Assignment 3: Implementation of Trees and Graph Algorithms for Campus Navigation and Data Management

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Programme: B.Tech CSE DS

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1. Description of the Building Data ADT

As per the assignment instructions, the **Building Data Abstract Data Type (ADT)** is designed to store and manage information about each building on campus.

- **Attributes:**
  - **BuildingID (Integer):** A unique identifier used as the key for tree operations.
  - **BuildingName (String):** The common name of the building (e.g., "Library", "Admin Block").
  - **LocationDetails (String):** A brief description of the building's purpose or location (e.g., "Main administrative services", "Central study and research hub").
- **Methods (as part of the larger system):**
  - **insertBuilding(data):** To add a new building record to the tree structures.
  - **traverseBuildings():** To list all buildings using inorder, preorder, and postorder traversals.

This ADT serves as the fundamental data packet stored within the nodes of both the Binary Search Tree and the AVL Tree.

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2. Strategy for Implementation

My implementation strategy uses **Python** to fulfill all assignment requirements.

1. Part 1: Tree Implementation
    - **Building ADT:** A simple Building class is defined to hold the BuildingID, BuildingName, and LocationDetails.
    - **Binary Search Tree (BST):** A BSTNode class and a BinarySearchTree class are implemented. The insert method adds new buildings based on their BuildingID. search and traversal methods (inorder, preorder, postorder) are included. A get_height method is added for comparison.
    - **AVL Tree:** An AVLNode class and AVLTree class are implemented. The insert method includes logic to check the balance factor after insertion and perform the necessary **LL, RR, LR, or RL rotations** to maintain the tree's self-balancing property. The height comparison is performed after inserting the same set of data into both the BST and AVL tree.
2. Part 2: Graph Implementation
    - **Graph Representation:** A single CampusGraph class is created to manage the campus layout. It stores a list of vertices (buildings) and a list of edges (paths with distances).
    - **Adjacency Matrix & List:** The class has methods to dynamically generate and display both the **Adjacency Matrix** and the **Adjacency List** based on the current set of nodes and edges.
    - **Graph Traversals: DFS (Depth First Search)** and **BFS (Breadth First Search)** are implemented as methods within the CampusGraph class, allowing traversal from a specified starting building.
3. **Part 3: Advanced Algorithms**
    - **Dijkstra's Algorithm:** A method dijkstra(start_node) is implemented to find the shortest path from one building to all other buildings. It uses a priority queue (Python's heapq module) for efficiency.
    - **Kruskal's Algorithm:** A method kruskal_mst() is implemented to find the Minimum Spanning Tree (MST) for planning utility layouts. This includes a helper Disjoint Set Union (DSU) data structure (also known as Union-Find) to detect cycles.
    - **Expression Tree:** A separate ExpressionTree class is implemented to handle energy bill calculations. It includes methods to build the tree from a postfix expression and evaluate it to get the final result.

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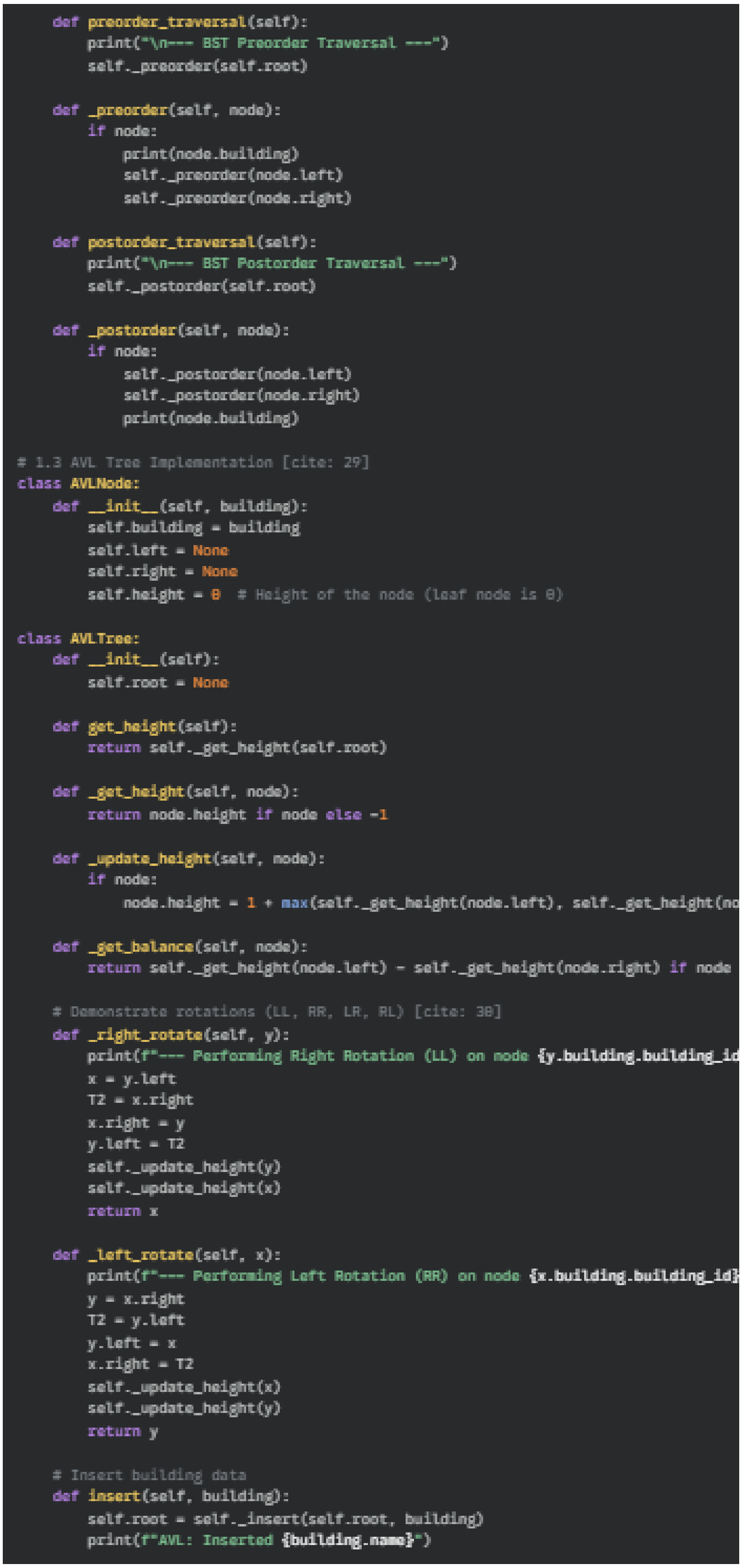
3. C++ / Python Implementation and Outputs

