```
# Project 9: Orthogonal matrices and 3D graphics
import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
import math
import itertools
from scipy.io import loadmat


print("\nSubtask 1-4\n")
def rotation(theta_x, theta_y, theta_z):
# Rotation matrix around the x-axis
    Rx = np.array([[1, 0, 0],
        [0, np.cos(theta_x), -np.sin(theta_x)],
        [0, np.sin(theta_x), np.cos(theta_x)]])
    # Rotation matrix around the y-axis
    Ry = np.array([[np.cos(theta_y), 0, -np.sin(theta_y)],
        [0, 1, 0],
        [np.sin(theta_y), 0, np.cos(theta_y)]])
    # Rotation matrix around the z-axis
    Rz = np.array([[np.cos(theta_z), -np.sin(theta_z), 0],
        [np.sin(theta_z), np.cos(theta_z), 0],
        [0, 0, 1]])
    # Combined rotation matrix
    rotmat = Rz @ Ry @ Rx
    return rotmat
```

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Subtask 1-4
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print("\nSubtask 5\n")
# Define cube vertices
Vertices = np.array([[1, 1, 1],
[-1, 1, 1],
[1, -1, 1],
[1, 1, -1],
[-1, -1, 1],
[-1, 1, -1],
[1, -1, -1],
[-1, -1, -1]])
# Define adjacency matrix (Edges)
Edges = np.zeros((8, 8))
Edges[0, 1] = 1
Edges[0, 2] = 1
Edges[0, 3] = 1
Edges[1, 4] = 1
Edges[1, 5] = 1
Edges[2, 4] = 1
Edges[2, 6] = 1
Edges[3, 5] = 1
Edges[3, 6] = 1
Edges[4, 7] = 1
Edges[5, 7] = 1
Edges[6, 7] = 1
Edges = Edges + Edges.T # Make the matrix symmetric
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Subtask 5
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print("\nSubtask 6\n")
# Define rotation angles
theta_x = np.pi / 3 # 60 degrees
theta_y = np.pi / 4 # 45 degrees
theta_z = np.pi / 6 # 30 degrees
# Generate the rotation matrix
rotmat = rotation(theta_x, theta_y, theta_z)
```

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Subtask 6
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print("\nSubtask 7\n")
# Rotate the vertices
VertRot = Vertices @ rotmat.T # Transpose the rotation matrix
```

