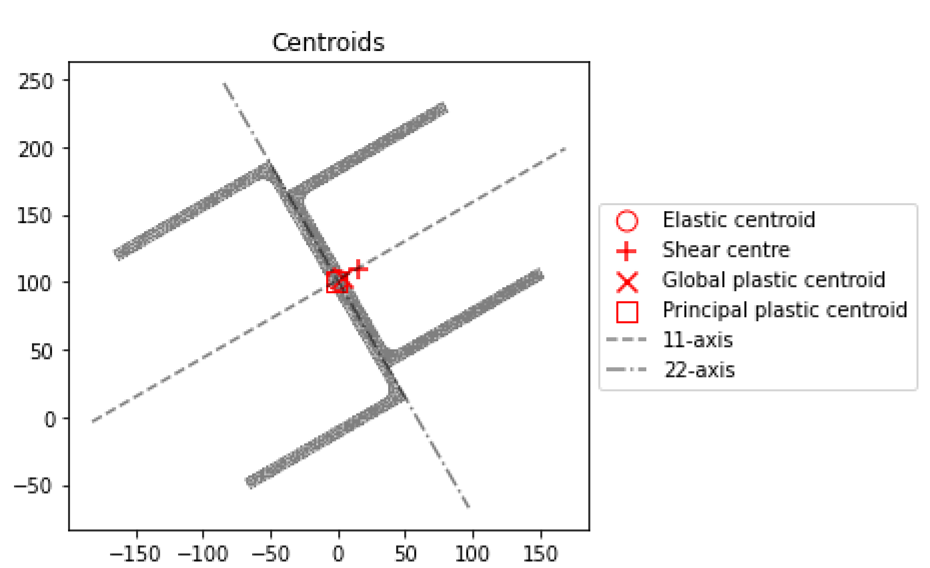


Out[34]: <Axes: title={'center': 'Finite Element Mesh'}>

Perform a geometric, warping and plastic analysis, displaying the time info and the iteration info for the plastic analysis

In [35]:
```
section.calculate_geometric_properties()
section.calculate_warping_properties()
section.calculate_plastic_properties(verbose=True)

section.plot_centroids()
```

```
Output()
Output()
Output()
d = -154.328341319365; f_norm = 1.0
d = 131.525142448589; f_norm = -1.0
d = -11.401599435387993; f_norm = 0.13458389687111885
d = 5.55231463203793; f_norm = -0.021090896125661042
d = 3.255390167671628; f_norm = -0.004055963678927537
d = 2.724499194243151; f_norm = 0.00045100079082289346
d = 2.7776241413031926; f_norm = -9.631031333251518e-06
d = 2.7765133886258857; f_norm = -2.1922919066993703e-08
d = 2.7765108545970905; f_norm = 5.977503270512459e-15
---x-axis plastic centroid calculation converged at 2.77651e+00 in 8 iterations.
d = -165.804528212969; f_norm = 1.0
d = 152.808229193691; f_norm = -1.0
d = -6.498149509638978; f_norm = 0.12894151075699403
d = 11.696951784368366; f_norm = -0.11748181846161726
d = 3.0224744372298193; f_norm = -5.230315361698405e-16
d = 3.022472425992601; f_norm = 2.7238961090721597e-08
---y-axis plastic centroid calculation converged at 3.02247e+00 in 5 iterations.
d = -101.49999999999976; f_norm = -1.0
d = 101.50000000000136; f_norm = 1.0
d = 7.958078640513122e-13; f_norm = 4.10953349847732e-15
d = -4.999992041925338e-07; f_norm = -1.905972795140489e-09
---11-axis plastic centroid calculation converged at 7.95808e-13 in 3 iterations.
d = -133.14647432951304; f_norm = -1.0
d = 132.8535256704867; f_norm = 1.0
d = -0.1464743295131825; f_norm = -0.050508389487418176
d = 6.248158849098923; f_norm = 0.34217314335062415
d = 0.6760309227206123; f_norm = 0.004360272672365583
d = 0.6106685276297984; f_norm = 3.026111030696966e-14
d = 0.6106677222955346; f_norm = -5.3723195071909884e-08
---22-axis plastic centroid calculation converged at 6.10669e-01 in 6 iterations.
```



Out[35]: <Axes: title={'center': 'Centroids'}>

6 Performing a Stress Analysis

Calculate and plot stresses on a section.

The following example demonstrates how a stress analysis can be performed on a cross-section. A 150x100x6 RHS is modelled on its side with a maximum mesh area of 2 mm\ :sup: `2` . The pre-requisite geometric and warping analyses are performed before two separate stress analyses are undertaken. The first combines bending and shear about the x-axis with a torsion moment and the second combines bending and shear about the y-axis with a torsion moment.

After the analysis is performed, various plots of the stresses are generated.

In [36]:
```
# sphinx_gallery_thumbnail_number = 1

import sectionproperties.pre.library.steel_sections as steel_sections
from sectionproperties.analysis.section import Section
```

Create a 150x100x6 RHS on its side

In [37]:
```
geometry = steel_sections.rectangular_hollow_section(d=100, b=150, t=6, r_out=15, n_r=8)
```

Create a mesh and section object. For the mesh, use a maximum area of 2

In [38]:
```
geometry.create_mesh(mesh_sizes=[2])
section = Section(geometry)
```

Perform a geometry and warping analysis

In [39]:
```
section.calculate_geometric_properties()
section.calculate_warping_properties()
```

