REVEALING THE HIDDEN LAYERS IN AN ENVIRONMENT: A CASE STUDY OF THE VISUALIZATION OF THE CORONAVIRUS CONTAMINATION AND NAVIGATION IN A HOSPITAL

by

Arghavan Ebrahimi

A thesis submitted to the faculty of
The University of North Carolina at Charlotte
in partial fulfillment of the requirements
for the degree of Master of Science in
Architecture and Master of Science in Information Technology

Charlotte

2021

Approved by:

____

Prof. Eric Sauda

____

Prof. Dimitris Papanikolaou

____

Prof. Catty Zhang

©2021
Arghavan Ebrahimi
ALL RIGHTS RESERVED

ABSTRACT

ARGHAVAN EBRAHIMI. Revealing the hidden layers in an environment: a case study of the visualization of the coronavirus contamination and navigation in a hospital. (Under the direction of PROF. ERIC SAUDA)

The current global pandemic experience has had significant influences on the health and economy of the entire world. Researchers around the world sought to understand the current situation and provide strategic solutions to protect the health of people in the community and reduce the damage and mortality. In this regard, this thesis attempts to develop a spatial spread model of COVID-19 within architectural spaces. It provides a method for evaluating the passages and the infection probability from traveling through the contaminated spaces, which have been divided into two categories, one category is the wide-open spaces and the other corridor-based spaces; These categories rely on various ways the developed algorithm is applied. The proposed model can be adopted to assess the existing systems as to the resistance to the infection. Furthermore can be applied to present more safe assistance in the navigation through an existing architectural setting. The model is subject to the discovery of epidemiological data and can be adjusted to reflect new epidemiological evidence.

DEDICATION

To Mom, my dearest Mom,

my brother and sister, Mahdi and Mahra

and my nephews, Ali and Arash

ACKNOWLEDGEMENTS

I would like to acknowledge with gratitude my advisor Prof. Eric Sauda, and thesis committee, Dimitris Papanikolaou, and Catty Zhang, for their guidance with this project.

Moreover, I'd like to express my sincere and heartfelt appreciation to everyone who has supported me in the pursuit of these master's degrees. It is with a deep sense of gratitude that I thank Dimitris Papanikolaou again, as well as Brook Muller, Emily Makas, Mohamed Shehab, and the DesCom program.

I am extremely thankful to my family, who has supported me through all life's ups and downs- of which there have been many.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HAI Hospital-Acquired Infections

HCoVs Human Coronaviruses

IPC infection prevention and control

MERS Middle East respiratory syndrome

SAR Spatial Augmented Reality

SPF Dijkstra Shortest-Path first

CHAPTER 1: INTRODUCTION

COVID-19 infection is a pandemic, surface to surface communicable disease with a case fatality rate of 3.4 % [4].So far, it has caused a substantial number of deaths and damage world wide. Human Coronaviruses (HCoVs) were first identified in patients with the common cold in the 1960s. More HCoVs have been identified since then, including those that cause SARS and the Middle East respiratory syndrome (MERS). These two viruses can cause lethal respiratory illness in infected people.[5]

HCoVs are classified into seven species (figure 1.1), according to existing information. Four of them trigger a runny nose and a minor upper respiratory tract infection. The three surviving human Coronaviruses are linked to a broader range of disease incidence. They cause acute pneumonia and other significant complications quite commonly [6].

In 2019, a new coronavirus was discovered to be the source of a disease outbreak in China. The virus is now known as Coronavirus 2 (Severe Acute Respiratory Syndrome) (SARS-CoV-2). Coronavirus disease 2019 (COVID-19) is the disease it causes. At that time, due to the limited information and novelty of this species, it was not possible to predict its prevalence as a pandemic disease worldwide. According to the various research, the first outbreak occurred at a local animal and fish market in Wuhan, China. Some vendors at the market sold live wild animals such as cobras, wild boars, and raccoon dogs, and pangolins. It is now considered the first transmitter of the virus to humans are pangolins, as some of the coronaviruses that infect pangolins are very similar to SARS-CoV-2. It soon became apparent that people in China and abroad were infected with the virus without any contact with any animals. This meant that the virus was capable of human-to-human transmission. The virus soon spread throughout the world. This growth of transmission around the world is now a pandemic.

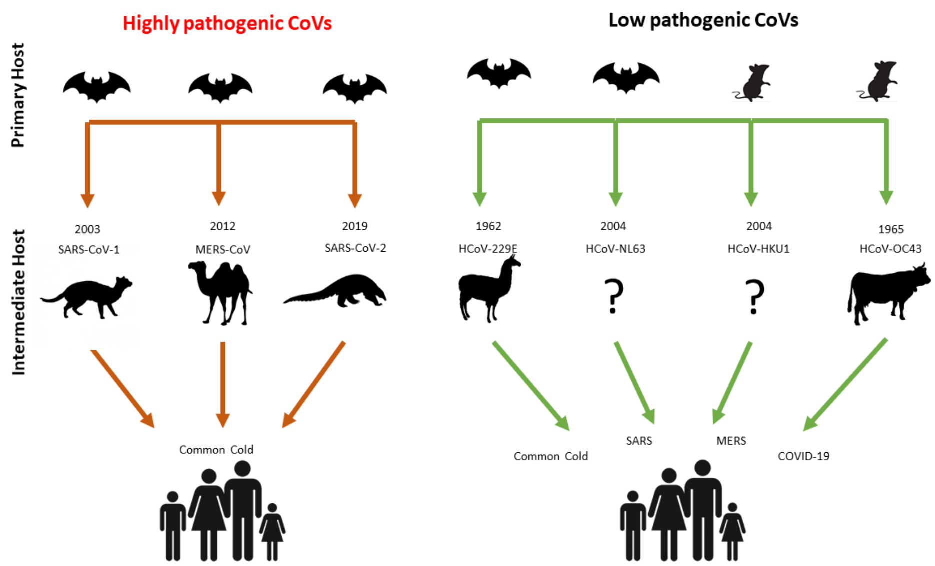


Figure 1.1: Cross-species transmission of human Coronaviruses from the primary and intermediate hosts

This respiratory disease is transmitted through sneezing and coughing or touching objects[7]. In general, according to the World Health Organization, the transfer of COVID-19 in this "Three C's" will be easier:

- Congested areas with a large number of people in the vicinity
- Close-contact situations, especially when people are conversing very close to each other
- Confined and enclosed places with defective ventilation

Overlapping these cases greatly increases the risk of infection. There are currently many places that have one or more of the above conditions. One of these places is hospitals. In the current situation, a lot of patients who tested positive with COVID-19 are hospitalized on a daily basis and hospitals are experiencing a high load of patients. Due to the large number of patients referred to the hospital, people are often forced to be positioned close to others, and this proximity increases the probability of transmitting the disease.

