**CONCORDIA UNIVERSITY**

**DEPARTMENT OF COMPUTER SCIENCE AND SOFTWARE ENGINEERING**

# COMP 6651 NN: Algorithm Design Techniques

**Winter 2022**

Project due dates:
Part I - **February 18, 2022 before noon**
Part II - **April 1, 2022 before noon**
(electronic submission only)

**Term Project**

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## WARNINGS

- Parts I and II of the project are to be done with the same team, with no more than 5 students
- All data and parameters have to be read from an (or several) input file(s), so that it is easy to change them. No hard coding is allowed for any of the input parameters.
- Notations should be kept similar to the ones used in the description of the project.
- Submission should be made with **single .zip file**
- Each project submission must be submitted with the signed originality form
- Possible choices for the programming language: Java, C++ or Python
- Programs need to be well written and structured, for instance, no program made of a single function. You need to write programs with good programming practice rules.

# 1 Background of the project

In accordance with the public health institute's social distancing rules, some health centers, including hospitals, have decided to orient and label (color) their hallways/corridors as one-way or two-way hallways/corridors for COVID or non-COVID patients, so that COVID patients move along red paths, in hallway/corridors lanes labeled red, and non-COVID patients would move along green lanes, consisting of green labeled hallway/corridors lanes. It is assumed that lanes are wider enough in order to satisfy the social distancing rules. In addition, patients must be spaced far enough apart to again satisfy these last rules..

The project is then about how to define the directions and the color labels of the corridor lanes, in order to make sure that for any two locations, there is a green path and a red path going from one direction to the next.

# 2 Part I: Identify feasible orientation of the corridors

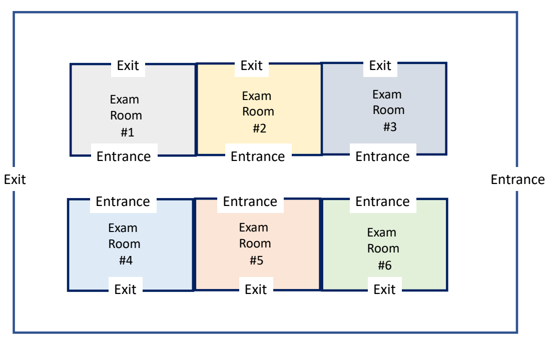
## 2.1 Case 1: A first simplified case

We assume that COVID patients are not allowed in, and therefore you are asked to identify paths in the context where each corridor corresponds to a one-way corridor. How to choose the direction of the corridors so that, for any pair of entrance and exit, you can find a path from main entrance to room entrance, and from room exit to main exit? See Figure 1.

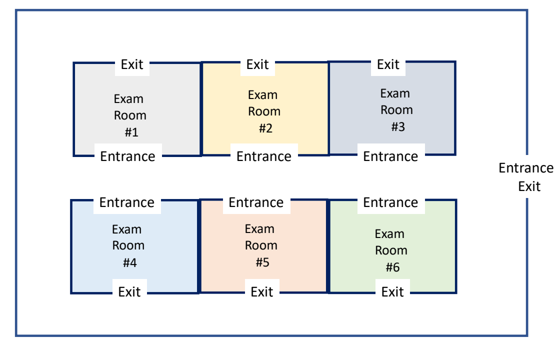
Show that this problem is equivalent to the one way street problem under the assumption that the floor map of the health center can be viewed as a set of rooms, some adjacent, some not, with each room having a door on a corridor, see Figure 1 for different examples. The floor plan of the health center is assumed to have either a single entrance and exit, or a combined entrance and exit, see Figure 1 for an illustration. You want to be able to:

- Go from the main hospital entrance to any room entrance
- Go from any room exit to the main exit of the hospital
- Go from the exit of any room to the entrance of any room without going outside

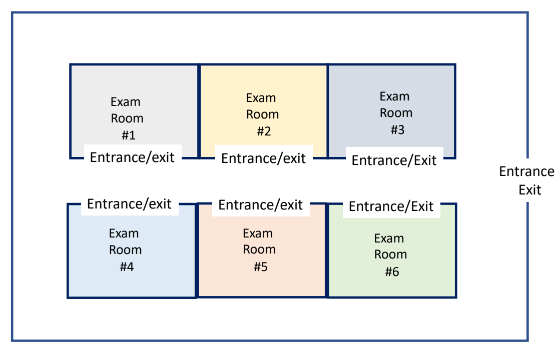
Definition of the one-way street problem
Streets and intersections in a town form a graph. Think of intersections as vertices




(a) Example 1: Entrance and exit are distinct




(b) Example 2: Entrance and exit are combined




(c) Example 3: Entrance and exit are combined for the floor map and the rooms

Figure 1: Three floor map examples

and streets as edges. Is it possible that all streets can be made one-way so that you can drive from every intersection to every other intersection without violating traffic regulations?