Perform a stress analysis with Mx = 5 kN.m; Vx = 10 kN and Mzz = 3 kN.m

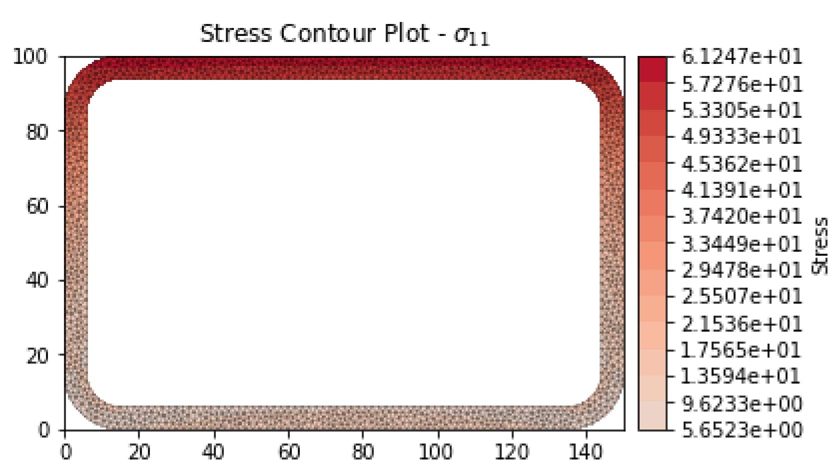
In [40]:
```
case1 = section.calculate_stress(mxx=5e6, vx=10e3, mzz=3e6)
```

Perform a stress analysis with My = 15 kN.m; Vy = 30 kN and Mzz = 1.5 kN.m

In [41]:
```
case2 = section.calculate_stress(myy=15e6, vy=30e3, mzz=1.5e6)
```

Plot the bending stress for case1

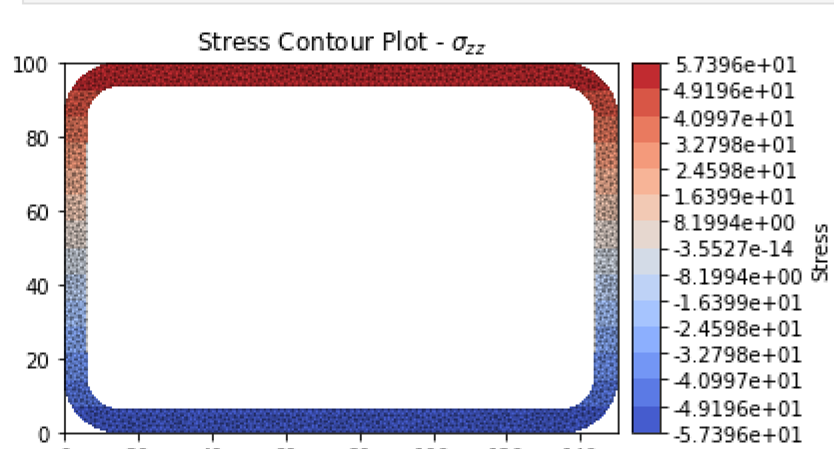
In [42]:
```
case1.plot_stress(stress="11")
```



Out[42]:
```
<Axes: title={'center': 'Stress Contour Plot - $\\sigma_{11}$'}>
```

Plot the torsion vectors for case1

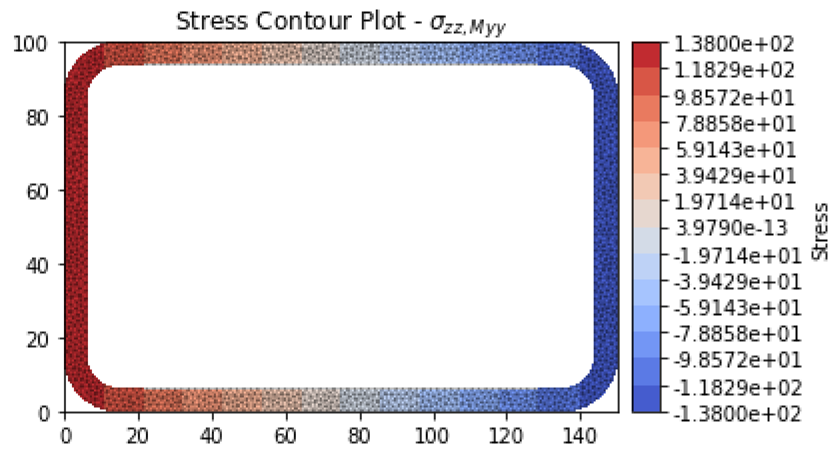
In [43]:
```
case1.plot_stress(stress="zz")
```



Out[43]:
```
<Axes: title={'center': 'Stress Contour Plot - $\\sigma_{zz}$'}>
```

Plot the shear stress for case2

In [44]:
```
case2.plot_stress(stress="myy_zz")
```



Out[44]: `<Axes: title={'center': 'Stress Contour Plot - $\\sigma_{zz,Myy}$'}>`

Plot the von mises stress for case1

7 Creating a Composite Section

Create a section of mixed materials.

The following example demonstrates how to create a composite cross-section by assigning different material properties to various regions of the mesh. A steel 310UB40.4 is modelled with a 50Dx600W timber panel placed on its top flange.

The geometry and mesh are plotted, and the mesh information printed to the terminal before the analysis is carried out. All types of cross-section analyses are carried out, with an axial force, bending moment and shear force applied during the stress analysis. Once the analysis is complete, the cross-section properties are printed to the terminal and a plot of the centroids and cross-section stresses generated.

In [45]:
```
# sphinx_gallery_thumbnail_number = 2

import sectionproperties.pre.library.primitive_sections as sections
import sectionproperties.pre.library.steel_sections as steel_sections
from sectionproperties.pre.geometry import CompoundGeometry
from sectionproperties.pre.pre import Material
from sectionproperties.analysis.section import Section
```

Create material properties

In [46]:
```
steel = Material(
    name="Steel",
    elastic_modulus=200e3,
    poissons_ratio=0.3,
    yield_strength=500,
    density=8.05e-6,
    color="grey",
)
timber = Material(
    name="Timber",
    elastic_modulus=8e3,
    poissons_ratio=0.35,
    yield_strength=20,
    density=0.78e-6,
    color="burlywood",
)
```

Create 310UB40.4

In [47]:
```
ub = steel_sections.i_section(
    d=304, b=165, t_f=10.2, t_w=6.1, r=11.4, n_r=8, material=steel
)
```

Create timber panel on top of the UB

In [48]:
```
panel = sections.rectangular_section(d=50, b=600, material=timber)
panel = panel.align_center(ub).align_to(ub, on="top")
# Create intermediate nodes in panel to match nodes in ub
panel = (panel - ub) | panel
```