To prevent the spread of COVID-19, hospitals have set additional standards, which several of them have been legislated and practiced in many countries since the beginning of the pandemic. However, despite these strictures and double standards, numerous new cases of COVID-19 have been reported in hospitals. Diseases that people in the hospital get are called Hospital-Acquired Infections (HAI). Many people may delay treatment for fear of getting sick in the hospital (especially during the current pandemic), which puts their health at risk. Research on the COVID-19 disease, which people in the hospital have gotten it, shows that a significant number of people in the hospital have infected by this virus.

These studies indicate a serious problem and lack of preparedness in the health care system in dealing with this crisis. This situation can cause people to be afraid and anxious to go to hospitals. According to reports, on average, about 12 to 15 percent of people who come to hospitals get COVID-19, which is not a small number at all[8].

This implicitly indicates the significance of buildings' role in these pandemic conditions. Closed spaces are the medium of the transmission of this disease, and the interior layout of the building and the materials used in it, are one of the critical factors in this contamination spread. Interestingly, although many studies have been conducted to model the spread of the virus since the onset of the pandemic,almost no studies have been undertaken to model the spread of the infection indoors, despite its great importance. The single research in this regard has been done by Yan& Lan[9]. However, the model presented by them does not take into account several real-world variables. In the absence of a comprehensive model for the spread of the virus indoors, thees questions are arising: to what dependent and non-dependent variables are involved in making this model? And what effect do these variables have on the spread of infection? What strategies can be used to reduce infection probability in a hospital?How routing science can help people to navigate safely and quickly in a hospital?

This study seeks to answer these questions to achieve these objectives:

- Extend existing research on the coronavirus infection spread and potential for infection which currently applies only to open architectural space to complex architectural plans, specifically to a hospital plan.
- Providing a model with the important variables that will influence the possibility for infection. These can be adjusted to reflect new epidemiological evidence about
  - Infection potential remaining after a patient is in the space
  - The spread of the inflection rate in space
  - How long and with what virulence does the infection potential remains
- Another goal of the study is to calculate a probable possibility of inflection based on the infection rates discussed above that will depend on
  - The path of all infected patients in the hospital
  - Average Speed and the number of stops for the infected patients
  - Resulting Inflection rates within the hospital
  - Origin and destination new patient path through the hospital
- For hospital plans, two forms of navigation must be studied, one for open lobby areas and another for the study of the typical narrow corridors that connect patient spaces. Open space required navigation around infected spaces while corridor navigation required a graph theory approach similar to street navigation.

- These studies are beneficial for providing
  - A guide for individuals' navigation through the building which could be an AR application on a smartphones
  - Can be used by the administrators and planners to understand the configuration or reconfiguration of the architectural plan that may be more resistant to potential infection

It is hypothesized that the model includes some factors based on the model of the virus spread, and some based on the specific location one studies with the model and some reconfiguration in the layout of a hospital and It also allows an understanding by hospital administrators regarding best practices for the navigation of people in it to minimize inflection probability. All the variables that will be defined and tested in this thesis are subject to epidemiological data and can be adjusted to reflect new epidemiological evidence about infection potential remaining after a patient is in the space, the spread of the inflection rate in space, how long and with what virulence does the infection potential remains.

Having identified the influential variables on the infection probability, multiple scenario-based simulations of their effects were conducted which The their results showed a strong correlation between the variables of the proposed model of this thesis and infection probability. Moreover, based on the proposed model including these factors, using the Dijkstra algorithm, the shortest path, safe short path and optimized safe path with the lowest infection probability, are offered for navigation of the susceptible people in a hypothetical hospital. The proposed model and its methodology can be applied to simulate the infection in any architectural plan, and there is no limitation in this application. For performing the graphical simulations and calculations related to the contamination spread and routing model, the Unity engine was used. The Rhino program also was used in drawing the 2D and 3D models of the hospital.

In order to answer the research questions and to achieve the set goals, after reviewing the relevant spatial-temporal spread model of the Coronoviurs, proposed by Yin & Lan, which in this thesis was extended, research on the individualsâ safe navigation in the high-risk events will be studied in the Literature Review chapter. In the Methods chapter, appropriate methods for addressing questions and objectives will be discussed, and implementation methods are elaborated, and the variables that affect the probability of contamination are defined. In the chapter on Results and Findings, by implementing several scenarios, the effects of each of these variables on the infection probability are tested, and the findings are presented.

At first, this thesis aimed to develop an AR application, using the developed model to provide a navigation guide to individuals in an infected hospital with the Coronovirus; However, to simulate the spatial spread of the Coronavirus, a need for a more comprehensive model was preceding to it which would be applied in the AR application for the visualizations and furthermore, testing the AR applicaiton during the current pandemic wasn't feasible. This research can be expanded and implemented and the methodology used in it has the ability in modeling for any contagious disease.

CHAPTER 2: LITERATURE REVIEW

This section reviews the relevant studies on the simulation of the spread of the virus in a closed environment and also articles that model the proposed routing in high-risk situations.

2.1 Mathematical Representation and Modeling

To know the level of contamination of a specific place in the hospital by the COVID-19 virus, the spatial- temporal model of COVID-19 infection in a confined space constructed by Yan Lan is the best model so far. By analyzing a various aspects of the interactions (the response of the human immune system, the shedding, and spreading of the virus, human motion, etc.) at the mesoscopic level, Yan & Lan in their paper, have constructed a spatial-temporal model of the Coronavirus transmission in a confined space. This model provides comprehensive interactions between mobile individuals and the spreading virus [9].

In their model, two variables (n_v, t_v) determine each individual's state in terms of infection by the virus. n_v is the concentration of the virus in individuals' bodies, and t_v is the tolerance of their bodies to the virus. For a susceptible person, n_v is 0. For convenience, the tolerance (t_v) to the virus is assumed to satisfy a uniform distribution in the interval of [0,10]. Because of the difficulties in the measurement of t_v, they assumed that the moving speed of each individual is:

$$s_v = s_{speed} * \frac{1}{1 + 2 * 10^{-4} * n_v^{11-t_v}} \tag{2.1}$$

where $s_{speed} = 4000$ m/day and s_v might be applied to outline the tolerance. In the model, individuals' states with different physiological conditions are subject to dynamic adjustments according to their interactions with viruses in the confined space. In the closed environment, spatial factors have fundamental roles in the distribution of the virus, and the humans' infections, which are extremely correlated in both space and time. The virus reproduction's rate in the body is considered to be sigmoidal :

$$p_T = \alpha * [1 + tanh[z * (n_v - N)]] \tag{2.2}$$

where α is a primary production rate and z controls the steepness of switch function. The average value of threshold of variable N is 4. In the below equation, the change of the virus concentration at the point p_t (m,n) is described; b_s is the surface contamination degree and at most one individual can occupy each grid point (m,n):

$$p_t(m,n) \xrightarrow{\gamma_b} b_S, b_s \xrightarrow{r_b} p_t(m,n), b_S \xrightarrow{\gamma_c} n_v, \tag{2.3}$$

γ_b is the Contamination rate and $\gamma_b = 2.3\ \times 10^4 units/day$.$r_b$ is the peeling off rate of virus from the body surface into the air and $r_b = 0.1\ \times 10^4 units/day$,$\gamma_c$ is the viral invasion rate into the human body and $\gamma_c = 1.8\ \times 10^4 units/day$.