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Subtask 7
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print("\nSubtask 8\n")
# Create a new figure window
plt.figure()
plt.axis('equal')
plt.title('Projection of Rotated Cube')
# Draw the projection of the cube
for j in range(8):
    for k in range(j + 1, 8): # Start with j + 1 to avoid repeating lines
        if Edges[j, k] == 1:
        # Draw lines connecting the vertices (projecting by dropping the last c
            plt.plot([VertRot[j, 0], VertRot[k, 0]], [VertRot[j, 1], VertRot[k,
plt.xlabel('X-axis')
plt.ylabel('Y-axis')
plt.grid()
plt.show()
```

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Subtask 8
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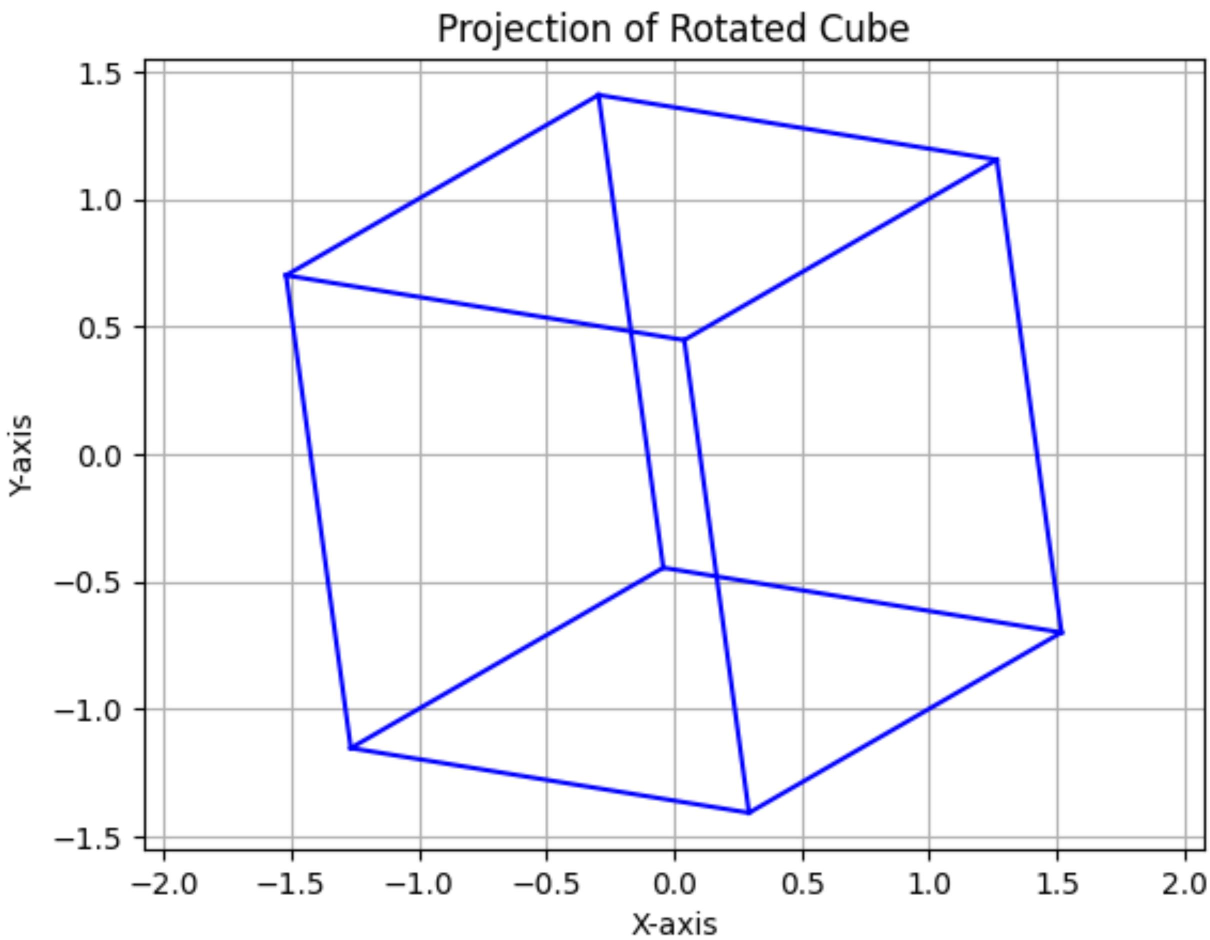
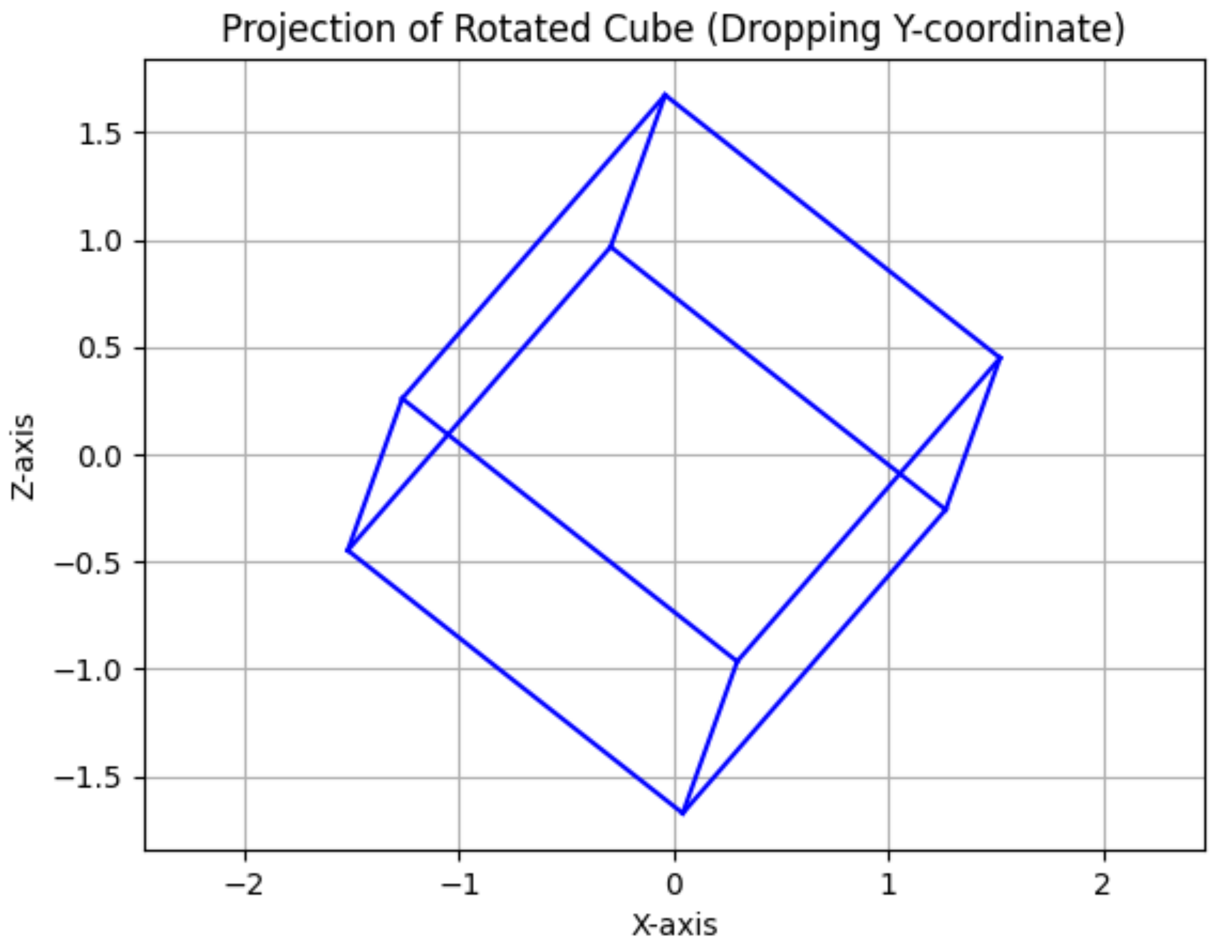