Merge the two sections into one geometry object

In [49]:
```
section_geometry = CompoundGeometry([ub, panel])
```

Create a mesh and a Section object. For the mesh use a mesh size of 5 for the UB, 20 for the panel

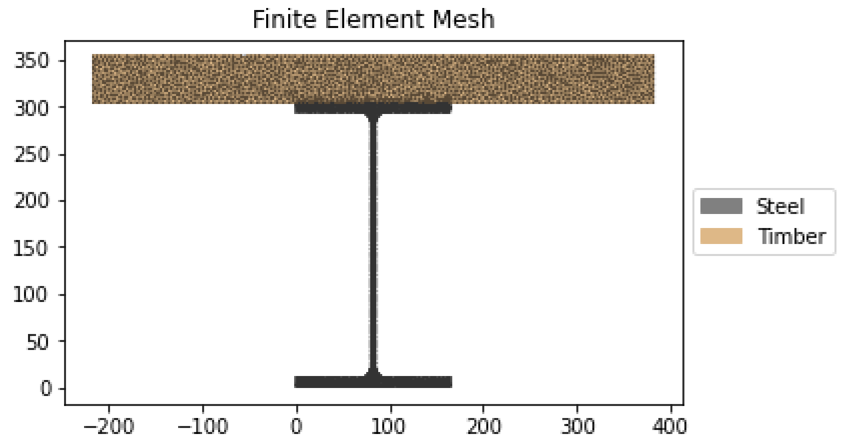
In [50]:
```
section_geometry.create_mesh(mesh_sizes=[5, 20])
comp_section = Section(section_geometry, time_info=True)
comp_section.display_mesh_info()  # display the mesh information
```

Mesh Statistics:

- 9083 nodes
- 4246 elements
- 2 regions

Plot the mesh with coloured materials and a line transparency of 0.6

In [51]:
```
comp_section.plot_mesh(materials=True, alpha=0.6)
```



Out[51]: `<Axes: title={'center': 'Finite Element Mesh'}>`

Perform a geometric, warping and plastic analysis

In [52]:
```
comp_section.calculate_geometric_properties()
comp_section.calculate_warping_properties()
comp_section.calculate_plastic_properties(verbose=True)
```

```
Output()
Output()
Output()
d = -185.130884950272; f_norm = 1.0
d = 168.869115049728; f_norm = -1.0
d = -8.13088495027199; f_norm = 0.13960518846748188
d = 13.5521668722403; f_norm = 0.0983423820518058
d = 60.60270845168366; f_norm = 0.008805290832494688
d = 64.90008929872147; f_norm = 0.000627383246551551
d = 65.22746216923495; f_norm = 4.393296043904811e-06
d = 65.22976962543778; f_norm = 2.21127426308038e-09
d = 65.2298027403226; f_norm = -6.080628894287011e-08
---x-axis plastic centroid calculation converged at 6.52298e+01 in 8 iterations.
d = -300.0; f_norm = 1.0
d = 300.0; f_norm = -1.0
d = 0.0; f_norm = 7.263545449900235e-17
d = 5e-07; f_norm = -4.773093592438759e-08
---y-axis plastic centroid calculation converged at 0.00000e+00 in 3 iterations.
d = -185.130884950272; f_norm = 1.0
d = 168.869115049728; f_norm = -1.0
d = -8.13088495027199; f_norm = 0.13960518846748188
d = 13.5521668722403; f_norm = 0.0983423820518058
d = 60.60270845168366; f_norm = 0.008805290832494688
d = 64.90008929872147; f_norm = 0.000627383246551551
d = 65.22746216923495; f_norm = 4.393296043904811e-06
d = 65.22976962543778; f_norm = 2.21127426308038e-09
d = 65.2298027403226; f_norm = -6.080628894287011e-08
---11-axis plastic centroid calculation converged at 6.52298e+01 in 8 iterations.
d = -300.0; f_norm = 1.0
d = 300.0; f_norm = -1.0
d = 0.0; f_norm = 7.263545449900235e-17
d = 5e-07; f_norm = -4.773093592438759e-08
---22-axis plastic centroid calculation converged at 0.00000e+00 in 3 iterations.
```

Perform a stress analysis with N = 100 kN, Mxx = 120 kN.m and Vy = 75 kN

In [53]:
```
stress_post = comp_section.calculate_stress(n=-100e3, mxx=-120e6, vy=-75e3)
```

```
Output()
```

Print the results to the terminal

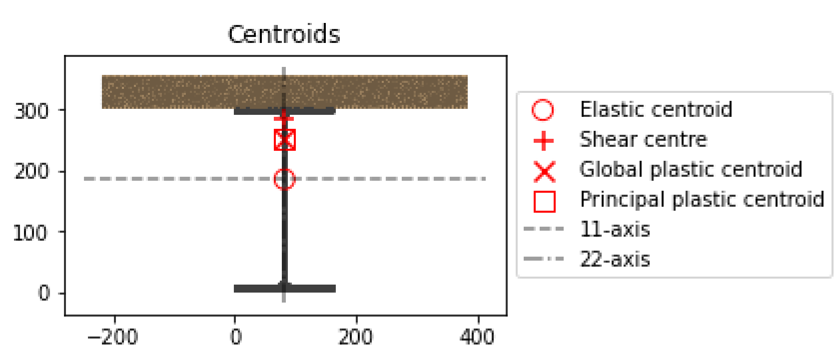
In [54]:
```
comp_section.display_results()
```