The model of virus concentration's diffusion and decay in the confined place is described by the below reactions:

$$p_t(m,n) \xrightarrow{r_d} \phi, p_t(m,n) \xrightarrow{D} \frac{1}{2} * p_t(m,n) \tag{2.4}$$

$$\sum_{(m_1,n_1)} p_t(m_1,n_1) = \frac{1}{2} * p_t(m,n) \tag{2.5}$$

The decay rate of Coronavirus is $r_d = 8\ \times 10^4$ units/day as it can remain in the air for 3 hours. The virus's diffusion coefficient is ($D_v = 2.9\ \times 10^{-5}\ m^2$/s). In general, the change of concentration in a time interval of Δt is:

$$\begin{aligned}\Delta p_t(m,n) &= p_t + \Delta t(m,n) - p_t(m,n)\\ &= D * [\sum_{(m_1,n_1)} p_t(m_1,n_1) - d * p_t(m,n)\Delta t]\\ &- r_d * p_t(m,n) * \Delta t + r_b * b_s * \Delta t + r_f * n_v * \Delta t\end{aligned} \tag{2.6}$$

where in the simulation lattice, d = 4 is the coordination number.Over the points of the adjacent lattice, is the summation. In the model, for the simulation of stochastic dynamics, the Gillespie algorithm has been applied. For each person, each grid point, and for getting updated in each time step, information vectors are employed.The confined space is presented as a square grid with a 100m side length which the interval of adjacent points of the grid is 5m. Each movement of a person is supposed as a reaction. By each reaction, the individual may move to an arbitrarily selected adjacent point in the grid.As the viruses' spread is a random motion, only half of the viruses spread to the adjacent points; Thus, the virus concentration is shrunken by half on the point(m, n) and the rest half of the viruses spread to the four neighboring grid points (Fig2.1).

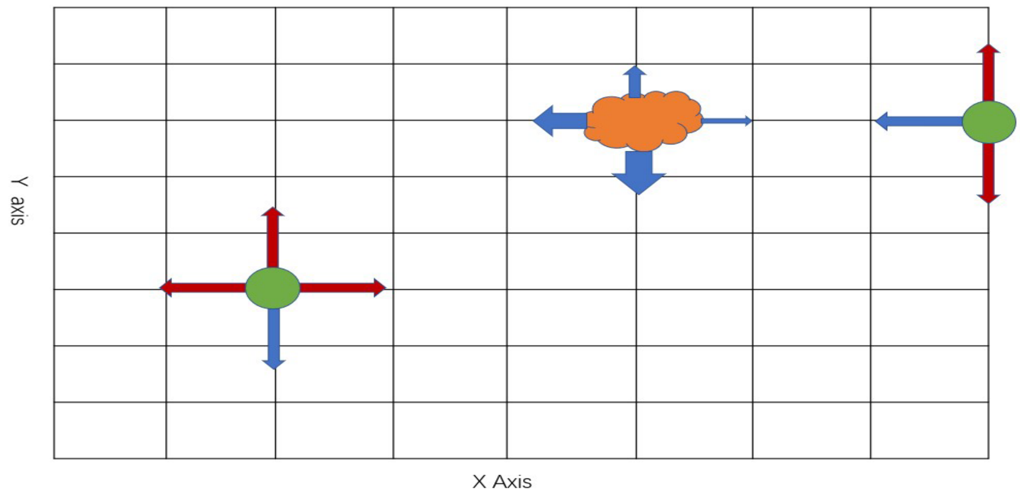


Figure 2.1: Schematic demonstration of human motion and the spread of the virus: viruses (yellow bubble), human (green circles), the diffusion probability(blue arrow signals' width)

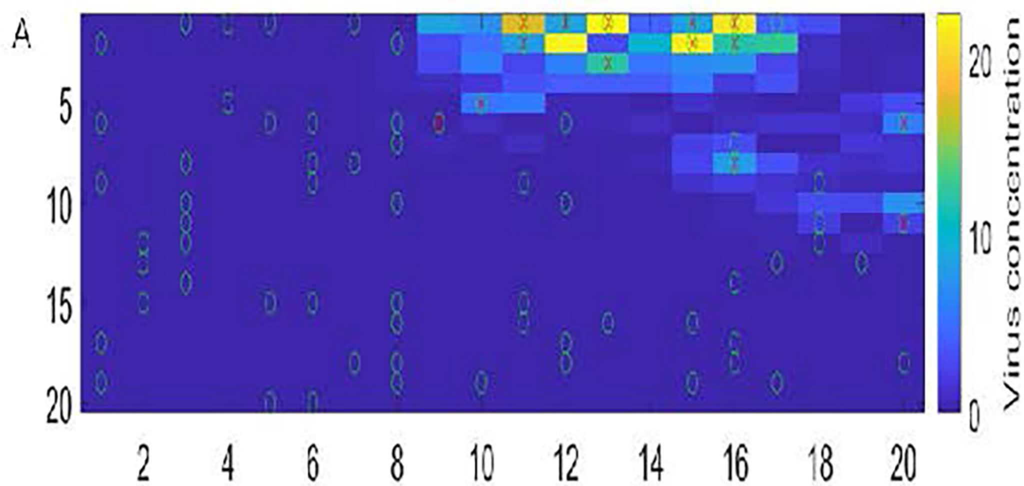


Figure 2.2: The representation of the rate of the infection evolution within 24 days

As explained, In their simulation, Yan& Lan simulated the spread of the virus only in a homogeneous square space (100 m by 100 m). In their simulation, they placed 74 people, only one of whom was infected. In the beginning, this number of people was homogeneously and randomly set in the environment, and their movement was stimulated by the Gillespie algorithm with the possibility of 4 directions (up, down, left, and right). According to their simulations, after 24 days, an average of 14 people was infected in this environment, which according to their information, this number was close to the real results.

Following is an analysis of the Gillespie algorithm, which in the article was used to simulate the movements of people in the environment, will be discussed.

2.2 Gillespie algorithm

This algorithm was originally proposed to simulate chemical and biochemical reactions, which in fact provides a simulation model of the distribution of probabilities for each type of stochastic process. The basis of this algorithm is based on a set of different probabilities for each reaction and the result of these reactions. At each moment (t), there is a specific combination with a certain amount of propensities for the reactions that indicate the probabilities of subsequent reactions. The type of reaction and the time required to perform the reaction is considered random values. To calculate the next reaction time, the following equation is applied:

$$t_{react} = \frac{1}{a_0} ln(r_1) \tag{2.7}$$

$$t = t_{react} + t \tag{2.8}$$

In this relation, r_1 is a random value between 0 and 1, and a_0 is equal to the sum of all possible probabilities for different reactions. The time elapsed since the start of the reaction (t), at each moment of the reaction, is equal to the sum of the value of t_{react} with the previous value of t.