```
print("\nSubtask 9\n")
# Create a new figure window
plt.figure()
plt.axis('equal')
plt.title('Projection of Rotated Cube (Dropping Y-coordinate)')
# Draw the projection of the cube by dropping the Y-coordinate
for j in range(8):
    for k in range(j + 1, 8):
        if Edges[j, k] == 1:
        # Draw lines connecting the vertices (projecting by dropping the Y coor
            plt.plot([VertRot[j, 0], VertRot[k, 0]], [VertRot[j, 2], VertRot[k,
plt.xlabel('X-axis')
plt.ylabel('Z-axis') # Update label to reflect the projection
plt.grid()
plt.show()
```

```
Subtask 9
```




```
print("\nSubtask 10-12\n")
def distance(a, b):
    '''Calculates the straight line distance between two points a and b.'''
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    return np.linalg.norm(np.array(a) - np.array(b))
def makecoords():
    '''Generate a list of coordinates for the buckyball.'''
    phi = 0.5 * (1 + math.sqrt(5))
    c1 = (0, 1, 3 * phi)
    c2 = (2, (1 + 2 * phi), phi)
    c3 = (1, 2 + phi, 2 * phi)
    combos1 = list(itertools.product((1, -1), repeat=2))
    for i in range(len(combos1)):
        combos1[i] = (1,) + combos1[i]
    combos23 = list(itertools.product((1, -1), repeat=3))
    coords = []
    for i in combos1:
        coords.append(np.array(c1) * np.array(i))
    for i in combos23:
        coords.append(np.array(c2) * np.array(i))
        coords.append(np.array(c3) * np.array(i))
    # Permutation matrices
    P1 = np.array([[0, 0, 1], [1, 0, 0], [0, 1, 0]])
    P2 = np.array([[0, 1, 0], [0, 0, 1], [1, 0, 0]])
    for i in coords[:]:
        coords.append(P1 @ i)
        coords.append(P2 @ i)
    return coords
def makeadjmat(coords):
    '''Make a 60x60 adjacency matrix for the coordinates.'''
    D = np.zeros((60, 60))
    for i in range(len(coords)):
        for j in range(len(coords)):
            if distance(coords[i], coords[j]) == 2.0:
                D[i][j] = 1
    return D
def rotation(theta_x, theta_y, theta_z):
    '''Create a rotation matrix based on the specified angles.'''
    rot_x = np.array([[1, 0, 0],
    [0, np.cos(theta_x), -np.sin(theta_x)],
    [0, np.sin(theta_x), np.cos(theta_x)]])
    rot_y = np.array([[np.cos(theta_y), 0, np.sin(theta_y)],
    [0, 1, 0],
    [-np.sin(theta_y), 0, np.cos(theta_y)]])
    rot_z = np.array([[np.cos(theta_z), -np.sin(theta_z), 0],
    [np.sin(theta_z), np.cos(theta_z), 0],
    [0, 0, 1]])
    return rot_z @ rot_y @ rot_x # Combined rotation matrix
def plot_buckyball(coords, edges, rotmat):
    '''Plot the 3D projection of the buckyball.'''
    fig = plt.figure()
    ax = fig.add_subplot(111, projection='3d')
```

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    ax.set_title('3D Projection of Buckyball')
    # Apply the rotation matrix to the coordinates
    rotated_coords = [np.dot(rotmat, vertex) for vertex in coords]
    num_vertices = len(coords)
    for j in range(num_vertices):
        for k in range(j + 1, num_vertices):
            if edges[j, k] == 1:
                ax.plot([rotated_coords[j][0], rotated_coords[k][0]],
                [rotated_coords[j][1], rotated_coords[k][1]],
                [rotated_coords[j][2], rotated_coords[k][2]], 'b-')
    ax.set_xlabel('X')
    ax.set_ylabel('Y')
    ax.set_zlabel('Z')
    plt.show()
if __name__ == "__main__":
    # Task 10: Generate coordinates for the buckyball
    coords = makecoords()
    # Generate the adjacency matrix
    edges = makeadjmat(coords)
    # Find and print the number of vertices
    num_vertices = len(coords)
    print("Number of vertices in the array Vertices2:", num_vertices)
    # Define rotation angles (in radians)
    theta_x = np.pi / 3
    theta_y = np.pi / 4
    theta_z = np.pi / 6
    # Generate the rotation matrix
    rotmat = rotation(theta_x, theta_y, theta_z)
    # Task 11: Plot the 3D projection of the buckyball
    plot_buckyball(coords, edges, rotmat)
```

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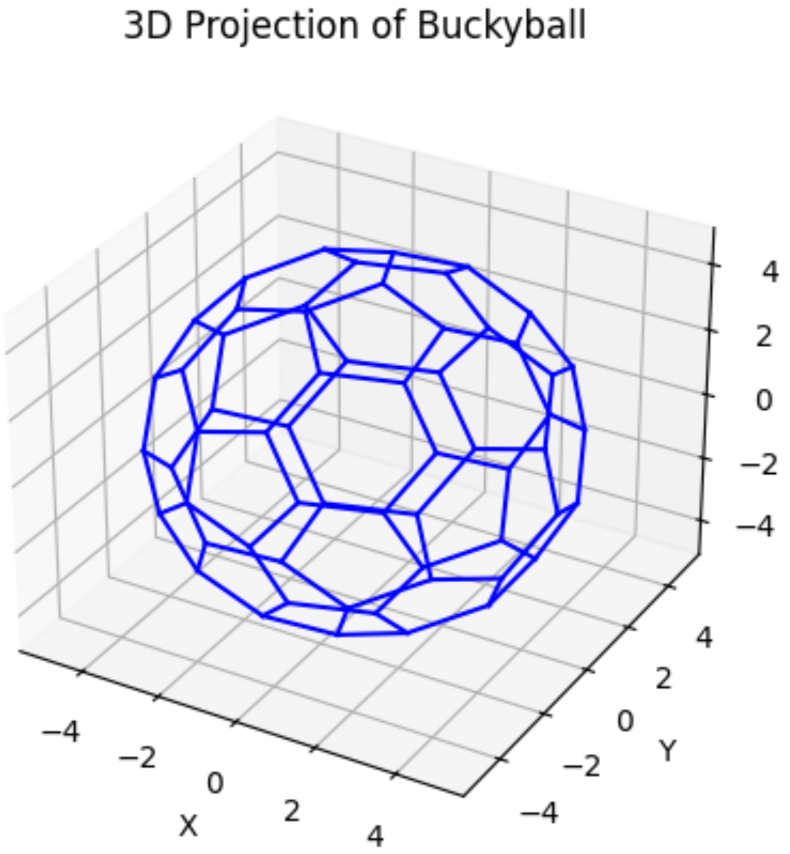
Subtask 10-12