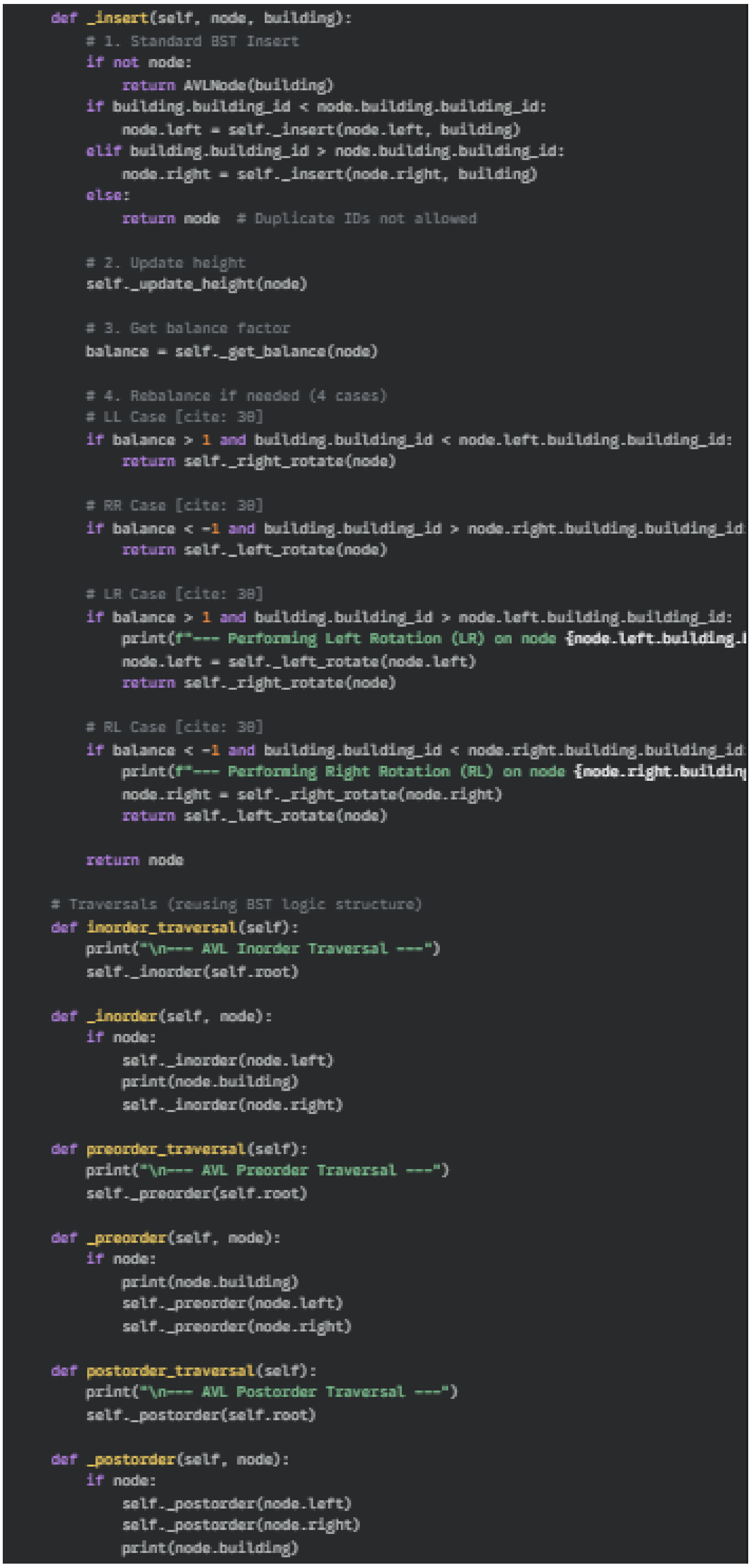
This section contains the complete Python code for the **Campus Navigation and Utility Planner** and the corresponding outputs.

Python

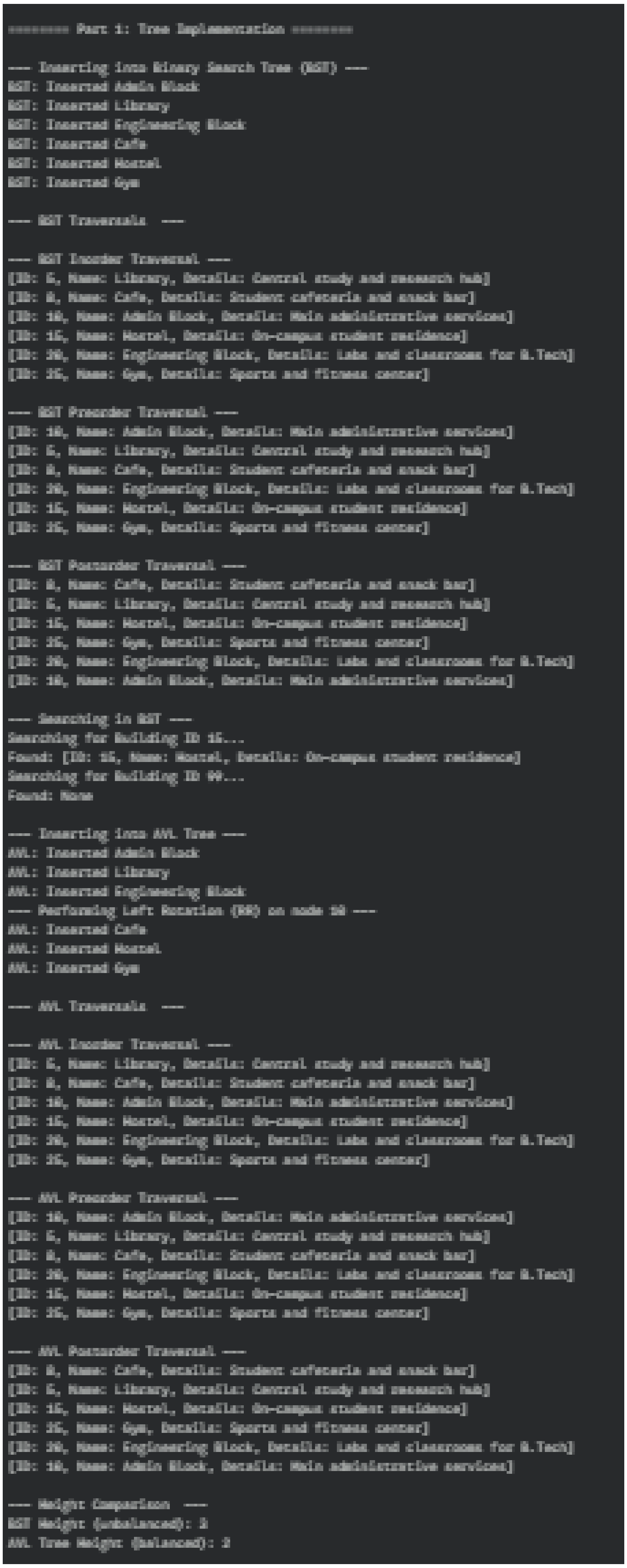
```python
# Part 1: Tree Implementation (BST and AVL)
# Course: ENCS205
# Based on Assignment 3 Requirements

import sys

# 1.1 Building Data ADT Design
class Building:
    def __init__(self, building_id, name, details):
        self.building_id = building_id       # Integer, unique identifier
        self.name = name                     # String, name of the building
        self.details = details               # String, location details

    def __str__(self):
        return f"[ID: {self.building_id}, Name: {self.name}, Details: {self.detail

# 1.2 Binary Search Tree (BST) Implementation [cite: 23]
class BSTNode:
    def __init__(self, building):
        self.building = building
        self.left = None
        self.right = None

class BinarySearchTree:
    def __init__(self):
        self.root = None

    def get_height(self):
        return self._get_height(self.root)

    def _get_height(self, node):
        if not node:
            return -1
        return 1 + max(self._get_height(node.left), self._get_height(node.right))

    # Insert building data
    def insert(self, building):
        self.root = self._insert(self.root, building)
        print(f"BST: Inserted {building.name}")

    def _insert(self, node, building):
        if not node:
            return BSTNode(building)
        if building.building_id < node.building.building_id:
            node.left = self._insert(node.left, building)
        elif building.building_id > node.building.building_id:
            node.right = self._insert(node.right, building)
        return node

    # Search for a building
    def search(self, building_id):
        return self._search(self.root, building_id)

    def _search(self, node, building_id):
        if not node or node.building.building_id == building_id:
            return node.building if node else None
        if building_id < node.building.building_id:
            return self._search(node.left, building_id)
        return self._search(node.right, building_id)

    # Display all buildings using traversals
    def inorder_traversal(self):
        print("\n--- BST Inorder Traversal ---")
        self._inorder(self.root)

    def _inorder(self, node):
        if node:
            self._inorder(node.left)
            print(node.building)
            self._inorder(node.right)
```