Section Properties

Property	Value
area	3.521094e+04
perimeter	2.206078e+03
mass	6.534804e-02
e.a	1.282187e+09
e.qx	2.373725e+11
e.qy	1.057805e+11
e.ixx_g	6.740447e+13
e.iyy_g	1.745613e+13
e.ixy_g	1.958323e+13
cx	8.250000e+01
cy	1.851309e+02
e.ixx_c	2.345949e+13
e.iyy_c	8.729240e+12
e.ixy_c	2.734375e-02
e.zxx+	1.389212e+11
e.zxx-	1.267184e+11
e.zyy+	2.909747e+10
e.zyy-	2.909747e+10
rx	1.352644e+02
ry	8.251112e+01
e.i11_c	2.345949e+13
e.i22_c	8.729240e+12
phi	0.000000e+00
e.z11+	1.389212e+11
e.z11-	1.267184e+11
e.z22+	2.909747e+10
e.z22-	2.909747e+10
r11	1.352644e+02
r22	8.251112e+01
e_eff	3.641446e+04
g_eff	1.390847e+04
nu_eff	3.090753e-01
e.j	3.768367e+11
x_se	8.250105e+01
y_se	2.863411e+02
x1_se	1.049231e-03
y2_se	1.012102e+02
x_st	8.250104e+01
y_st	2.857085e+02
e.gamma	6.687734e+16
e.a_sx	4.022647e+08
e.a_sy	3.718571e+08
e.a_s11	4.022647e+08
e.a_s22	3.718571e+08
beta_x+	2.039435e+02
beta_x-	-2.039435e+02
beta_y+	2.098462e-03
beta_y-	-2.098462e-03
beta_11+	2.039435e+02
beta_11-	-2.039435e+02
beta_22+	2.098462e-03
beta_22-	-2.098462e-03
x_pc	8.250000e+01
y_pc	2.503607e+02
x11_pc	8.250000e+01
y22_pc	2.503607e+02
mp_xx	4.238101e+08
mp_yy	4.226021e+08
mp_11	4.238101e+08
mp_22	4.226021e+08

Plot the centroids

In [55]:
```
comp_section.plot_centroids()
```



Out[55]: <Axes: title={'center': 'Centroids'}>

Plot the axial stress

8 Frame Analysis Example

Analyse a cross-section to be used in frame analysis.

The following example demonstrates how *sectionproperties* can be used to calculate the cross-section properties required for a frame analysis. Using this method is preferred over executing a geometric and warping analysis as only variables required for a frame analysis are computed. In this example the torsion constant of a rectangular section is calculated for a number of different mesh sizes and the accuracy of the result compared with the time taken to obtain the solution.

In [56]:
```python
# sphinx_gallery_thumbnail_number = 1

import time
import numpy as np
import matplotlib.pyplot as plt
import sectionproperties.pre.library.primitive_sections as sections
from sectionproperties.analysis.section import Section
```

Create a rectangular section

In [57]:
```python
geometry = sections.rectangular_section(d=100, b=50)
```

Create a list of mesh sizes to analyse

In [58]:
```python
mesh_sizes = [3, 4, 5, 10, 15, 20, 25, 30, 40, 50, 75, 100, 200]
j_calc = []  # list to store torsion constants
t_calc = []  # list to store computation times
```

Loop through mesh sizes

In [59]:
```python
for mesh_size in mesh_sizes:
    geometry.create_mesh(mesh_sizes=[mesh_size])  # create mesh
    section = Section(geometry)  # create a Section object
    start_time = time.time()  # start timing
    # calculate the frame properties
    (_, _, _, _, j, _) = section.calculate_frame_properties()
    t = time.time() - start_time  # stop timing
    t_calc.append(t)  # save the time
    j_calc.append(j)  # save the torsion constant
    # print the result
    str = "Mesh Size: {0}; ".format(mesh_size)
    str += "Solution Time {0:.5f} s; ".format(t)
    str += "Torsion Constant: {0:.12e}".format(j)
    print(str)
```

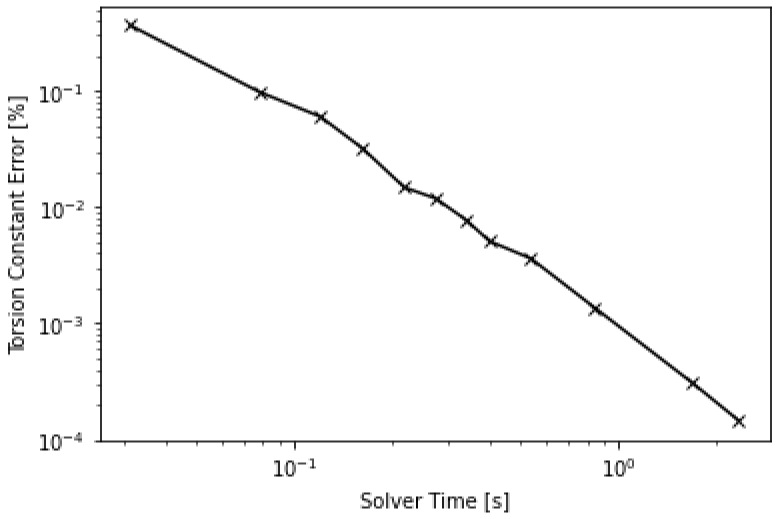
```
Mesh Size: 3; Solution Time 3.07929 s; Torsion Constant: 2.858525191518e+06
Mesh Size: 4; Solution Time 2.35015 s; Torsion Constant: 2.858529348617e+06
Mesh Size: 5; Solution Time 1.68847 s; Torsion Constant: 2.858533994778e+06
Mesh Size: 10; Solution Time 0.84268 s; Torsion Constant: 2.858564308063e+06
Mesh Size: 15; Solution Time 0.53706 s; Torsion Constant: 2.858628499542e+06
Mesh Size: 20; Solution Time 0.40043 s; Torsion Constant: 2.858670496343e+06
Mesh Size: 25; Solution Time 0.33810 s; Torsion Constant: 2.858748138885e+06
Mesh Size: 30; Solution Time 0.27300 s; Torsion Constant: 2.858865014806e+06
Mesh Size: 40; Solution Time 0.21869 s; Torsion Constant: 2.858947255775e+06
Mesh Size: 50; Solution Time 0.16271 s; Torsion Constant: 2.859438375764e+06
Mesh Size: 75; Solution Time 0.12049 s; Torsion Constant: 2.860241467603e+06
Mesh Size: 100; Solution Time 0.07812 s; Torsion Constant: 2.861326245766e+06
Mesh Size: 200; Solution Time 0.03125 s; Torsion Constant: 2.869013885610e+06
```

Compute the error, assuming that the finest mesh (index 0) gives the 'correct' value

In [60]:
```python
correct_val = j_calc[0]
j_np = np.array(j_calc)
error_vals = (j_calc - correct_val) / j_calc * 100
```

Produce a plot of the accuracy of the torsion constant with computation time

In [61]:
```python
plt.loglog(t_calc[1:], error_vals[1:], "kx-")
plt.xlabel("Solver Time [s]")
plt.ylabel("Torsion Constant Error [%]")
plt.show()
```



9 Importing Geometry from CAD DXF

CRASHING

Demonstrates loading :class: `~sectionproperties.pre.geometry.Geometry` and :class: `~sectionproperties.pre.geometry.CompoundGeometry` objects from `.dxf` and `.3dm` (Rhino) files.