Number of vertices in the array Vertices2: 60
```



```
print("\nSubtask 13\n")
data_v = loadmat("/content/v.mat")
data_f = loadmat("/content/f.mat")
# Extract the vertices (v) and faces (f) from the loaded data
v = data_v['v'] # Ensure the key matches the variable name in the .mat file
f = data_f['f'] # Ensure the key matches the variable name in the .mat file
# Variables: v, f
print("Vertices (v):")
print(v)
print("\nFaces (f):")
print(f)
```

```
Subtask 13

Vertices (v):
[[ 58.64743805 111.18914032   6.92400026]
 [ 60.88143921 106.30313873  14.13500023]
 [ 67.99643707 114.31414032   8.17200089]
 ...
 [ 87.3354187   43.88992691   1.28999996]
 [ 97.1484375   53.10213852   1.47399998]
 [ 88.33444214  45.02913666   3.69500017]]

Faces (f):
[[   1    2    3]
 [   4    5    6]
 [   7    8    9]
 ...
 [1312 1313 1314]
 [1315 1316 1317]
 [1318 1319 1320]]
```

```
print("\nSubtask 14\n")
mFaces, nFaces = f.shape # Get the number of rows and columns in f
# Output the dimensions of f
print("\nDimensions of the face matrix f,")
print("Number of faces (mFaces):", mFaces)
print("Number of vertices per face (nFaces):", nFaces)
```

```
Subtask 14


Dimensions of the face matrix f,
Number of faces (mFaces): 440
Number of vertices per face (nFaces): 3
```

```
print("\nSubtask 15\n")
```

```
# Get the number of faces
mFaces = f.shape[0]
# Generate the 3D model
fig = plt.figure()
ax = fig.add_subplot(111, projection='3d')
ax.set_box_aspect([1, 1, 1]) # Set aspect ratio to equal
# Loop through each face and plot the edges
for j in range(mFaces):
# Draw lines between the vertices of each face
    ax.plot([v[f[j, 0] - 1, 0], v[f[j, 1] - 1, 0]], [v[f[j, 0] - 1, 1], v[f[j,
    [v[f[j, 0] - 1, 2], v[f[j, 1] - 1, 2]], color='b') # Edge between vertex 1
    ax.plot([v[f[j, 0] - 1, 0], v[f[j, 2] - 1, 0]], [v[f[j, 0] - 1, 1], v[f[j,
    [v[f[j, 0] - 1, 2], v[f[j, 2] - 1, 2]], color='b') # Edge between vertex 1
    ax.plot([v[f[j, 1] - 1, 0], v[f[j, 2] - 1, 0]], [v[f[j, 1] - 1, 1], v[f[j,
    [v[f[j, 1] - 1, 2], v[f[j, 2] - 1, 2]], color='b') # Edge between vertex 2
# Set labels for the axes
ax.set_xlabel('X')
ax.set_ylabel('Y')
ax.set_zlabel('Z')
# Set the viewpoint (azimuth, elevation)
ax.view_init(elev=10, azim=210) # You can change the angles here
# Show the 3D plot
plt.show()
```