To select the next reaction, the random number r_2 is used, which is also a number between 0 and 1. To do this, we use a hypothetical diagram:

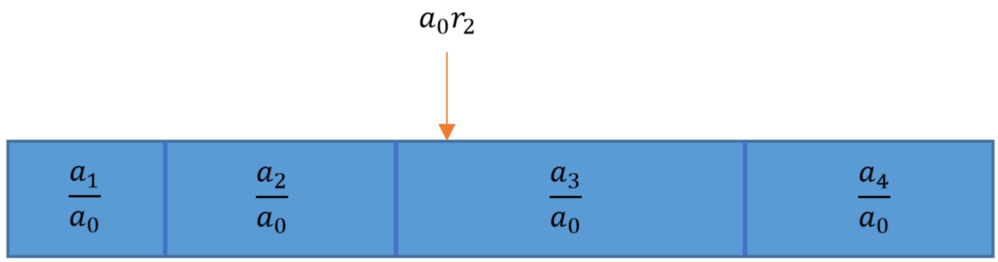


Figure 2.3: Random Selection of Reaction

The product of a_0 r_2 multiplication, based on the probability values of different reactions, refers to a point in the range of one of the reactions (in this example, 4 different reactions are considered). In fact, in the diagram above, the selected reaction is the third reaction.

Finally, the probabilities of different reactions are updated based on the previous reaction, and this process continues until the expected time has elapsed since the start of the reaction (or any other condition is met). In the model presented in the Yan & Lan paper, at any time, the Gillespie algorithm randomly presents a motion in four main directions. According to the simulations performed in this thesis,Which will be discussed in the next chapters, this algorithm is not a good option for simulating the movement of people in a hospital [10]; because in the paper the limited movement of the individuals who mainly considered stationary for the most of the time, the contamination was spread in excess in the environment which is far from the reality. To solve this problem, the Dijkstra algorithm is proposed to simulate the individual's movements and generate the short safe, optimized safe and shortest paths to navigate the susceptible people in the hospital[11].

2.3 Dijkstra Algorithm

Dijkstra Algorithm or Dijkstra Shortest-Path first (SPF) is an algorithm used to find the shortest path between two nodes in a graph. This method is one of the best ways to find the shortest path [12]. The graph in which the shortest route is examined may indicate a network of roads or other items. The Dijkstra algorithm was introduced in 1956 by a computer scientist named Edsger Wybe Dijkstra and published three years later.

The Dijkstra algorithm comes in many forms. The main algorithm finds the shortest path between the two nodes, But the more common type of this algorithm considers a single node as the source node and finds the shortest path from the source to other nodes in the graph by constructing the shortest path tree. To do so, in this algorithm, a cost is considered for passing each edge, which can be related to the distance between two nodes or any other parameter. To find the shortest path between the source node and all the other nodes in the graph, Dijkstra examines all possible paths and selects the shortest path (the least costly path) to reach each node[13].

For instance, in the graph below, after running the algorithm, the cost required to reach each of the nodes is calculated and specified in the node. Moreover, the shortest route from origin A to node B, which costs 7, is shown in blue in the figure.

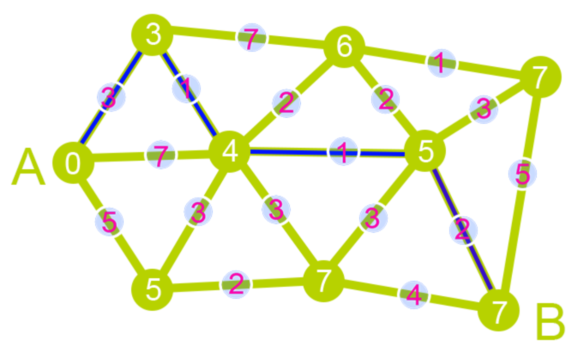


Figure 2.4: The shortest path between nodes A and B

The steps of this algorithm are given below:

1. Assigning a set called "Visited" in which each node that is finalized and placed in the shortest path tree is added. At the start of the algorithm, this set is considered empty.

2. To each node of the graph, a value of the distance is assigned, which is initialized

with an infinite value.Furthermore, the value of the distance is assumed to be 0 for the node that is considered as the origin.

3. The following steps are performed until the "Visited" set includes all nodes:

   - The node U is selected, which is not present in "Visited" set and has the least amount of distance in the whole graph.
   - The node is added to the "Visited" set.
   - The distance value from all adjacent nodes is updated. Repeat is performed on all adjacent nodes to update the distance values. For each adjacent node V, if the sum of the distance attributed to node U and the weight of the edge UV is less than the distance attributed to node V, the value of distance v would be the sum of the distance attributed to node u and edge UV weight will be updated.

Because of its efficiency, this algorithm was applied in this dissertation to generate the shortest, safe short and optimized safe routes and determine the navigation routes of individuals in the hospital.

2.4 Individuals' Safe Navigation in the High-Risk Events

A variety of routing methods have been developed over the years. This routing includes a set of recommendations to improve the navigation of the individuals or the car or etc to reach the desired destination. This improvement can mean finding the shortest route to the destination, finding the least traffic route, finding a route that has a special feature (such as a gas station), and so on.

There are various algorithms to provide a suitable route based on effective parameters in the selected route type. The routing process is currently being developed and implemented on smartphones and wearable gadgets such as smartwatches or smart glasses to be used in navigating people in different places.

One of the places where the use of routing can be helpful is sensitive places with potential for life or financial danger (such as nuclear facilities, hospitals, workshops, and factories for the production and storage of hazardous materials, etc.). It can also be utilized to evacuate people from high-risk areas, such as residential or office buildings or markets that have caught fire (or any other emergency situations).

Hospitals are one of the most sensitive places in times of crisis. During the outbreak of pandemic diseases, the condition of hospitals and the observance of health tips in them becomes doubly important. Because if a hospital becomes infected, other patients and treatment staff will be at risk. This implies that an individual who goes to the hospital expecting to get treatment, will get a new disease. Furthermore, illness of the medical staff can cause fatigue of the medical staff and disruption of the medical system in general. Given the high transmission rate of the COVID-19 virus's infection and the high risk of hospitals spreading and transmitting the virus, assisting people in hospitals to navigate through a safe and short route will be very relevant. The following is a review of several articles that address this vital issue.

During an emergency evacuation, the intelligent autonomous evacuation navigation (AEN) system solves way-finding problems, particularly for those who are unfamiliar with the building. Via dynamic signs, the AEN system is intended to provide autonomous evacuation navigation, guiding occupants to the safest and shortest route to the nearest exit.In order to combine these factors and take into account the dangerous area, it employs a modified Dijkstra's algorithm. The AEN system makes use of existing systems such as the fire alarm control panel, the fire indicator, and the original floor plan. [2]

People in the affected area, as well as others who might be on their way there, must be aware of the situation and navigate safely to reduce the risk of casualties[14].

In their paper, Iadanza et al [1] proposed a Dijkstra-based routing algorithm for discharging patients from the hospital in the event of a fire. In their proposed method, route safety is the main parameter, and the proposed route may not be the shortest. In their paper, they present an algorithm based on the parameters typology of the user, speed, the spatial position of ignition, fire and smoke propagation, and congestion to evaluate the safest route of the evacuation of people in the hospital in case of fire.