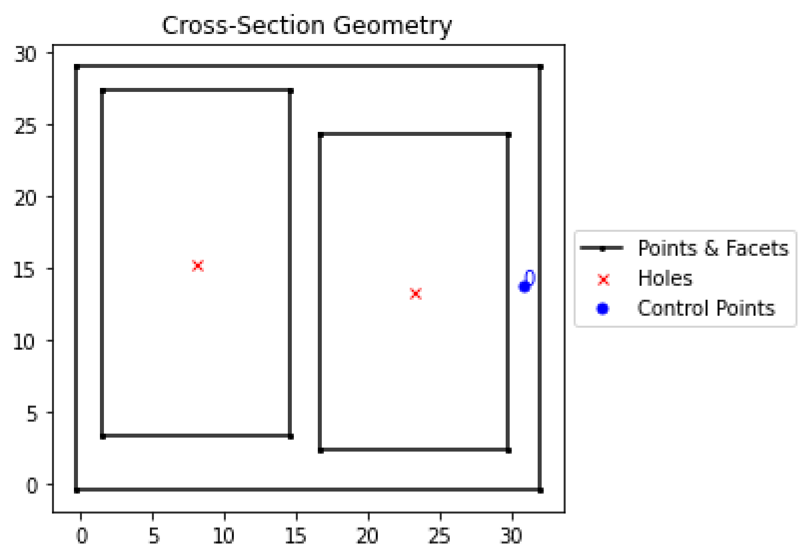
In [62]:
```python
# sphinx_gallery_thumbnail_number = 8

!pip install cad_to_shapely
# install once if needed
```

```
from sectionproperties.pre.geometry import Geometry, CompoundGeometry
from sectionproperties.analysis.section import Section
```

```
Requirement already satisfied: cad_to_shapely in c:\users\thomas\appdata\local\programs\python\python39\lib\site-packages (0.3.1)
Requirement already satisfied: ezdxf in c:\users\thomas\appdata\local\programs\python\python39\lib\site-packages (from cad_to_shape
ly) (1.1.1)
Requirement already satisfied: numpy in c:\users\thomas\appdata\local\programs\python\python39\lib\site-packages (from cad_to_shape
ly) (1.26.1)
Requirement already satisfied: shapely in c:\users\thomas\appdata\local\programs\python\python39\lib\site-packages (from cad_to_sha
pely) (2.0.2)
Requirement already satisfied: geomdl in c:\users\thomas\appdata\local\programs\python\python39\lib\site-packages (from cad_to_shap
ely) (5.3.1)
Requirement already satisfied: pyparsing>=2.0.1 in c:\users\thomas\appdata\local\programs\python\python39\lib\site-packages (from e
zdxf->cad_to_shapely) (3.1.0)
Requirement already satisfied: typing-extensions>=4.6.0 in c:\users\thomas\appdata\local\programs\python\python39\lib\site-packages
(from ezdxf->cad_to_shapely) (4.6.3)
Requirement already satisfied: fonttools in c:\users\thomas\appdata\local\programs\python\python39\lib\site-packages (from ezdxf->c
ad_to_shapely) (4.40.0)
```

Load a geometry with a single region from a dxf file

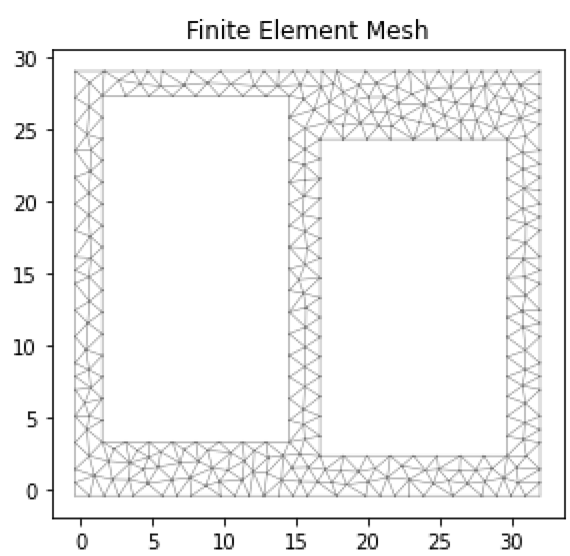
In [63]:
```
geom = Geometry.from_dxf(dxf_filepath="assets/section_holes.dxf")
geom.plot_geometry()
```