```
Subtask 15
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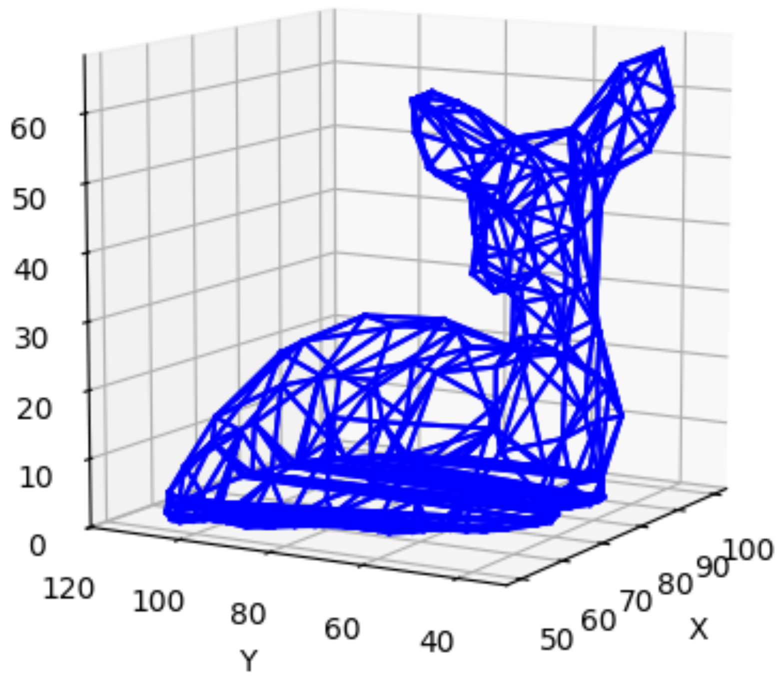

```
print("\nSubtask 16\n")
theta1 = np.pi / 3 # Rotation around x-axis
theta2 = np.pi / 4 # Rotation around y-axis
theta3 = np.pi # Rotation around z-axis
# Generate the rotation matrix
rotmat = rotation(theta1, theta2, theta3)
# Transform the coordinates of the vertices with the rotation matrix
VertRot = v @ rotmat.T # Apply rotation
# Create a new figure window for the 2D projection
plt.figure()
plt.axis('equal')
plt.title("2D Projection of the 3D Model")
# Plot the 2D projection by connecting the edges defined in f
for j in range(f.shape[0]):
    plt.plot([VertRot[f[j, 0] - 1, 0], VertRot[f[j, 1] - 1, 0]],
    [VertRot[f[j, 0] - 1, 1], VertRot[f[j, 1] - 1, 1]], color='b')
    plt.plot([VertRot[f[j, 0] - 1, 0], VertRot[f[j, 2] - 1, 0]],
    [VertRot[f[j, 0] - 1, 1], VertRot[f[j, 2] - 1, 1]], color='b')
    plt.plot([VertRot[f[j, 1] - 1, 0], VertRot[f[j, 2] - 1, 0]],
    [VertRot[f[j, 1] - 1, 1], VertRot[f[j, 2] - 1, 1]], color='b')
# Set labels for the axes
plt.xlabel('X')
plt.ylabel('Y')
plt.grid()
plt.show()
```

```
Subtask 16
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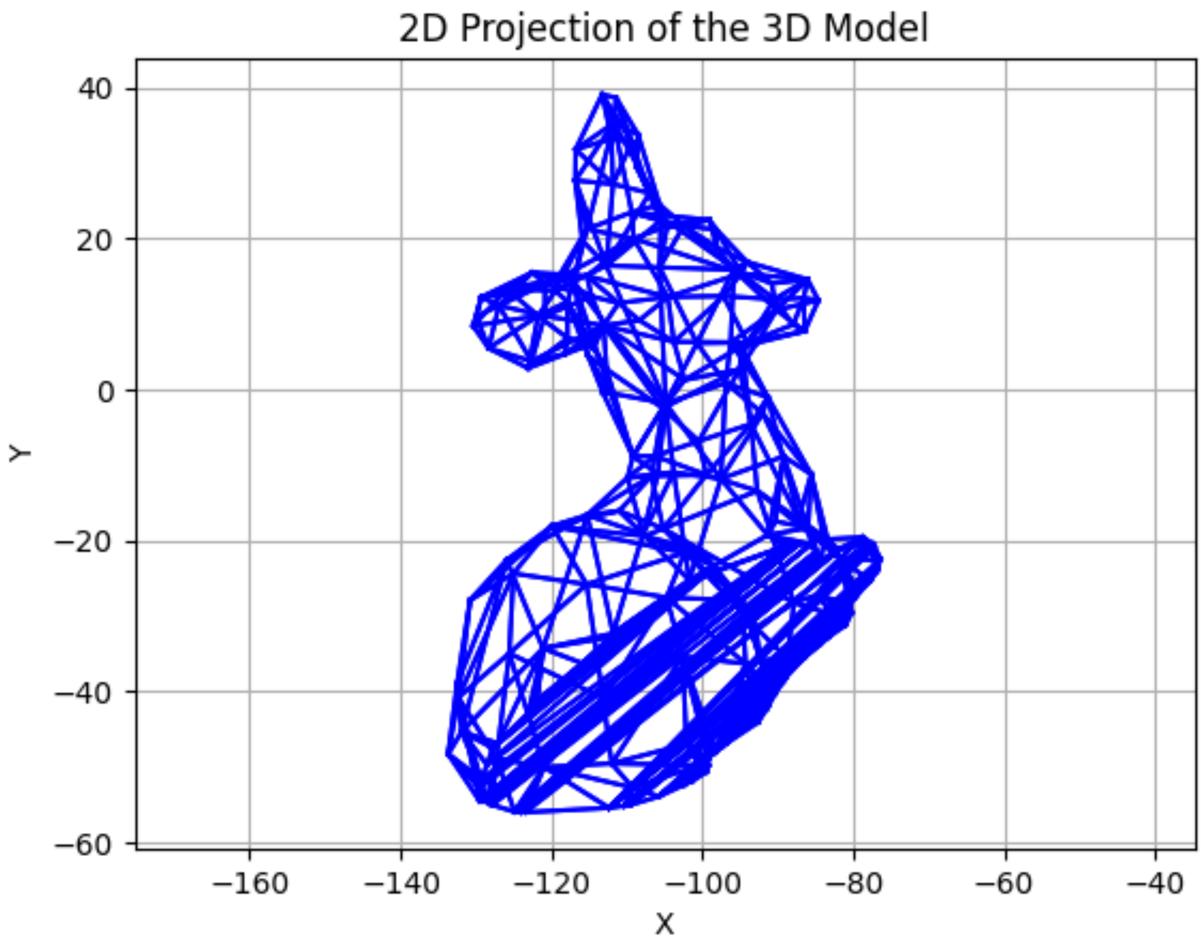