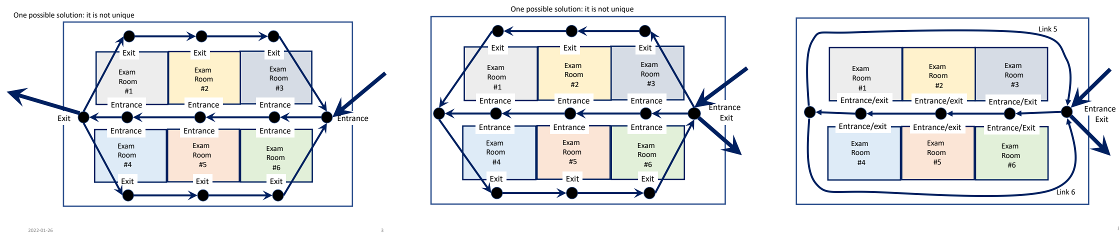
**Question 1.**

- Identify the conditions under which the above problem is equivalent to the one-way street problem [4] (Chap. 2), [3]. In your answer,

  1a. Describe the graph that you need to build in order to reformulate the problem as a one-way street problem, with a formal definition of the set of nodes and the set of edges

  **Definition of the set of nodes: 3 points.** Very clear and concise definition: 3, reasonable clear: 2 points, difficult to understand: 1

  **Definition of the set of edges: 3 points.** Similar to the set of nodes.




(a) One possible graph for Example 1: Entrance and exit are distinct

(b) One possible graph for Example 2: Entrance and exit are combined

(c) One possible graph for Example 3: Entrance and exit are combined for the floor map and the rooms

Figure 2: Three possible graph solutions (not unique, and not necessarily the best)

1b. Describe a greedy or a DFS algorithm (**DFS/Greedy Algorithm 1**) that allows the checking that one feasible (wrt to the one-way street problem) graph orientation exists. Discuss whether your algorithm is an exact one or a heuristic one.

**Greedy/DFS Algorithm: 10 points.** Very clear and concise algo: 10, reasonable clear: 5 points, difficult to understand: 1

**Exact vs. heuristic: 2 points.** Full mark only if correct answer with clear justification, 0 otherwise.

1c. What is the complexity of that algorithm. Provide the justification of that complexity.

**Complexity: 3 points.** Full mark only if correct answer with clear justification, 0 otherwise.

1d. Describe the algorithm (**Orientation Algorithm 1**) that defines the orientation. Provide its complexity and the justification of it.

**Greedy/DFS Algorithm: 10 points.** Very clear and concise algo: 10, reasonable clear: 5 points, difficult to understand: 1

**Complexity: 2 points.** Full mark only if correct answer with clear justification, 0 otherwise.

1e. Implement both algorithms and make them running for the data sets (see Section 4). Provide the source files, figures of the floor map and of the graph, as well as the direction of the edges.

**Implementation: 5 points.** Well documented Program: 5, 0 otherwise.

**Results: 5 points.** Well presented results: 5 points, 0 otherwise.

1f. Provide an example in which the problem is not equivalent to the one-way street problem, and for which, if you solve it as a one-way street problem, you may require more than what is needed.

**Example: 5 points.** Valid and well documented example: 5, 0 otherwise.

You do not need to design and implement an algorithm that generate the graph of Question 1a. However, you need to read the graph form a file for Question 1d.

## 2.2 Case 2

Some corridors may have multiple lanes, due to their large width.