Out[63]: `<Axes: title={'center': 'Cross-Section Geometry'}>`

Generate a mesh

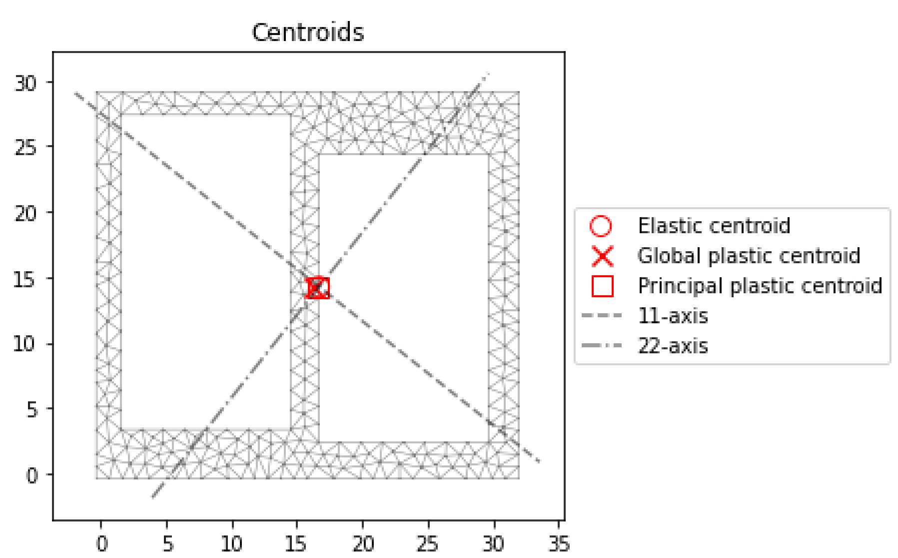
In [64]:
```
geom.create_mesh([1])
sec = Section(geom)
sec.plot_mesh(materials=False)
```



Out[64]: `<Axes: title={'center': 'Finite Element Mesh'}>`

Conduct a geometric & plastic analysis

In [65]:
```
sec.calculate_geometric_properties()
sec.calculate_plastic_properties()
sec.plot_centroids()
```



Out[65]: `<Axes: title={'center': 'Centroids'}>`

Display the geometric & plastic properties

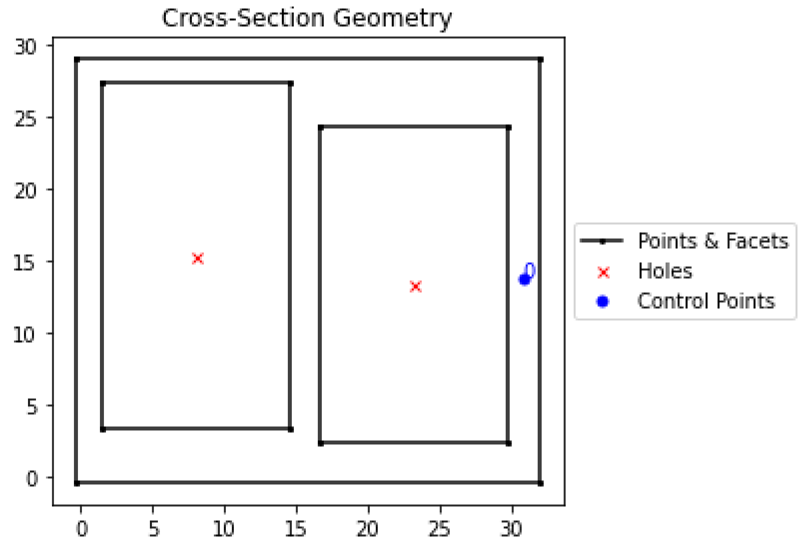
In [66]:
```python
sec.display_results()
```

Section Properties

Property	Value
area	3.543777e+02
perimeter	1.235768e+02
qx	5.047390e+03
qy	5.923689e+03
ixx_g	1.137665e+05
iyy_g	1.387654e+05
ixy_g	8.892907e+04
cx	1.671575e+01
cy	1.424297e+01
ixx_c	4.187664e+04
iyy_c	3.974650e+04
ixy_c	4.558164e+03
zxx+	2.820099e+03
zxx-	2.860789e+03
zyy+	2.606925e+03
zyy-	2.330570e+03
rx	1.087058e+01
ry	1.059049e+01
i11_c	4.549251e+04
i22_c	3.613063e+04
phi	-3.842404e+01
z11+	2.155143e+03
z11-	2.061571e+03
z22+	1.717082e+03
z22-	1.599443e+03
r11	1.133018e+01
r22	1.009728e+01
x_pc	1.626707e+01
y_pc	1.427513e+01
x11_pc	1.662479e+01
y22_pc	1.427103e+01
sxx	3.548750e+03
syy	3.153834e+03
s11	3.492177e+03
s22	2.898242e+03
sf_xx+	1.258378e+00
sf_xx-	1.240479e+00
sf_yy+	1.209791e+00
sf_yy-	1.353246e+00
sf_11+	1.620392e+00
sf_11-	1.693940e+00
sf_22+	1.687888e+00
sf_22-	1.812032e+00

Load a geometry with multiple holes from a dxf file

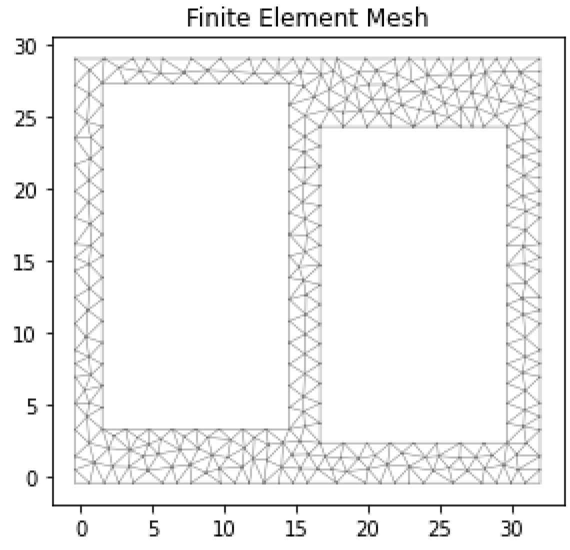
In [67]:
```python
geom = Geometry.from_dxf(dxf_filepath="assets/section_holes.dxf")
geom.plot_geometry()
```