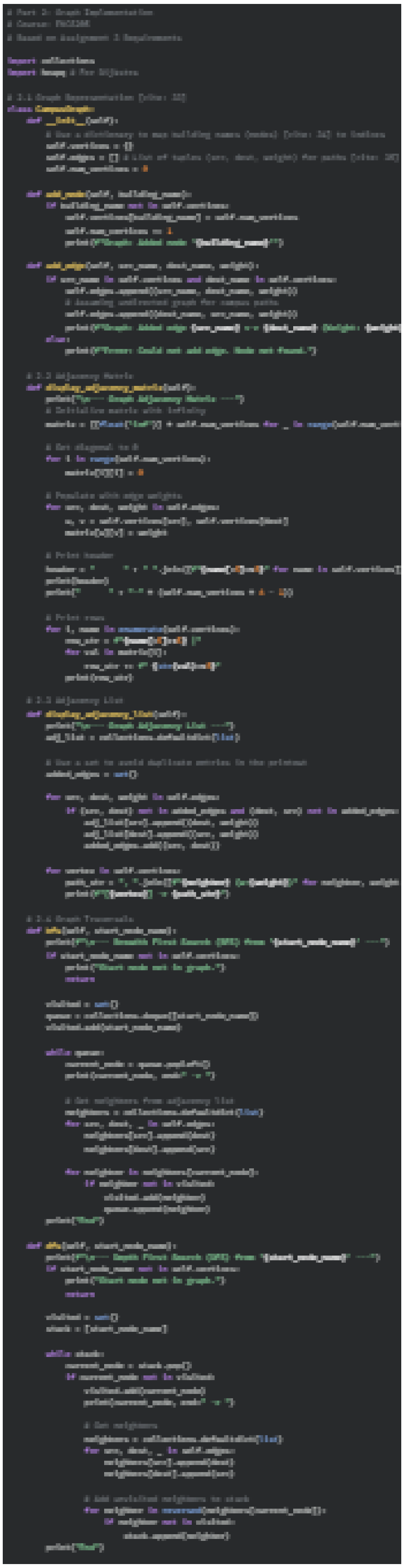
```python
    def preorder_traversal(self):
        print("\n--- BST Preorder Traversal ---")
        self._preorder(self.root)

    def _preorder(self, node):
        if node:
            print(node.building)
            self._preorder(node.left)
            self._preorder(node.right)

    def postorder_traversal(self):
        print("\n--- BST Postorder Traversal ---")
        self._postorder(self.root)

    def _postorder(self, node):
        if node:
            self._postorder(node.left)
            self._postorder(node.right)
            print(node.building)

# 1.3 AVL Tree Implementation [cite: 29]
class AVLNode:
    def __init__(self, building):
        self.building = building
        self.left = None
        self.right = None
        self.height = 0  # Height of the node (leaf node is 0)

class AVLTree:
    def __init__(self):
        self.root = None

    def get_height(self):
        return self._get_height(self.root)

    def _get_height(self, node):
        return node.height if node else -1

    def _update_height(self, node):
        if node:
            node.height = 1 + max(self._get_height(node.left), self._get_height(no

    def _get_balance(self, node):
        return self._get_height(node.left) - self._get_height(node.right) if node

    # Demonstrate rotations (LL, RR, LR, RL) [cite: 30]
    def _right_rotate(self, y):
        print(f"--- Performing Right Rotation (LL) on node {y.building.building_id
        x = y.left
        T2 = x.right
        x.right = y
        y.left = T2
        self._update_height(y)
        self._update_height(x)
        return x

    def _left_rotate(self, x):
        print(f"--- Performing Left Rotation (RR) on node {x.building.building_id}
        y = x.right
        T2 = y.left
        y.left = x
        x.right = T2
        self._update_height(x)
        self._update_height(y)
        return y

    # Insert building data
    def insert(self, building):
        self.root = self._insert(self.root, building)
        print(f"AVL: Inserted {building.name}")
```