```
print("\nSubtask 17\n")
# Define the new rotation angles
theta1 = -np.pi / 3 # Rotation around x-axis
theta2 = 0 # No rotation around y-axis
theta3 = np.pi / 4 # Rotation around z-axis
# Generate the rotation matrix
rotmat2 = rotation(theta1, theta2, theta3)
# Rotate the vertices
vRot = v @ rotmat2.T # Apply rotation
# Project to the XY plane
vPrj = vRot[:, :2] # Keep only the first two coordinates
# Create a new figure window for the 2D projection
plt.figure()
plt.axis('equal')
plt.title("2D Projection of the 3D Model using rotmat2")
# Plot the 2D projection by connecting the edges defined in f
for j in range(f.shape[0]):
    plt.plot([vPrj[f[j, 0] - 1, 0], vPrj[f[j, 1] - 1, 0]],
    [vPrj[f[j, 0] - 1, 1], vPrj[f[j, 1] - 1, 1]], color='b')
    plt.plot([vPrj[f[j, 0] - 1, 0], vPrj[f[j, 2] - 1, 0]],
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```
    plt.plot([vPrj[f[j, 0] - 1, 0], vPrj[f[j, 2] - 1, 0]],
    [vPrj[f[j, 0] - 1, 1], vPrj[f[j, 2] - 1, 1]], color='b')
    plt.plot([vPrj[f[j, 1] - 1, 0], vPrj[f[j, 2] - 1, 0]],
    [vPrj[f[j, 1] - 1, 1], vPrj[f[j, 2] - 1, 1]], color='b')
# Set labels for the axes
plt.xlabel('X')
plt.ylabel('Y')
plt.grid()
plt.show()
```

```
Subtask 17
```