Using a plan designed with CAD, they create a weighted graph whose weight on each edge is equal to the length of the path between the two nodes. Then, having this graph, the adjacency of the corresponding matrix is implemented and using this matrix, the shortest path is evaluated through the Dijkstra algorithm. In their proposed model, each room is considered as a node and each room is equipped with temperature, humidity, air pressure, and smoke density sensors. that model the proposed routing in high-risk situations.

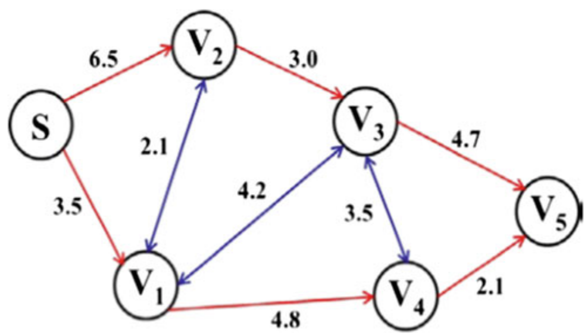


Figure 2.5: An interconnected weighted graph example[1]

If one of the values of these sensors exceeds the hazard level in a room, the corresponding node of that room will be removed from the graph and matrix and that node will not be included in the routing. The number of people who need to be evacuated from the hospital has a direct effect on the evacuation time. In their paper, the discharge time of individuals through a fluid in a hydraulic model is calculated:

$$t = \frac{N}{D.V.W} \tag{2.9}$$

In the formula, N is the number of people, D is the density of people, V is the speed of people, which fits the typology of the user, and W is the width of the corridor that these people intend to cross. The time obtained will be in seconds. In this article, a table of the average speed of patients with various diseases is given.

Table 2.1: The average speed of patients with various diseases

Subject group	Mean (m/s)	Standard deviation range (m/s)	Range (m/s)	Interquartile range (m/s)
All Disabled	1.00	0.42	0.10 –1.77	0.71–1.28
With Locomotion Disability	0.80	0.37	0.10–1.68	0.57–1.02
No Aid	0.95	0.32	0.24–1.68	0.70–1.02
Crutches	0.94	0.30	0.63–1.35	0.67–1.24
Walking Stick	0.81	0.38	0.26–1.60	0.49–1.08
Walking Frame or Rollator	0.57	0.29	0.10–1.02	0.34–0.83
With out Locomotion diability	1.38	0.32	0.82–1.77	1.05–1.38
Electric Wheelchair	0.89	–	0.85–0.93	–
Manual Wheelchair	0.69	0.35	0.13–1.35	0.38–0.94
Assisted Manual Wheelchair	1.30	0.34	0.84–1.98	1.02–1.59
Assisted Ambulant	0.78	0.34	0.21–1.40	0.58–0.92

In conclusion, using Pyrosim software (which is a fire simulation program) and a model of a real hospital in Italy, they simulated the evacuation of 4 people at an average speed of 1.2 m / s, which according to the method Provided, this discharge (up to the exit) took 30 seconds.

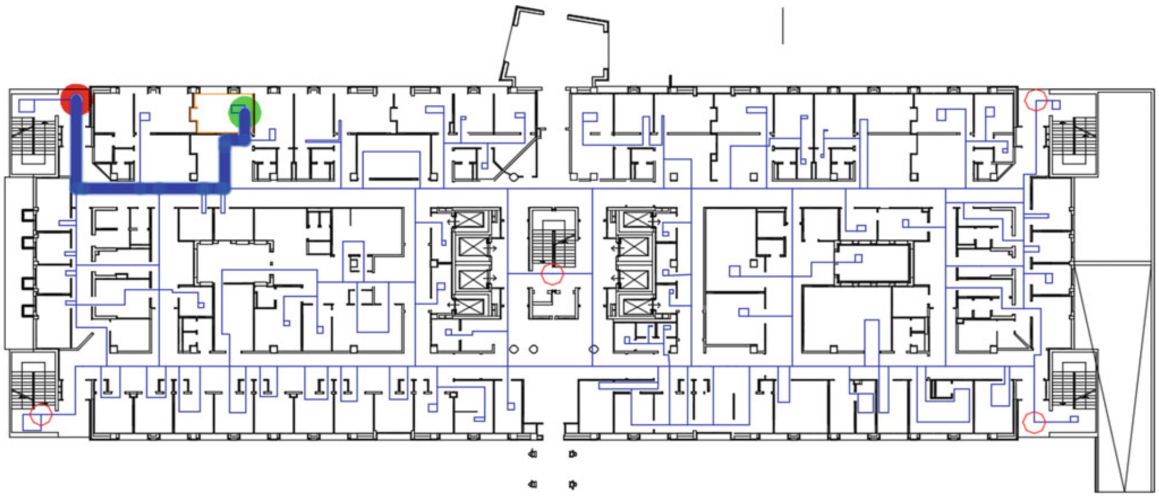


Figure 2.6: Shortest path with no fire incident in the place [1]

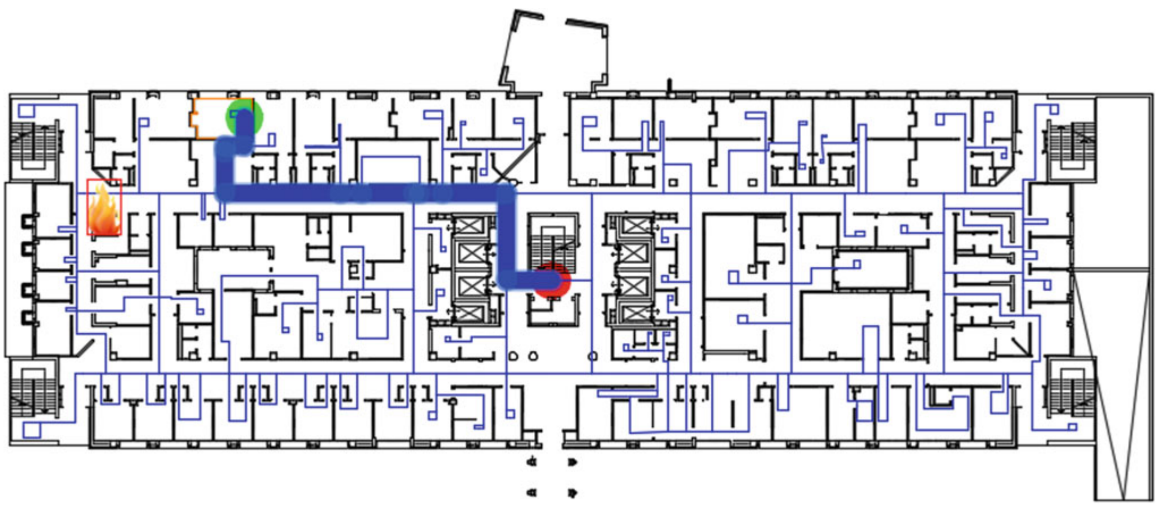


Figure 2.7: Shortest safest path with no fire incident in the place [1]

One of the notable aspects of their work is to consider all the variables related to fire risk detection, which increases the accuracy of risk detection. Also, considering the speed variation in different patients brings the results closer to reality. However, the implementation of this method requires creating a wireless sensor network (WSN), each node of which requires a large number of sensors, which increases the total cost of this method. Also, in their modeling, they did not consider the direction of fire propagation, which could cause patients and fire to reach a common corridor at the same time.