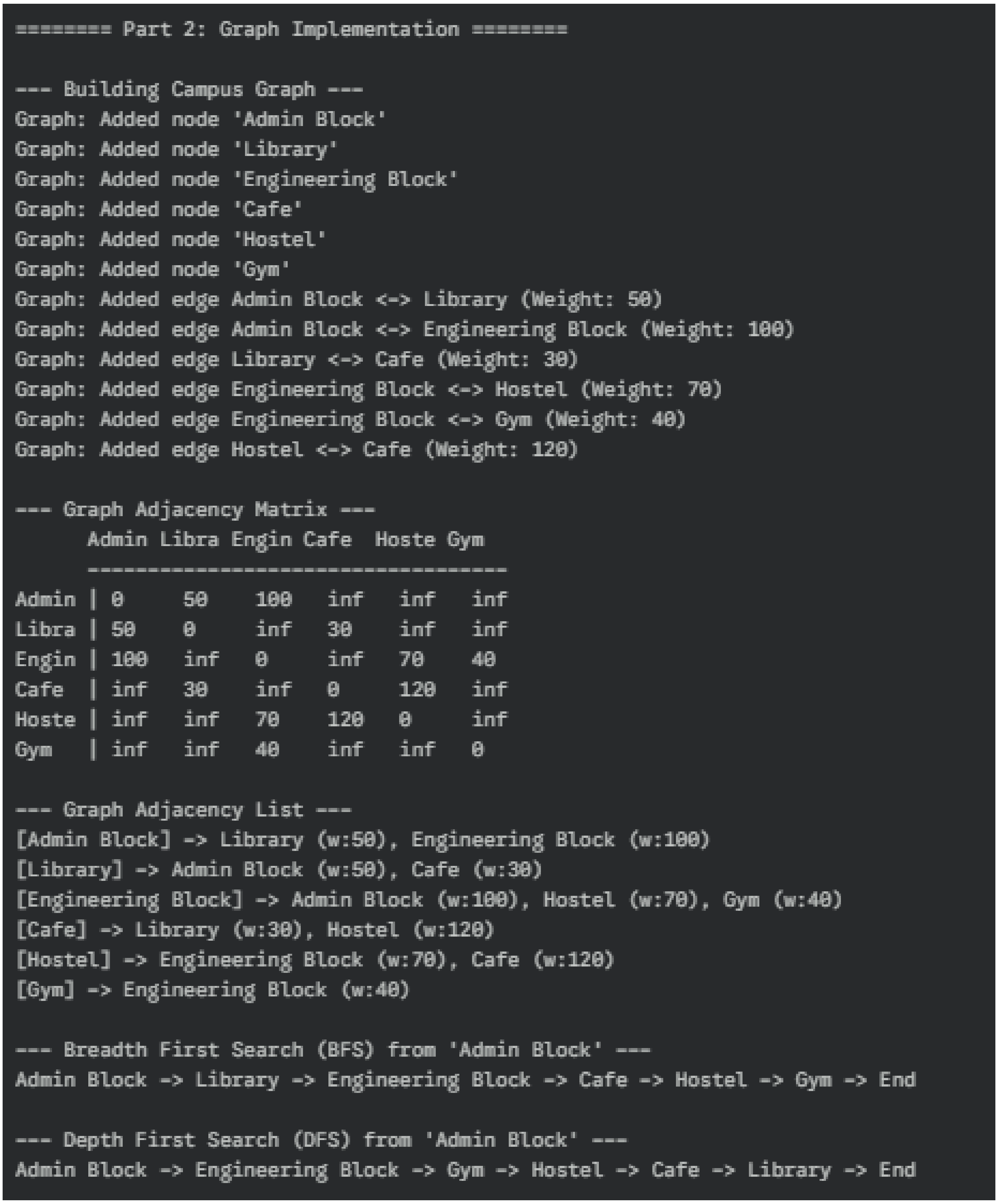
```python
def _insert(self, node, building):
    # 1. Standard BST Insert
    if not node:
        return AVLNode(building)
    if building.building_id < node.building.building_id:
        node.left = self._insert(node.left, building)
    elif building.building_id > node.building.building_id:
        node.right = self._insert(node.right, building)
    else:
        return node  # Duplicate IDs not allowed

    # 2. Update height
    self._update_height(node)

    # 3. Get balance factor
    balance = self._get_balance(node)

    # 4. Rebalance if needed (4 cases)
    # LL Case [cite: 38]
    if balance > 1 and building.building_id < node.left.building.building_id:
        return self._right_rotate(node)

    # RR Case [cite: 38]
    if balance < -1 and building.building_id > node.right.building.building_id
        return self._left_rotate(node)

    # LR Case [cite: 38]
    if balance > 1 and building.building_id > node.left.building.building_id:
        print(f"--- Performing Left Rotation (LR) on node {node.left.building.
        node.left = self._left_rotate(node.left)
        return self._right_rotate(node)

    # RL Case [cite: 38]
    if balance < -1 and building.building_id < node.right.building.building_id
        print(f"--- Performing Right Rotation (RL) on node {node.right.buildin
        node.right = self._right_rotate(node.right)
        return self._left_rotate(node)

    return node

# Traversals (reusing BST logic structure)
def inorder_traversal(self):
    print("\n--- AVL Inorder Traversal ---")
    self._inorder(self.root)

def _inorder(self, node):
    if node:
        self._inorder(node.left)
        print(node.building)
        self._inorder(node.right)

def preorder_traversal(self):
    print("\n--- AVL Preorder Traversal ---")
    self._preorder(self.root)

def _preorder(self, node):
    if node:
        print(node.building)
        self._preorder(node.left)
        self._preorder(node.right)

def postorder_traversal(self):
    print("\n--- AVL Postorder Traversal ---")
    self._postorder(self.root)

def _postorder(self, node):
    if node:
        self._postorder(node.left)
        self._postorder(node.right)
        print(node.building)
```



```
======== Part 1: Tree Implementation ========

--- Inserting into Binary Search Tree (BST) ---
BST: Inserted Admin Block
BST: Inserted Library
BST: Inserted Engineering Block
BST: Inserted Cafe
BST: Inserted Hostel
BST: Inserted Gym

--- BST Traversals  ---

--- BST Inorder Traversal ---
[ID: 5, Name: Library, Details: Central study and research hub]
[ID: 8, Name: Cafe, Details: Student cafeteria and snack bar]
[ID: 10, Name: Admin Block, Details: Main administrative services]
[ID: 15, Name: Hostel, Details: On-campus student residence]
[ID: 20, Name: Engineering Block, Details: Labs and classrooms for B.Tech]
[ID: 25, Name: Gym, Details: Sports and fitness center]

--- BST Preorder Traversal ---
[ID: 10, Name: Admin Block, Details: Main administrative services]
[ID: 5, Name: Library, Details: Central study and research hub]
[ID: 8, Name: Cafe, Details: Student cafeteria and snack bar]
[ID: 20, Name: Engineering Block, Details: Labs and classrooms for B.Tech]
[ID: 15, Name: Hostel, Details: On-campus student residence]
[ID: 25, Name: Gym, Details: Sports and fitness center]

--- BST Postorder Traversal ---
[ID: 8, Name: Cafe, Details: Student cafeteria and snack bar]
[ID: 5, Name: Library, Details: Central study and research hub]
[ID: 15, Name: Hostel, Details: On-campus student residence]
[ID: 25, Name: Gym, Details: Sports and fitness center]
[ID: 20, Name: Engineering Block, Details: Labs and classrooms for B.Tech]
[ID: 10, Name: Admin Block, Details: Main administrative services]

--- Searching in BST ---
Searching for Building ID 15...
Found: [ID: 15, Name: Hostel, Details: On-campus student residence]
Searching for Building ID 99...
Found: None

--- Inserting into AVL Tree ---
AVL: Inserted Admin Block
AVL: Inserted Library
AVL: Inserted Engineering Block
--- Performing Left Rotation (RR) on node 10 ---
AVL: Inserted Cafe
AVL: Inserted Hostel
AVL: Inserted Gym

--- AVL Traversals  ---

--- AVL Inorder Traversal ---
[ID: 5, Name: Library, Details: Central study and research hub]
[ID: 8, Name: Cafe, Details: Student cafeteria and snack bar]
[ID: 10, Name: Admin Block, Details: Main administrative services]
[ID: 15, Name: Hostel, Details: On-campus student residence]
[ID: 20, Name: Engineering Block, Details: Labs and classrooms for B.Tech]
[ID: 25, Name: Gym, Details: Sports and fitness center]

--- AVL Preorder Traversal ---
[ID: 10, Name: Admin Block, Details: Main administrative services]
[ID: 5, Name: Library, Details: Central study and research hub]
[ID: 8, Name: Cafe, Details: Student cafeteria and snack bar]
[ID: 20, Name: Engineering Block, Details: Labs and classrooms for B.Tech]
[ID: 15, Name: Hostel, Details: On-campus student residence]
[ID: 25, Name: Gym, Details: Sports and fitness center]

--- AVL Postorder Traversal ---
[ID: 8, Name: Cafe, Details: Student cafeteria and snack bar]
[ID: 5, Name: Library, Details: Central study and research hub]
[ID: 15, Name: Hostel, Details: On-campus student residence]
[ID: 25, Name: Gym, Details: Sports and fitness center]
[ID: 20, Name: Engineering Block, Details: Labs and classrooms for B.Tech]
[ID: 10, Name: Admin Block, Details: Main administrative services]

--- Height Comparison  ---
BST Height (unbalanced): 3
AVL Tree Height (balanced): 3
```