**Question 2.**

- 2a. Describe the graph that you need to build in order to reformulate the problem as a **one/two-way** street problem, with a formal definition of the set of nodes and the set of edges
- 2b. Describe a DFS or a greedy algorithm (**DFS/Greedy Algorithm 2**) that allows the checking that one feasible (wrt to the **one/two-way** street problem) graph orientation exists. Discuss whether your algorithm is an exact one or a heuristic one.
- 2c. What is the complexity of that algorithm. Provide the justification of that complexity.
- 2d. Describe the algorithm (**Orientation Algorithm 2**) that defines the orientation. Provide its complexity and the justification of it.
- 2e. Implement both algorithms and make them running for the data sets (see Section 4). Provide the source files, figures of the floor map and of the graph, as well as the direction of the edges.

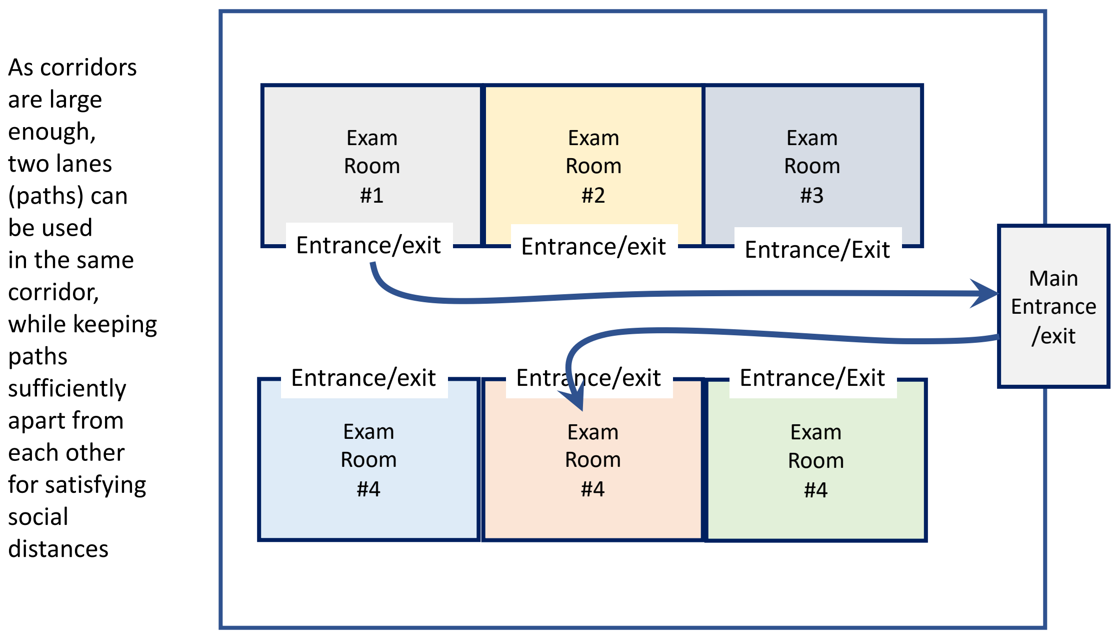



Figure 3: Examples for Case 2

## 2.3 Case 3

COVID patients are allowed. Assume that corridors can all have 2 lanes (not necessarily in the same direction: directions need to be determined).

**General Question:** Can you assign a direction and a color to each edge so that, for any pair of entrance and exit doors, you can find one red and one green path from main entrance to room entrance, and the same from room exit to main exit?

**Question 3. Let us go one step at a time**

- 3a. Describe the graph **(if different from previous questions)** that you need to build in order to reformulate the problem as a **one/two-way** street problem, with a formal definition of the set of nodes and the set of edges
- 3b. Describe a DFS or greedy algorithm (**DFS/Greedy Algorithm 3**) that allows the checking that one feasible (wrt to the **one/two-way** street problem) graph orientation **and coloring** exists. Discuss whether your algorithm is an exact one or a heuristic one.
- 3c. What is the complexity of that algorithm. Provide the justification of that complexity.
- 3d. Describe the algorithm (**Orientation/Coloring Algorithm 3**) that defines the orientation and coloring. Provide its complexity and the justification of it.
- 3e. Implement both algorithms and make them running for the data sets (see Section 4). Provide the source files, figures of the floor map and of the graph, as well as the direction of the edges.