Another research is the study of Abu Samah et al. [2]. In their paper, they presented a modified Dijkstra algorithm to evacuate people in emergencies through the shortest and safest route. Their first modification is to limit the direction of the edges between plan nodes, and the second change is to block fire nodes. Their proposed method for emergency evacuations will be reviewed in the following.

Abu Samah et al. in their paper, analyzed the evacuation routing process in two layers called information retrieval and decision making. The first layer consists of two parts, input, and processing. In the first layer first, the building plan is designed, then in Auto CAD, based on that plan, a 2D routing graph is created. Then a matrix is formed from this graph.

If one of the Fire Detection Alarms is active, the suggested path is provided by the safest path algorithm. Otherwise, the proposed route will be presented through the shortest path algorithm. The weight of the edges is equal to the distance between the nodes in meters. They consider limiting the direction of corridors to one direction and two directions to be a factor for faster evacuation of the building.

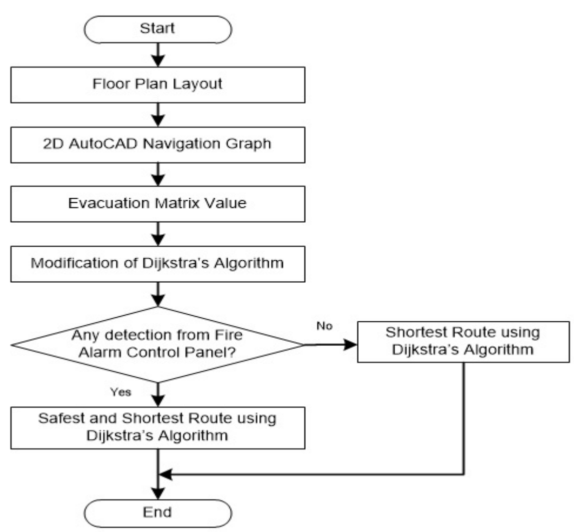


Figure 2.8: AEN First Layer Methodology Flowchart [2]

Their second modification is to block nodes in which the fire alarm is activated, and as a result, in the routing matrix of the Dijkstra, the elements corresponding to the paths leading to that node are assumed to be 999 (so that they will not be selected). According to the authors, the contribution made in their article is to make the evacuation process of the building more intelligent and more automated in case of danger.

One of the advantages of this method is the assumption of two different scenarios for the shortest route and the safest route. In their proposed method, the safest route algorithm is executed only at the time of emergency detection. Typically, the shortest path between two points of the building is the best choice for routing a person. In contrast, one of the drawbacks of this article is the lack of an accurate and practical solution to identify the types of hazards claimed in the article. Also, despite the need to form a matrix from the output graph manually, their proposed method can not be considered intelligent and automatic.

2.5 Architectural Design Strategies for Infection Prevention

A hospital's or institution's physical architecture and facilities are critical components of the infection prevention strategy. As a result, taking these into account from the beginning of the building's design and design processes would be required.It's critical to strike a balance between making a hospital accessible, affordable, and public while still controlling the transmission of infectious diseases[15].

One way to reduce the spread of the virus inside a hospital is through architectural considerations that can be effective. For example, in their article, Emmanuel et al. Offer different solutions for infection prevention and control (IPC) in healthcare facilities. They state that When architectural spaces are conceptualized and built with a specific purpose in mind, they can assist or facilitate the prevention of infectious diseases. Florence Nightingale was the first one who experimented with this idea and unveiled the hospital ward concept, she noted that natural daylight and cross ventilation are important components to disinfect and reduce the incidence of infection in hospitals. One of the design solutions, for keeping the social distancing, suggest that By providing enough space in waiting rooms, halls, hallways, stairwells, and entrance lobby to enable social distancing of at least 1000 mm. Since aerosol droplets only fly short distances of 1000 mm to 2000 mm before landing on surfaces, this would not only limit contact transmission but also establish secure distancing. By excluding nooks with benches or ledges, as seen in fig. 2.9, corridors may be built to avoid casual conversations. Carthey [16] applied the ledge corridor design to hospital design to facilitate interactions among team members.

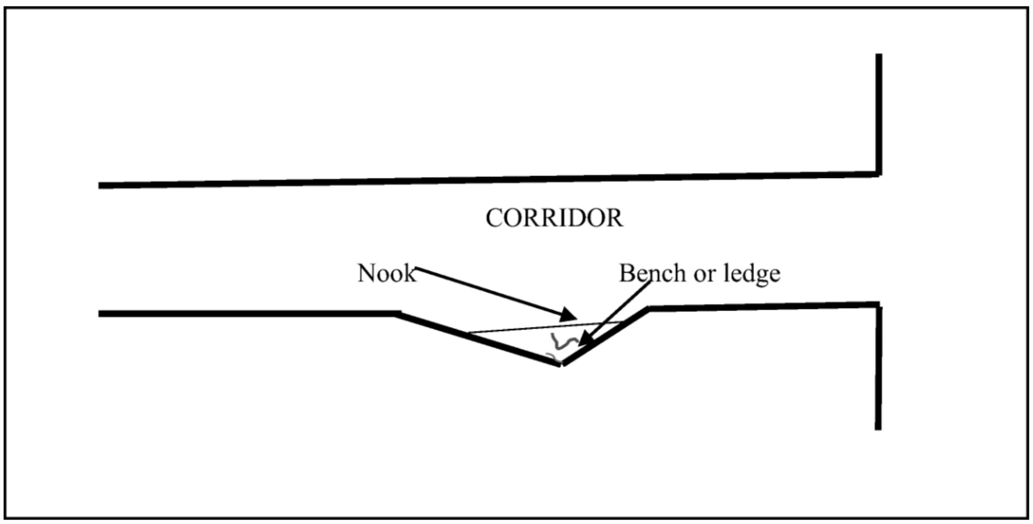


Figure 2.9: Corridor nook example used by some hospitals [3]

It has come to light that, besides wheelchairs, crouches, trolleys, and beds, but even safe distancing, as suggested by the CDC, should be accommodated in corridor and lobby architecture considerations. As illustrated in Fig. 2.10, the UK Department of Health's proposed corridor width of 1500 mm [3] is insufficient for secure distancing inside hospital space. As a result, the authors' analysis recommends a corridor width of at least 2600 mm.