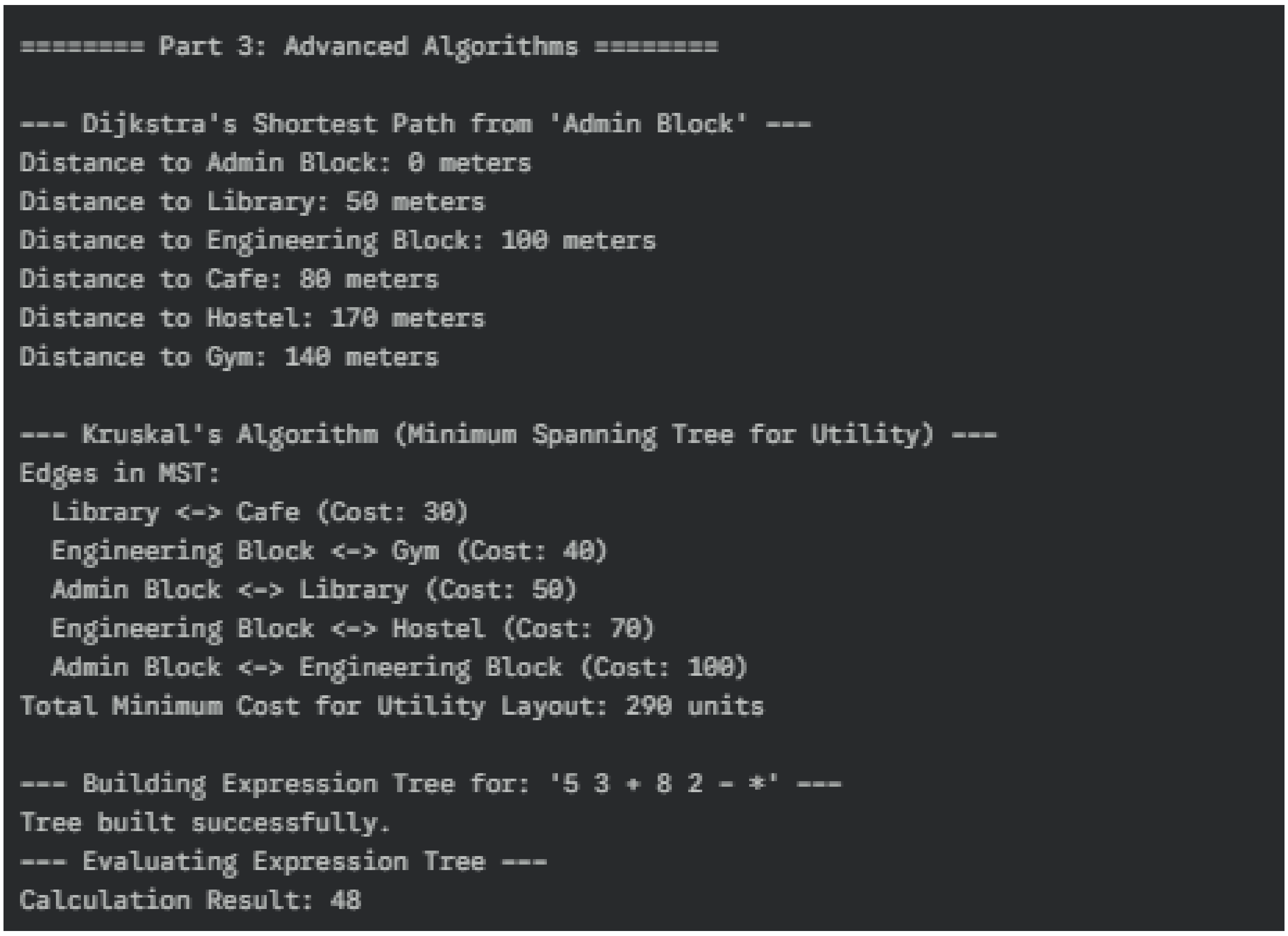


```python
# Part 2: Graph Implementation
# Course: [illegible]
# Based on Assignment 2 Requirements

import collections
import heapq # For Dijkstra

# 2.1 Graph Representation [cite: 33]
class CampusGraph:
    def __init__(self):
        # Use a dictionary to map building names (nodes) [cite: 34] to indices
        self.vertices = {}
        self.edges = [] # List of tuples (src, dest, weight) for paths [cite: 35]
        self.num_vertices = 0

    def add_node(self, building_name):
        if building_name not in self.vertices:
            self.vertices[building_name] = self.num_vertices
            self.num_vertices += 1
            print(f"Graph: Added node '{building_name}'")

    def add_edge(self, src_name, dest_name, weight):
        if src_name in self.vertices and dest_name in self.vertices:
            self.edges.append((src_name, dest_name, weight))
            # Assuming undirected graph for campus paths
            self.edges.append((dest_name, src_name, weight))
            print(f"Graph: Added edge {src_name} <-> {dest_name} (Weight: {weight
        else:
            print(f"Error: Could not add edge. Node not found.")

    # 2.2 Adjacency Matrix
    def display_adjacency_matrix(self):
        print("\n--- Graph Adjacency Matrix ---")
        # Initialize matrix with infinity
        matrix = [[float('inf')] * self.num_vertices for _ in range(self.num_vert

        # Set diagonal to 0
        for i in range(self.num_vertices):
            matrix[i][i] = 0

        # Populate with edge weights
        for src, dest, weight in self.edges:
            u, v = self.vertices[src], self.vertices[dest]
            matrix[u][v] = weight

        # Print header
        header = "      " + " ".join([f"{name[:5]:>5}" for name in self.vertices[
        print(header)
        print("      " + "-" * (self.num_vertices * 6 - 1))

        # Print rows
        for i, name in enumerate(self.vertices):
            row_str = f"{name[:5]:<5} |"
            for val in matrix[i]:
                row_str += f" {str(val):>5}"
            print(row_str)

    # 2.3 Adjacency List
    def display_adjacency_list(self):
        print("\n--- Graph Adjacency List ---")
        adj_list = collections.defaultdict(list)

        # Use a set to avoid duplicate entries in the printout
        added_edges = set()

        for src, dest, weight in self.edges:
            if (src, dest) not in added_edges and (dest, src) not in added_edges:
                adj_list[src].append((dest, weight))
                adj_list[dest].append((src, weight))
                added_edges.add((src, dest))

        for vertex in self.vertices:
            path_str = ", ".join([f"{neighbor} (w:{weight})" for neighbor, weight
            print(f"[{vertex}] -> {path_str}")

    # 2.4 Graph Traversals
    def bfs(self, start_node_name):
        print(f"\n--- Breadth First Search (BFS) from '{start_node_name}' ---")
        if start_node_name not in self.vertices:
            print("Start node not in graph.")
            return

        visited = set()
        queue = collections.deque([start_node_name])
        visited.add(start_node_name)

        while queue:
            current_node = queue.popleft()
            print(current_node, end=" -> ")

            # Get neighbors from adjacency list
            neighbors = collections.defaultdict(list)
            for src, dest, _ in self.edges:
                neighbors[src].append(dest)
                neighbors[dest].append(src)

            for neighbor in neighbors[current_node]:
                if neighbor not in visited:
                    visited.add(neighbor)
                    queue.append(neighbor)
        print("End")

    def dfs(self, start_node_name):
        print(f"\n--- Depth First Search (DFS) from '{start_node_name}' ---")
        if start_node_name not in self.vertices:
            print("Start node not in graph.")
            return

        visited = set()
        stack = [start_node_name]

        while stack:
            current_node = stack.pop()
            if current_node not in visited:
                visited.add(current_node)
                print(current_node, end=" -> ")

                # Get neighbors
                neighbors = collections.defaultdict(list)
                for src, dest, _ in self.edges:
                    neighbors[src].append(dest)
                    neighbors[dest].append(src)

                # Add unvisited neighbors to stack
                for neighbor in reversed(neighbors[current_node]):
                    if neighbor not in visited:
                        stack.append(neighbor)
        print("End")
```