Out[67]: <Axes: title={'center': 'Cross-Section Geometry'}>

Generate a mesh

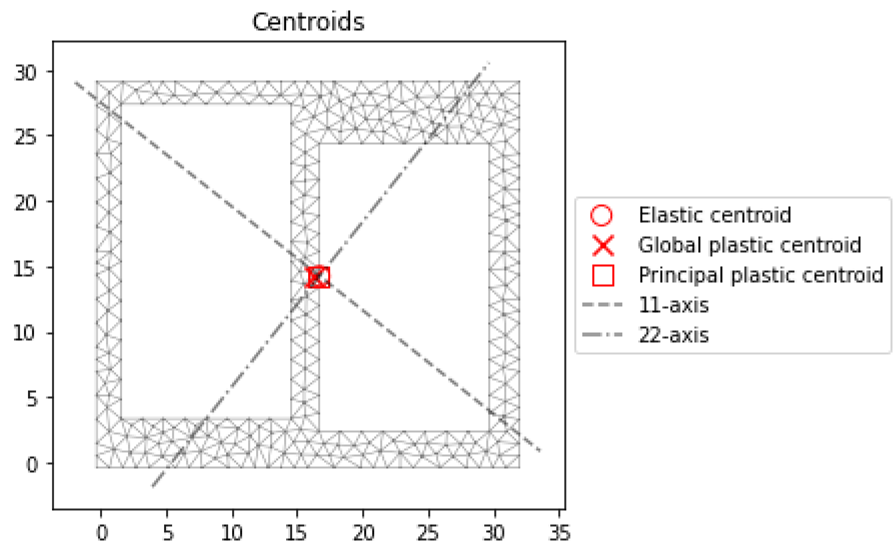
In [68]:
```python
geom.create_mesh([1])
sec = Section(geom)
sec.plot_mesh(materials=False)
```



Out[68]: <Axes: title={'center': 'Finite Element Mesh'}>

Conduct a geometric & plastic analysis

In [69]:
```
sec.calculate_geometric_properties()
sec.calculate_plastic_properties()
sec.plot_centroids()
```



Out[69]: <Axes: title={'center': 'Centroids'}>

Display the geometric & plastic properties

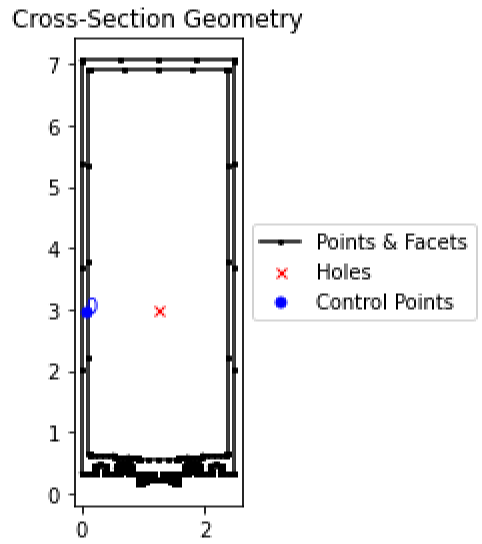
In [70]:
```
sec.display_results()
```

Section Properties

Property	Value
area	3.543777e+02
perimeter	1.235768e+02
qx	5.047390e+03
qy	5.923689e+03
ixx_g	1.137665e+05
iyy_g	1.387654e+05
ixy_g	8.892907e+04
cx	1.671575e+01
cy	1.424297e+01
ixx_c	4.187664e+04
iyy_c	3.974650e+04
ixy_c	4.558164e+03
zxx+	2.820099e+03
zxx-	2.860789e+03
zyy+	2.606925e+03
zyy-	2.330570e+03
rx	1.087058e+01
ry	1.059049e+01
i11_c	4.549251e+04
i22_c	3.613063e+04
phi	-3.842404e+01
z11+	2.155143e+03
z11-	2.061571e+03
z22+	1.717082e+03
z22-	1.599443e+03
r11	1.133018e+01
r22	1.009728e+01
x_pc	1.626707e+01
y_pc	1.427513e+01
x11_pc	1.662479e+01
y22_pc	1.427103e+01
sxx	3.548750e+03
syy	3.153834e+03
s11	3.492177e+03
s22	2.898242e+03
sf_xx+	1.258378e+00
sf_xx-	1.240479e+00
sf_yy+	1.209791e+00
sf_yy-	1.353246e+00
sf_11+	1.620392e+00
sf_11-	1.693940e+00
sf_22+	1.687888e+00
sf_22-	1.812032e+00

Load a geometry from a 3dm (Rhino) file

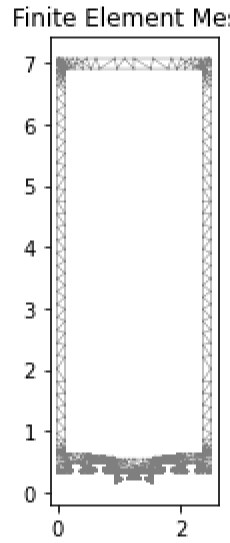
In [71]:
```
# !pip install rhino-shapley-interop

geom = Geometry.from_3dm(filepath="assets/complex_shape.3dm")
geom.plot_geometry()
```



Out[71]: <Axes: title={'center': 'Cross-Section Geometry'}>

Generate a mesh

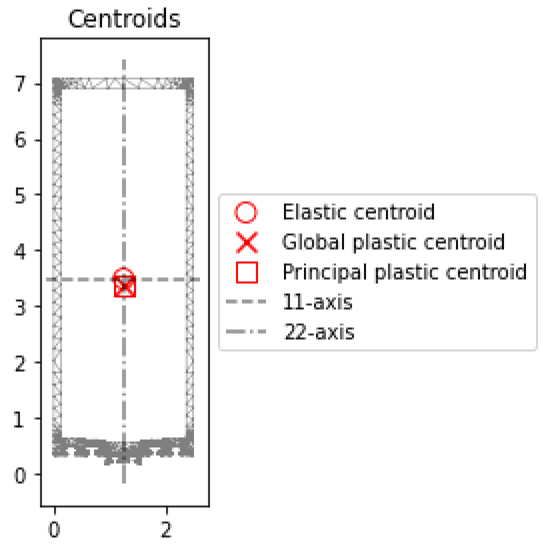
In [72]:
```
geom.create_mesh([1])
sec = Section(geom)
sec.plot_mesh(materials=False)
```



Out[72]: <Axes: title={'center': 'Finite Element Mesh'}>

Conduct a geometric & plastic analysis

In [73]:
```
sec.calculate_geometric_properties()
sec.calculate_plastic_properties()
sec.plot_centroids()
```