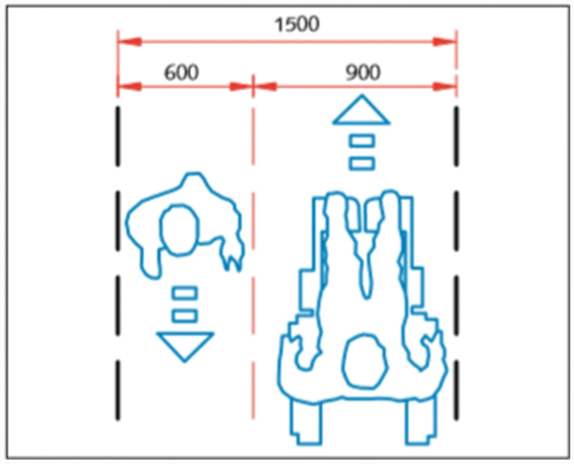


Figure 2.10: UKDH's suggested corridor width [3]

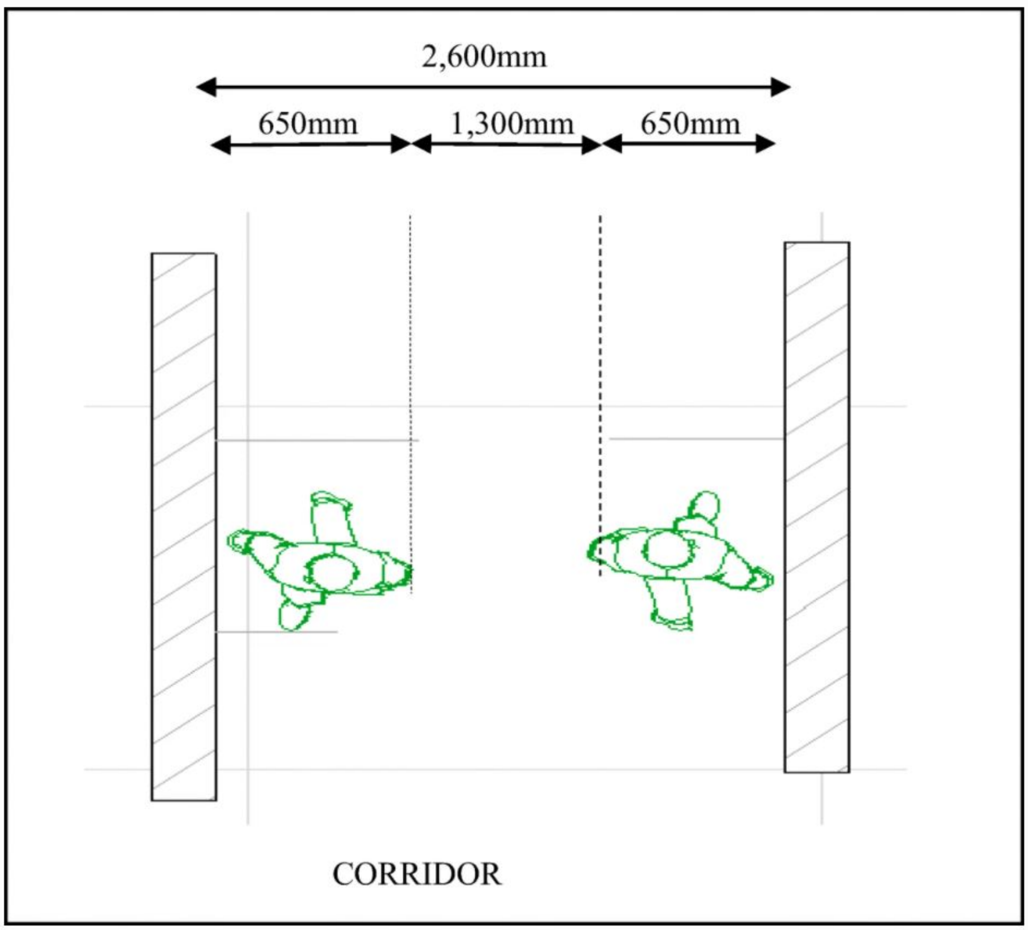


Figure 2.11: Authors' suggested corridor width [3]

Pandey et al.[17], in their experience in converting a general hospital into an operative contagious disease isolation section, outlined the movement of patients and hospital staff to ensure that contaminated (dirty), semi-clean, and clean areas were clearly marked.The point of entry for patients was established as the medical block at the farthest end of the hospital building (fig.2.23,block C2). By dividing the spaces into three categories in terms of the amount of contamination and allocating a special entry door for the infected patients, the researchers limited the amount of contamination to a small part of the hospital.

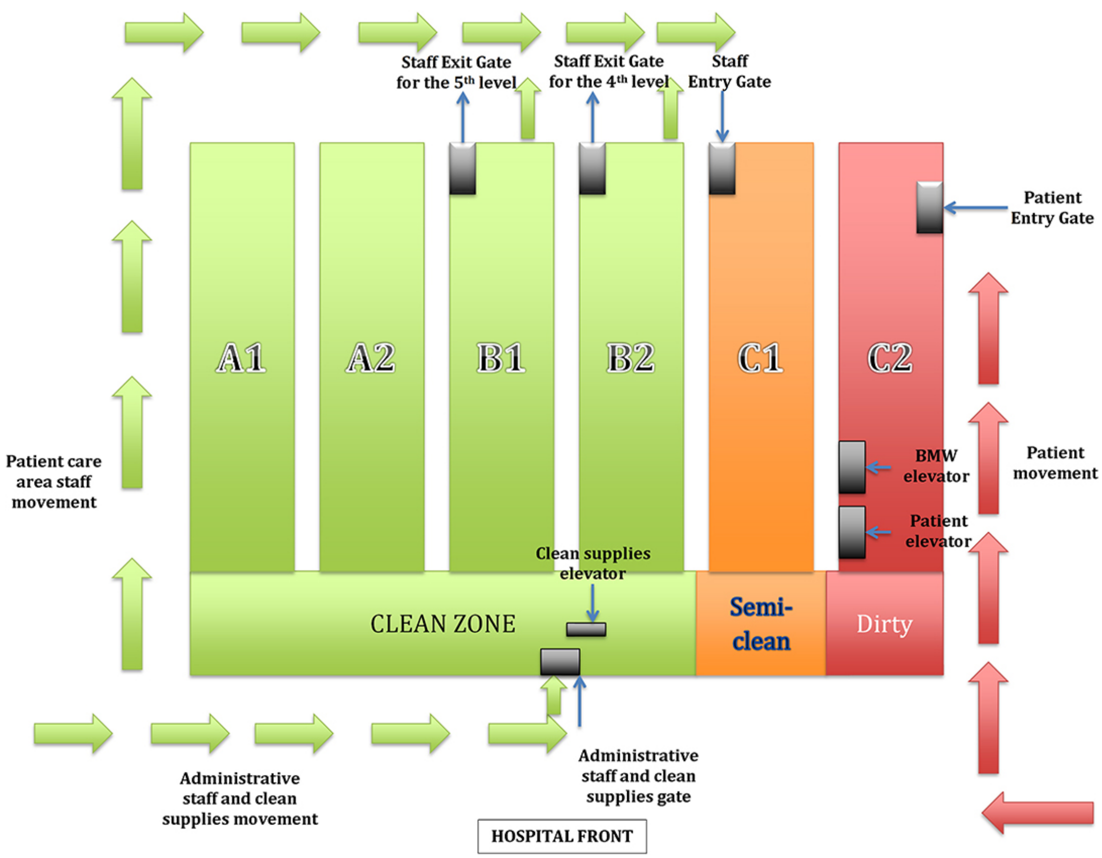


Figure 2.12: A diagram depicting the converted hospital's operation. In the picture, a simple demarcation between the clean and contaminated zones can be seen.