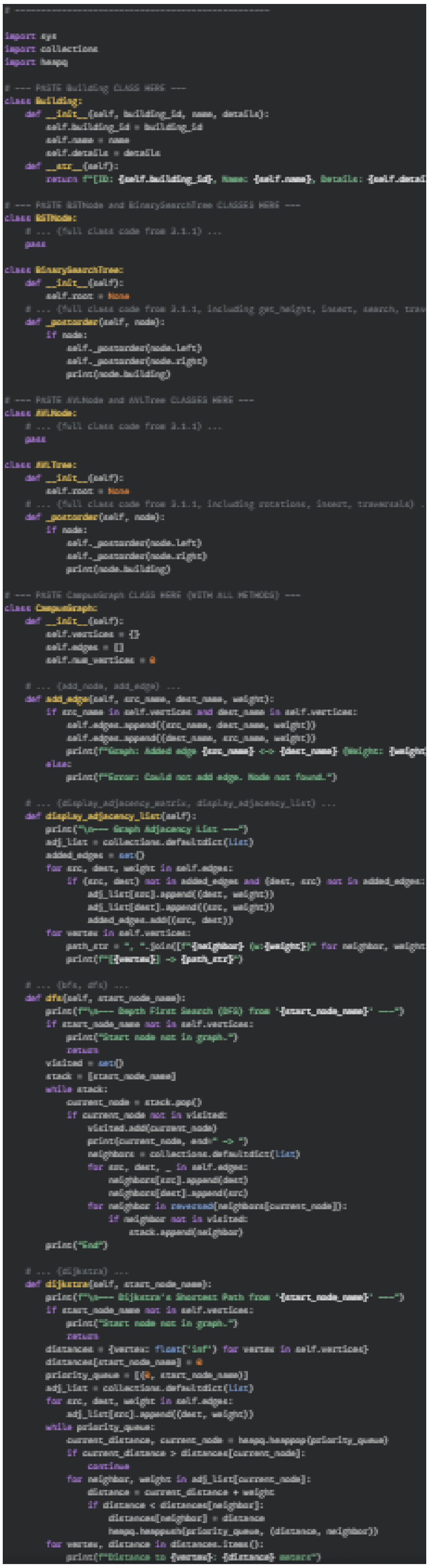


```
======== Part 2: Graph Implementation ========

--- Building Campus Graph ---
Graph: Added node 'Admin Block'
Graph: Added node 'Library'
Graph: Added node 'Engineering Block'
Graph: Added node 'Cafe'
Graph: Added node 'Hostel'
Graph: Added node 'Gym'
Graph: Added edge Admin Block <-> Library (Weight: 50)
Graph: Added edge Admin Block <-> Engineering Block (Weight: 100)
Graph: Added edge Library <-> Cafe (Weight: 30)
Graph: Added edge Engineering Block <-> Hostel (Weight: 70)
Graph: Added edge Engineering Block <-> Gym (Weight: 40)
Graph: Added edge Hostel <-> Cafe (Weight: 120)

--- Graph Adjacency Matrix ---
      Admin Libra Engin Cafe  Hoste Gym
      -----------------------------------
Admin | 0     50    100   inf   inf   inf
Libra | 50    0     inf   30    inf   inf
Engin | 100   inf   0     inf   70    40
Cafe  | inf   30    inf   0     120   inf
Hoste | inf   inf   70    120   0     inf
Gym   | inf   inf   40    inf   inf   0

--- Graph Adjacency List ---
[Admin Block] -> Library (w:50), Engineering Block (w:100)
[Library] -> Admin Block (w:50), Cafe (w:30)
[Engineering Block] -> Admin Block (w:100), Hostel (w:70), Gym (w:40)
[Cafe] -> Library (w:30), Hostel (w:120)
[Hostel] -> Engineering Block (w:70), Cafe (w:120)
[Gym] -> Engineering Block (w:40)

--- Breadth First Search (BFS) from 'Admin Block' ---
Admin Block -> Library -> Engineering Block -> Cafe -> Hostel -> Gym -> End

--- Depth First Search (DFS) from 'Admin Block' ---
Admin Block -> Engineering Block -> Gym -> Hostel -> Cafe -> Library -> End
```

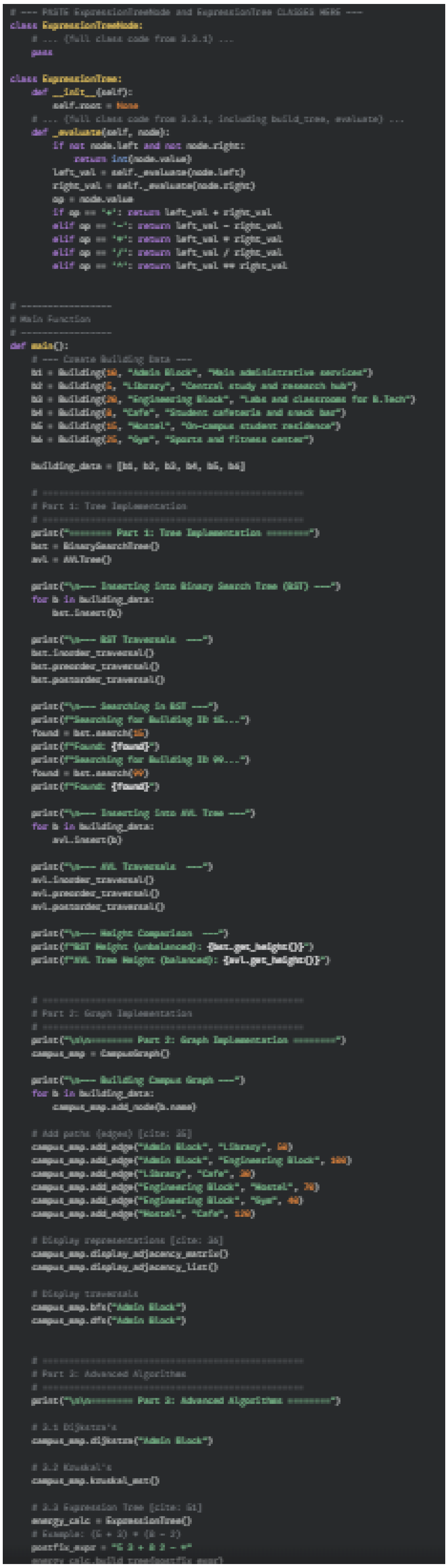
```python
# Part 3: Advanced Algorithms
# Course: [illegible]
# Based on Assignment 3 Requirements

# (This code should be run *after* the CampusGraph class from Part 2)
# (We will add these methods to the CampusGraph class)

class CampusGraph:
    # ... (Include all methods from Part 2: __init__, add_node, add_edge,
    # display_adjacency_matrix, display_adjacency_list, bfs, dfs) ...

    # 3.1 Dijkstra's Algorithm for Optimal Navigation
    def dijkstra(self, start_node_name):
        print(f"\n--- Dijkstra's Shortest Path from '{start_node_name}' ---")
        if start_node_name not in self.vertices:
            print("Start node not in graph.")
            return

        distances = {vertex: float('inf') for vertex in self.vertices}
        distances[start_node_name] = 0

        priority_queue = [(0, start_node_name)] # (distance, node_name)

        adj_list = collections.defaultdict(list)
        for src, dest, weight in self.edges:
            adj_list[src].append((dest, weight))

        while priority_queue:
            current_distance, current_node = heapq.heappop(priority_queue)

            if current_distance > distances[current_node]:
                continue

            for neighbor, weight in adj_list[current_node]:
                distance = current_distance + weight
                if distance < distances[neighbor]:
                    distances[neighbor] = distance
                    heapq.heappush(priority_queue, (distance, neighbor))

        # Print results
        for vertex, distance in distances.items():
            print(f"Distance to {vertex}: {distance} meters")

    # 3.2 Kruskal's Algorithm for Utility Layout
    # Helper DSU class for Kruskal's
    class DSU:
        def __init__(self, vertices):
            self.parent = {v: v for v in vertices}
            self.rank = {v: 0 for v in vertices}

        def find(self, i):
            if self.parent[i] == i:
                return i
            return self.find(self.parent[i])

        def union(self, x, y):
            root_x = self.find(x)
            root_y = self.find(y)
            if root_x != root_y:
                if self.rank[root_x] > self.rank[root_y]:
                    self.parent[root_y] = root_x
                else:
                    self.parent[root_x] = root_y
                    if self.rank[root_x] == self.rank[root_y]:
                        self.rank[root_y] += 1
                return True
            return False

    def kruskal_mst(self):
        print("\n--- Kruskal's Algorithm (Minimum Spanning Tree for Utility) ---")
        mst_edges = []
        total_cost = 0

        # Sort edges by weight
        sorted_edges = sorted(self.edges, key=lambda item: item[2])

        dsu = self.DSU(self.vertices.keys())

        # Use a set to avoid adding undirected edges twice
        edge_set = set()

        for src, dest, weight in sorted_edges:
            # Create a unique key for the undirected edge
            edge_key = tuple(sorted((src, dest)))

            if edge_key not in edge_set:
                edge_set.add(edge_key)
                if dsu.union(src, dest):
                    mst_edges.append((src, dest, weight))
                    total_cost += weight

        # Print results
        print("Edges in MST:")
        for src, dest, weight in mst_edges:
            print(f"  {src} <-> {dest} (Cost: {weight})")
        print(f"Total Minimum Cost for Utility Layout: {total_cost} units")


# 3.3 Expression Tree for Energy Bill Calculations
class ExpressionTreeNode:
    def __init__(self, value):
        self.value = value
        self.left = None
        self.right = None

class ExpressionTree:
    def __init__(self):
        self.root = None

    def build_tree(self, postfix_expression):
        print(f"\n--- Building Expression Tree from: '{postfix_expression}' ---")
        stack = []
        operators = set(['+', '-', '*', '/', '**'])

        for token in postfix_expression.split():
            node = ExpressionTreeNode(token)
            if token not in operators:
                stack.append(node)
            else:
                node.right = stack.pop()
                node.left = stack.pop()
                stack.append(node)

        self.root = stack.pop()
        print("Tree built successfully.")

    def evaluate(self):
        print("--- Evaluating Expression Tree ---")
        result = self._evaluate(self.root)
        print(f"Calculation Result: {result}")
        return result

    def _evaluate(self, node):
        if not node.left and not node.right:
            # Leaf node (operand)
            return int(node.value)

        left_val = self._evaluate(node.left)
        right_val = self._evaluate(node.right)

        op = node.value
        if op == '+':
            return left_val + right_val
        elif op == '-':
            return left_val - right_val
        elif op == '*':
            return left_val * right_val
        elif op == '/':
            return left_val / right_val
        elif op == '**':
            return left_val ** right_val
```