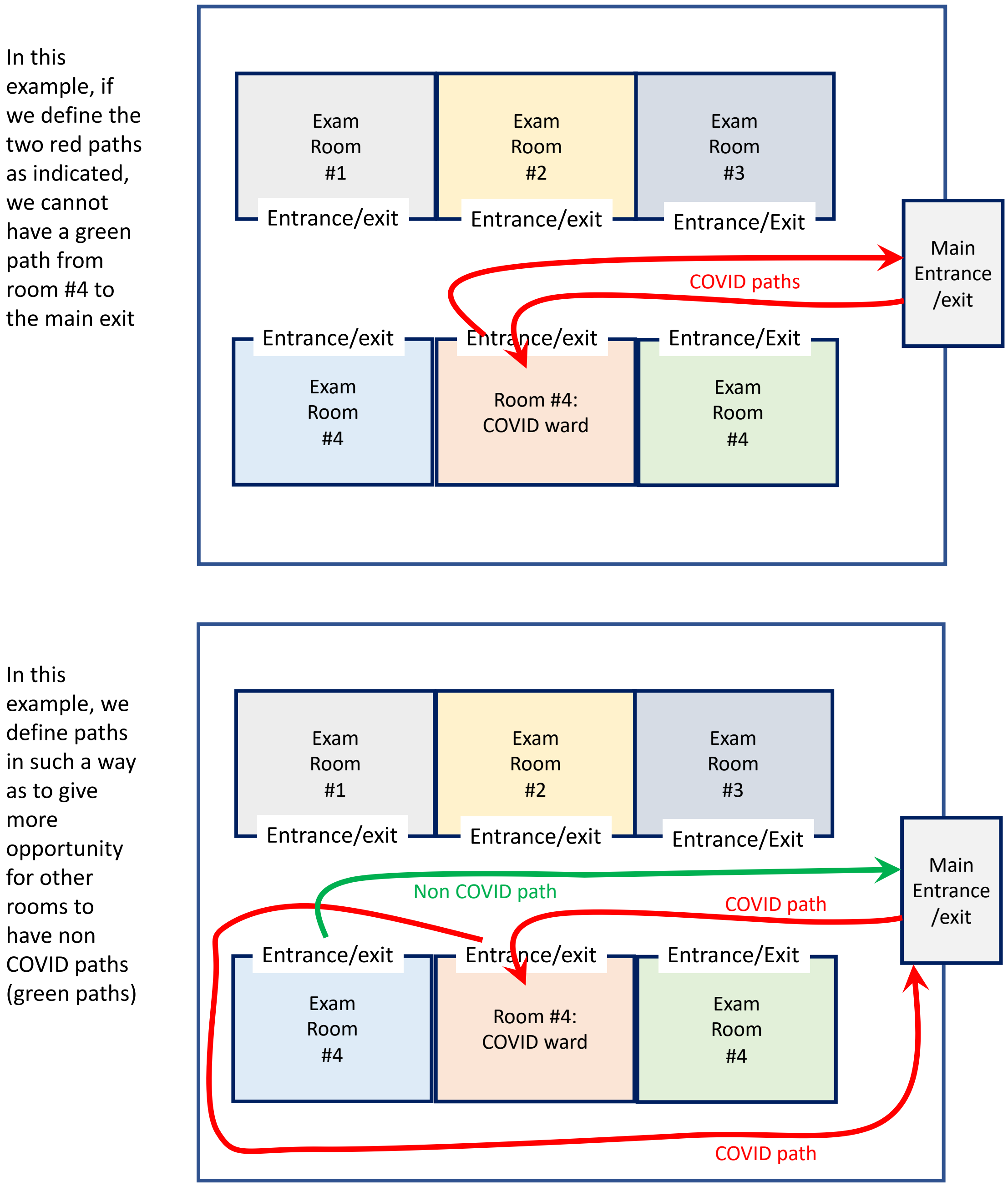



Figure 4: Examples for Case 3

# 3 Part II: Identify minimal sharing of the lanes in order to find feasible orientation of the corridors

Part II consists in writing an article in at most 5 pages with the IEEE format that addresses the following question:
**Input:** two sets of node pairs, $\mathcal{SD}_1$ (non-COVID set) and $\mathcal{SD}_2$ (COVID set).