Out[73]: <Axes: title={'center': 'Centroids'}>

Display the geometric & plastic properties

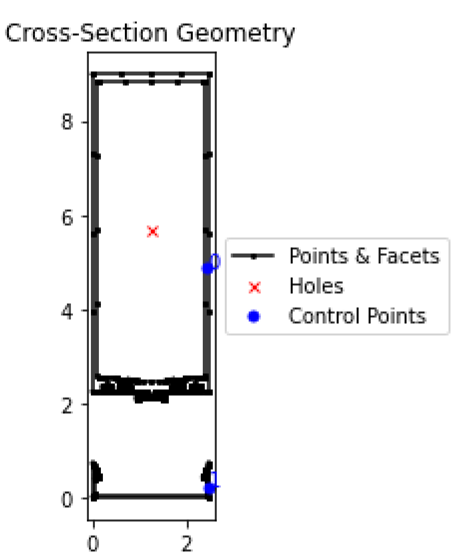
In [74]:
```
sec.display_results()
```

Section Properties

Property	Value
area	2.602049e+00
perimeter	2.130651e+01
qx	9.082300e+00
qy	3.252560e+00
ixx_g	4.773758e+01
iyy_g	6.824622e+00
ixy_g	1.135287e+01
cx	1.249999e+00
cy	3.490441e+00
ixx_c	1.603635e+01
iyy_c	2.758925e+00
ixy_c	5.755182e-06
zxx+	4.476583e+00
zxx-	4.813398e+00
zyy+	2.207139e+00
zyy-	2.207142e+00
rx	2.482533e+00
ry	1.029704e+00
i11_c	1.603635e+01
i22_c	2.758925e+00
phi	0.000000e+00
z11+	4.476583e+00
z11-	4.813398e+00
z22+	2.207139e+00
z22-	2.207142e+00
r11	2.482533e+00
r22	1.029704e+00
x_pc	1.249996e+00
y_pc	3.353406e+00
x11_pc	1.249996e+00
y22_pc	3.353406e+00
sxx	5.801661e+00
syy	2.504936e+00
s11	5.801661e+00
s22	2.504936e+00
sf_xx+	1.296002e+00
sf_xx-	1.205315e+00
sf_yy+	1.134925e+00
sf_yy-	1.134923e+00
sf_11+	1.296002e+00
sf_11-	1.205315e+00
sf_22+	1.134925e+00
sf_22-	1.134923e+00

Load a compound geometry with multiple regions from a 3dm (Rhino) file

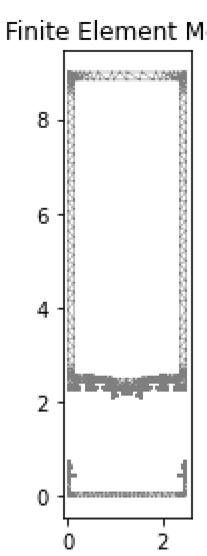
In [75]:
```
geom = CompoundGeometry.from_3dm(filepath="assets/compound_shape.3dm")
geom.plot_geometry()
```



Out[75]: `<Axes: title={'center': 'Cross-Section Geometry'}>`

Generate a mesh

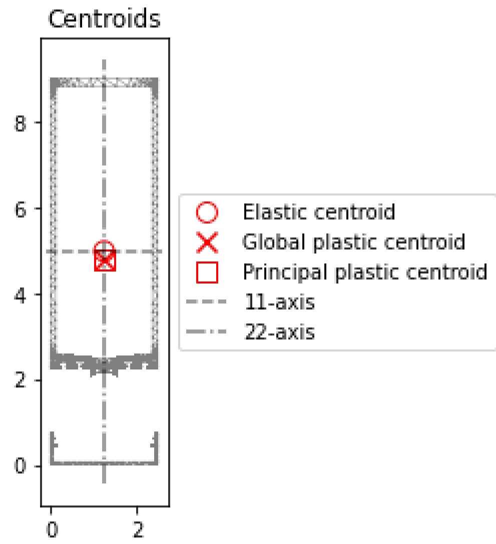
In [76]:
```
geom.create_mesh([1])
sec = Section(geom)
sec.plot_mesh(materials=False)
```



Out[76]: `<Axes: title={'center': 'Finite Element Mesh'}>`

Conduct a geometric & plastic analysis N.B a warping analysis would be invalid due to the lack of connectivity between the two regions

In [77]:
```
sec.calculate_geometric_properties()
sec.calculate_plastic_properties()
sec.plot_centroids()
```



Out[77]:
```
<Axes: title={'center': 'Centroids'}>
```

Display the geometric & plastic properties

In [78]:
```
sec.display_results()
```

Section Properties

Property	Value
area	2.838725e+00
perimeter	-1.000000e+00
qx	1.413033e+01
qy	3.548404e+00
ixx_g	9.237156e+01
iyy_g	7.393179e+00
ixy_g	1.766291e+01
cx	1.249999e+00
cy	4.977702e+00
ixx_c	2.203499e+01
iyy_c	2.957676e+00
ixy_c	4.909920e-06
zxx+	5.480936e+00
zxx-	4.426740e+00
zyy+	2.366139e+00
zyy-	2.366142e+00
rx	2.786088e+00
ry	1.020736e+00
i11_c	2.203499e+01
i22_c	2.957676e+00
phi	0.000000e+00
z11+	5.480936e+00
z11-	4.426740e+00
z22+	2.366139e+00
z22-	2.366142e+00
r11	2.786088e+00
r22	1.020736e+00
x_pc	1.249996e+00
y_pc	4.805339e+00
x11_pc	1.249996e+00
y22_pc	4.805339e+00
sxx	6.956641e+00
syy	2.699474e+00
s11	6.956641e+00
s22	2.699474e+00
sf_xx+	1.269243e+00
sf_xx-	1.571504e+00
sf_yy+	1.140877e+00
sf_yy-	1.140876e+00
sf_11+	1.269243e+00
sf_11-	1.571504e+00
sf_22+	1.140877e+00
sf_22-	1.140876e+00