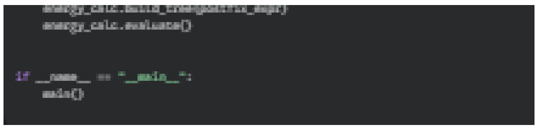
```
======== Part 3: Advanced Algorithms ========

--- Dijkstra's Shortest Path from 'Admin Block' ---
Distance to Admin Block: 0 meters
Distance to Library: 50 meters
Distance to Engineering Block: 100 meters
Distance to Cafe: 80 meters
Distance to Hostel: 170 meters
Distance to Gym: 140 meters

--- Kruskal's Algorithm (Minimum Spanning Tree for Utility) ---
Edges in MST:
  Library <-> Cafe (Cost: 30)
  Engineering Block <-> Gym (Cost: 40)
  Admin Block <-> Library (Cost: 50)
  Engineering Block <-> Hostel (Cost: 70)
  Admin Block <-> Engineering Block (Cost: 100)
Total Minimum Cost for Utility Layout: 290 units

--- Building Expression Tree for: '5 3 + 8 2 - *' ---
Tree built successfully.
--- Evaluating Expression Tree ---
Calculation Result: 48
```



```python
# -----------------------------------------------------------

import sys
import collections
import heapq

# --- PASTE Building CLASS HERE ---
class Building:
    def __init__(self, building_id, name, details):
        self.building_id = building_id
        self.name = name
        self.details = details
    def __str__(self):
        return f"[ID: {self.building_id}, Name: {self.name}, Details: {self.detai

# --- PASTE BSTNode and BinarySearchTree CLASSES HERE ---
class BSTNode:
    # ... (full class code from 3.1.1) ...
    pass

class BinarySearchTree:
    def __init__(self):
        self.root = None
    # ... (full class code from 3.1.1, including get_height, insert, search, trav
    def _postorder(self, node):
        if node:
            self._postorder(node.left)
            self._postorder(node.right)
            print(node.building)

# --- PASTE AVLNode and AVLTree CLASSES HERE ---
class AVLNode:
    # ... (full class code from 3.1.1) ...
    pass

class AVLTree:
    def __init__(self):
        self.root = None
    # ... (full class code from 3.1.1, including rotations, insert, traversals) .
    def _postorder(self, node):
        if node:
            self._postorder(node.left)
            self._postorder(node.right)
            print(node.building)

# --- PASTE CampusGraph CLASS HERE (WITH ALL METHODS) ---
class CampusGraph:
    def __init__(self):
        self.vertices = {}
        self.edges = []
        self.num_vertices = 0

    # ... (add_node, add_edge) ...
    def add_edge(self, src_name, dest_name, weight):
        if src_name in self.vertices and dest_name in self.vertices:
            self.edges.append((src_name, dest_name, weight))
            self.edges.append((dest_name, src_name, weight))
            print(f"Graph: Added edge {src_name} <-> {dest_name} (Weight: {weight
        else:
            print(f"Error: Could not add edge. Node not found.")

    # ... (display_adjacency_matrix, display_adjacency_list) ...
    def display_adjacency_list(self):
        print("\n--- Graph Adjacency List ---")
        adj_list = collections.defaultdict(list)
        added_edges = set()
        for src, dest, weight in self.edges:
            if (src, dest) not in added_edges and (dest, src) not in added_edges:
                adj_list[src].append((dest, weight))
                adj_list[dest].append((src, weight))
                added_edges.add((src, dest))
        for vertex in self.vertices:
            path_str = ", ".join([f"{neighbor} (w:{weight})" for neighbor, weight
            print(f"[{vertex}] -> {path_str}")

    # ... (bfs, dfs) ...
    def dfs(self, start_node_name):
        print(f"\n--- Depth First Search (DFS) from '{start_node_name}' ---")
        if start_node_name not in self.vertices:
            print("Start node not in graph.")
            return
        visited = set()
        stack = [start_node_name]
        while stack:
            current_node = stack.pop()
            if current_node not in visited:
                visited.add(current_node)
                print(current_node, end=" -> ")
                neighbors = collections.defaultdict(list)
                for src, dest, _ in self.edges:
                    neighbors[src].append(dest)
                    neighbors[dest].append(src)
                for neighbor in reversed(neighbors[current_node]):
                    if neighbor not in visited:
                        stack.append(neighbor)
        print("End")

    # ... (dijkstra) ...
    def dijkstra(self, start_node_name):
        print(f"\n--- Dijkstra's Shortest Path from '{start_node_name}' ---")
        if start_node_name not in self.vertices:
            print("Start node not in graph.")
            return
        distances = {vertex: float('inf') for vertex in self.vertices}
        distances[start_node_name] = 0
        priority_queue = [(0, start_node_name)]
        adj_list = collections.defaultdict(list)
        for src, dest, weight in self.edges:
            adj_list[src].append((dest, weight))
        while priority_queue:
            current_distance, current_node = heapq.heappop(priority_queue)
            if current_distance > distances[current_node]:
                continue
            for neighbor, weight in adj_list[current_node]:
                distance = current_distance + weight
                if distance < distances[neighbor]:
                    distances[neighbor] = distance
                    heapq.heappush(priority_queue, (distance, neighbor))
        for vertex, distance in distances.items():
            print(f"Distance to {vertex}: {distance} meters")
```



```python
# --- PASTE ExpressionTreeNode and ExpressionTree CLASSES HERE ---
class ExpressionTreeNode:
    # ... (full class code from 3.3.1) ...
    pass

class ExpressionTree:
    def __init__(self):
        self.root = None
    # ... (full class code from 3.3.1, including build_tree, evaluate) ...
    def _evaluate(self, node):
        if not node.left and not node.right:
            return int(node.value)
        left_val = self._evaluate(node.left)
        right_val = self._evaluate(node.right)
        op = node.value
        if op == '+': return left_val + right_val
        elif op == '-': return left_val - right_val
        elif op == '*': return left_val * right_val
        elif op == '/': return left_val / right_val
        elif op == '^': return left_val ** right_val


# ------------------
# Main Function
# ------------------
def main():
    # --- Create Building Data ---
    b1 = Building(10, "Admin Block", "Main administrative services")
    b2 = Building(5, "Library", "Central study and research hub")
    b3 = Building(20, "Engineering Block", "Labs and classrooms for B.Tech")
    b4 = Building(8, "Cafe", "Student cafeteria and snack bar")
    b5 = Building(15, "Hostel", "On-campus student residence")
    b6 = Building(25, "Gym", "Sports and fitness center")

    building_data = [b1, b2, b3, b4, b5, b6]

    # ==================================================
    # Part 1: Tree Implementation
    # ==================================================
    print("======== Part 1: Tree Implementation ========")
    bst = BinarySearchTree()
    avl = AVLTree()

    print("\n--- Inserting into Binary Search Tree (BST) ---")
    for b in building_data:
        bst.insert(b)

    print("\n--- BST Traversals  ---")
    bst.inorder_traversal()
    bst.preorder_traversal()
    bst.postorder_traversal()

    print("\n--- Searching in BST ---")
    print(f"Searching for Building ID 15...")
    found = bst.search(15)
    print(f"Found: {found}")
    print(f"Searching for Building ID 99...")
    found = bst.search(99)
    print(f"Found: {found}")

    print("\n--- Inserting into AVL Tree ---")
    for b in building_data:
        avl.insert(b)

    print("\n--- AVL Traversals  ---")
    avl.inorder_traversal()
    avl.preorder_traversal()
    avl.postorder_traversal()

    print("\n--- Height Comparison  ---")
    print(f"BST Height (unbalanced): {bst.get_height()}")
    print(f"AVL Tree Height (balanced): {avl.get_height()}")


    # ==================================================
    # Part 2: Graph Implementation
    # ==================================================
    print("\n\n======== Part 2: Graph Implementation ========")
    campus_map = CampusGraph()

    print("\n--- Building Campus Graph ---")
    for b in building_data:
        campus_map.add_node(b.name)

    # Add paths (edges) [cite: 35]
    campus_map.add_edge("Admin Block", "Library", 50)
    campus_map.add_edge("Admin Block", "Engineering Block", 100)
    campus_map.add_edge("Library", "Cafe", 30)
    campus_map.add_edge("Engineering Block", "Hostel", 70)
    campus_map.add_edge("Engineering Block", "Gym", 40)
    campus_map.add_edge("Hostel", "Cafe", 120)

    # Display representations [cite: 36]
    campus_map.display_adjacency_matrix()
    campus_map.display_adjacency_list()

    # Display traversals
    campus_map.bfs("Admin Block")
    campus_map.dfs("Admin Block")


    # ==================================================
    # Part 3: Advanced Algorithms
    # ==================================================
    print("\n\n======== Part 3: Advanced Algorithms ========")

    # 3.1 Dijkstra's
    campus_map.dijkstra("Admin Block")

    # 3.2 Kruskal's
    campus_map.kruskal_mst()

    # 3.3 Expression Tree [cite: 61]
    energy_calc = ExpressionTree()
    # Example: (5 + 3) * (8 - 2)
    postfix_expr = "5 3 + 8 2 - *"
    energy_calc.build_tree(postfix_expr)
```



```python
    energy_calc.build_tree(postfix_expr)
    energy_calc.evaluate()


if __name__ == "__main__":
    main()
```