Given the undirected graph that was developed in Part I, how can you define an orientation of the edges, and a coloring of the links so that:

1. for every node pair of $\mathcal{SD}_1$ and $\mathcal{SD}_2$, there is a path made of links of the same color
2. sharing of the links should be minimized between paths linking node pairs of $\mathcal{SD}_1$ and $\mathcal{SD}_2$
3. orientation of the edges and coloring of the links should be done in order to maximize the throughput (i.e., the circulation of people).

You are entitled to use the concept of alternating links, i.e., of edges that are used in both directions, used alternately in each direction, with the use of one direction as required, and a waiting area at each end of the edge.

You can borrow ideas from the following papers: Arkin and Hassin [1], Omran, Sack and Zarrabi-Zadeh [2], which will be briefly discussed in the lecture of Feb. 11, 2022.

Plan of the conference paper (maximum length: 5 pages):

**Title and Abstract.** No more than 15 lines for the abstract

**Introduction.** No more than 1 column

**Problem statement.** No more than 1.5 column (you can start to put here some variable/parameter definitions

**Literature review.** No more than 1 column. Cite all the references that you use.

**Your proposal.** You can divide it into several sections/subsections. Figures are allowed as long as text + figures does not exceed 5 pages.

**Conclusion.** No more than 10 lines

**References.** No more than 1 column

Marking of Part II will reward:

- The algorithm provides a clear answer to the problem: it is allowed to re-use results of published papers, as long as you cite them.
- Clear and concise description of the algorithms (make sure to define all parameters and variables), taking into account the page limit

It is not allowed to change/alter the IEEE conference format, and additional pages will not be graded.

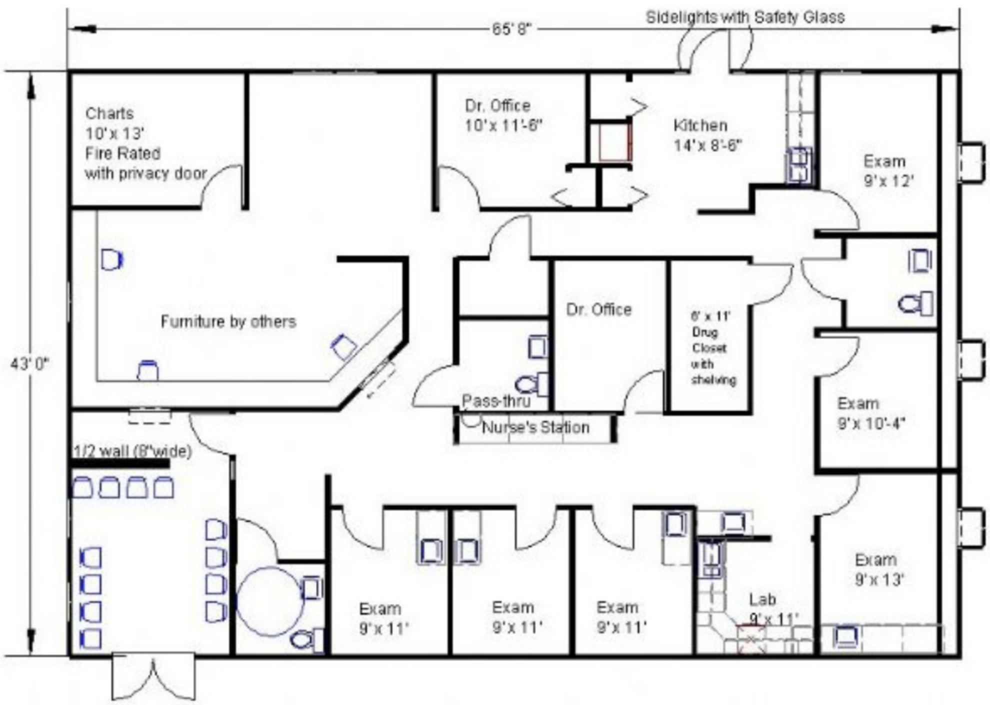



Figure 5: Example from https://rosemedicalbuildings.com/floor-plan-category/medical-healthcare-buildings/

# 4 Experiments

## 4.1 Data sets for Part I

Using the two floor maps of Figures 5 and 6, derive two floor plans for your implementations for which one feasible orientation exists. Explain/draw your resulting modified floor maps.

If you cannot figure out how to automatically derive the graph from an input file describing the floor map, you can explain in an algorithm how you derive the undirected graph from a floor map, and then enter directly your undirected graph in an input file. However, make sure that the grader will be able to map you graph on the floor map as in the slides provided with examples.

## 4.2 Results to be submitted for Part I

In terms of the results of Part I, please submit

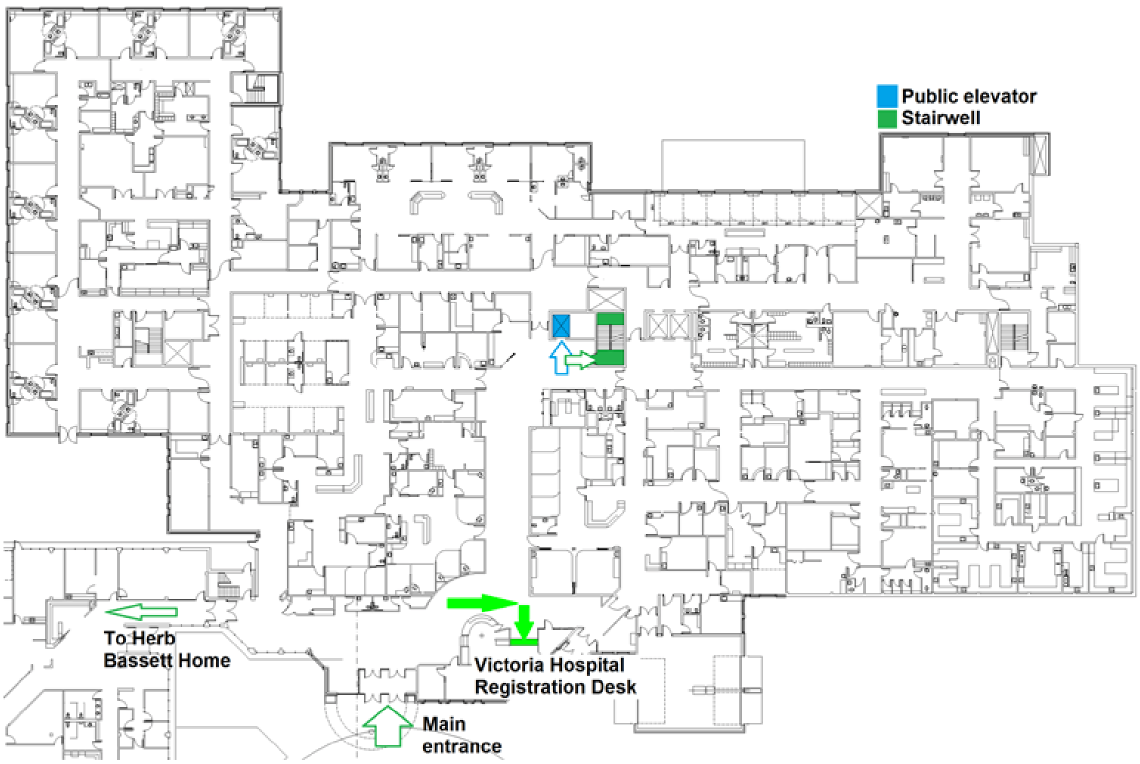



Figure 6: Victoria Hospital - Saskatchewan https://paphr.ca/hospitals-clinic-locations/hospitals-acute-care/victoria-hospital/victoria-hospital-level-2-maps

1. your programs
2. your input files
3. for each of the two data sets, three floor map on which you have drawn the undirected graph for each of the three cases (each floor map for each case)
4. for each of the two data sets, three floor map on which you have drawn the directed graph for each of the three cases (each floor map for each case)

# References


[1] E.M. Arkin and R. Hassin. A note on orientations of mixed graphs. *Discrete Applied Mathematics*, 116(3):271–278, Feb. 2002.

[2] M.T. Omran, J. Sack, and H. Zarrabi-Zadeh. Finding paths with minimum shared edges. *J. Comb. Optim.*, 26(4):709–722, Nov. 2013.

[3] H.E. Robbins. A theorem on graphs, with an application to a problem of traffic control. *The American Mathematical Monthly*, 46(5):281 – 283, 1939.

[4] Fred S. Roberts. *Graph Theory and Its Applications to Problems of Society*. Society for Industrial and Applied Mathematics, 1987.