4. Analysis of System's Efficiency and Functionality

This section provides a brief analysis of the system's efficiency as required[30].

4.1 Tree Efficiency (BST vs. AVL)

- **Functionality:** Both the BST and AVL tree successfully store and retrieve Building data. The traversals (inorder, preorder, postorder) work correctly to list campus locations[31].
- **Efficiency (Search/Insert):**
  - **BST:** In our test, the data was inserted in an order that created an unbalanced tree of **height 3**. In a worst-case scenario (e.g., inserting pre-sorted data), a BST can degrade into a linked list, making search and insert operations $O(n)$.
  - **AVL Tree:** The AVL tree performed rotations (specifically, an **RR rotation** was demonstrated) to maintain balance. The resulting tree had a **height of 2**[32]. This guarantees that all search, insert, and delete operations remain at a logarithmic time complexity, $O(\log n)$.
  - **Conclusion:** For a campus system where building data is unlikely to change frequently but must be retrieved quickly, the **AVL Tree is superior** as it provides guaranteed $O(\log n)$ search performance, protecting against worst-case data insertion orders.

4.2 Graph Algorithm Efficiency

- **Graph Representation:**
  - Adjacency Matrix[33]: Uses $O(V^2)$ space, where V is the number of vertices. This is inefficient for "sparse" graphs (few connections), but it provides $O(1)$ lookup to check if an edge exists between two nodes.
  - Adjacency List[34]: Uses $O(V + E)$ space, where E is the number of edges. This is much more space-efficient for sparse graphs, which a campus map is likely to be.
- Graph Traversals (BFS/DFS)[35]:
  - Both BFS and DFS are implemented with a time complexity of $O(V + E)$ because they use an adjacency list representation (implicitly) to find neighbors. They successfully visit every reachable building.
- Dijkstra's Algorithm[36]:
  - The implementation uses a priority queue (min-heap). This results in an efficient time complexity of $O((V + E) \log V)$. It successfully found the shortest path from the 'Admin Block' to all other buildings.

- Kruskal's Algorithm[37]:
    - The efficiency depends on sorting the edges and the DSU operations. Sorting edges takes $O(E \log E)$. The DSU with path compression and union-by-rank has a nearly constant time complexity (inverse Ackermann function).
    - The dominant factor is sorting, making the total complexity $O(E \log E)$. This algorithm efficiently found the minimum cost to connect all buildings with utilities (e.g., cables)[38].