In terms of layout and design solutions, Megahed et el. in their research on the learned lessons form COVID-19 pandemic for the antivirus-built environment [18] believe The post-pandemic design will have further divisions between departments, and open-plan spaces may be phased out. Wider corridors and doorways, as well as numerous additional staircases, can necessitate revisions to the building code and design strategies.Furthermore, Design can be made more affordable by ensuring open and adaptable environments for all people, allowing it to adapt to changing demands and lifestyles.

2.6 Augmented Reality for Emergency Situations

In this section, some augmented reality applications designed for emergencies are studied.Its first application is called "RescueMe" an application. Ahn et al. [19] have developed an Augmented-Reality-based mobile evacuation system called RescueMe. Outdoor emergency applications are widely developed and focus on providing incident information. In contrast, in indoor spaces, due to the lack of access to GPS, it will be challenging to identify the location of the accident or the injured person. In their article, they use a person's pedometry, which is obtained through a smartphone, to identify her/his location and, by combining this system with Augmented-Reality, recommend the most appropriate way out.Some existing systems based on RFID or WiFi signals have used locations to recommend the best way out. But none of them have used AR to guide a person, and it also costs a lot to build the infrastructure for these proposed systems.

(a) (b)

Figure 2.13: Viewing 3D & 2D maps

In the images above, RescueMe shows the exit route and the length of the remaining route. The working mechanism of this system is that in case of emergency exit, the user takes a photo of a known place around him with his mobile phone (for example, in the hotel from the room number, office name, etc.) and with Use a tool like IQEngine. The person's location is identified, and the shortest exit route is displayed using AR.

One of the authors' contributions is that there is no need for infrastructure for emergency exits. Another contribution is developing a mobile guide using AR on the mobile phone that enhances secure navigation. They also provide a pedometry system that predicts the length of a person's steps. Finally, They have developed an algorithm to find the exit route with the least interruption and congestion.

According to the article, accurate location inside the building is the critical part in implementing AR-based systems, which should have the lease delay and not bear a high burden (in terms of CPU usage and other hardware) on the smartphone. In their article, they have not considered any particular infrastructure to implement their proposed system and have only used the camera, accelerometer sensor, and digital compass sensor which all of these items are available on all mobile phones.

Of course, they have assumed for their design that the exact map image of the building with accurate dimensions, geographical location, and location of the doors has been prepared in advance.

Their system architecture consists of 3 logical components:

1. Mobile phone (to take a picture and send it, step counting and location recognition, 3D rendering of the space from the user's view to create AR, and finally recording walking patterns such as recognizing the length of steps Outdoors, to predict walking distance in indoor space)

2. External Image Labeling Service (This service can be any known technique; The authors have used a commercial image labeling Web service called IQ Engines)

3. RescueMe server (a system that real-time generates secure routes for the navigation for the people's exit)

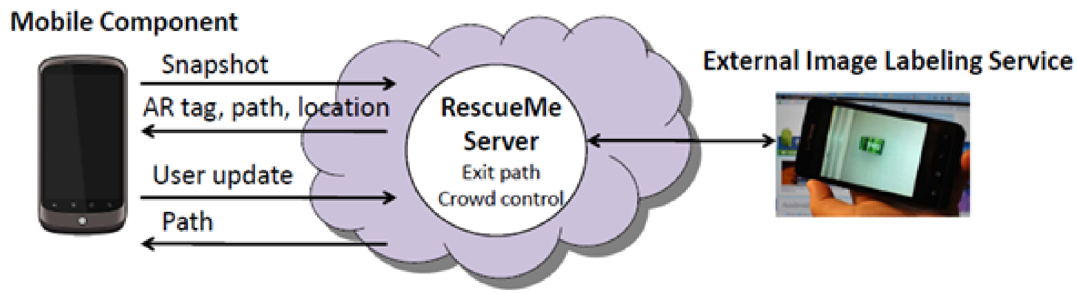


Figure 2.14: Cloud Based RescueMe Architecture

Several steps have been taken to locate a person through pedometry-based dead-reckoning (PDR):

1. Footstep Detection: First, the accelerometer values on the x-axis, y-axis, and z-axis are normalized by subtracting the influence of gravity using a mean elimination process. Second, we measure the normalized accelerometer signal's moving average. A moving average is used to reduce errors caused by changing the phone's user orientation in three directions, as well as to eliminate unnecessary high frequencies from the results.

2. Learned Gait Pattern Between Outdoor Places: Using personal information and walking style and speed using motion detection, GPS and accelerometer sensor in outdoor places, to get the exact length of walking in different situations.

3. Daily-based Personalized Stride Estimation: The length of a person's steps is estimated daily with previous data and compared to the actual measured length, and if necessary, corrections are made to these values.

4. Map-Matching-Based Orientation and Userâs Direction Estimation: which is based on the digital compass sensor and the detection of steps, angles of movement, and turning left and right.

5. Solution for incremental measurement problem: Given that pedometry routing error is continuously increasing, they came up with two solutions to this problem: one is that when the positioning system detects left or right rotation, it compares it to the actual building plan. And if there was a corridor there, it resets the person's location and considers the exact beginning of the corridor as his location. Another solution is to manually select the room and location of the person.

They performed various experiments to evaluate their proposed method. According to their results, the average error of the method of recognizing the number of steps is 3.33%, the average error of recognizing the length of the step in their method is 2.33 %.

One of the advantages of their proposed method is the accuracy of location through pedometry, which has a high precision according to the results. Also, the low cost of this method makes it suitable for many public places. Disadvantages of this method include the lack of accurate reference to the algorithm used for routing and lack of attention to the hazards of the route (such as fire, etc.), and only attention to the congestion and speed of departure. Using an External service to capture photos and location information may also violate users' privacy.

Another study belongs to Codina el et. [20]. In their paper, they present an augmented reality implementation for emergency situations in smart buildings, which does indoor positioning using sub-GHz radio beacons.

It is difficult to reach a person trapped in a fire situation due to high temperatures, low visibility due to smoke, and road closures due to the building's destruction. Time is significant in such a situation, and seconds can keep a person alive.

The method they offer is a combination of augmented reality and indoor positioning and radio communication, which speeds up relief. Due to a power outage due to a fire or a power outage, it is necessary for such a system to use a battery for power supply, and this type of power supply is suitable for sending messages and radio communications in the sub-GHz band. They used Bluetooth 5 technology to locate the person. In this way, each agent carries a small device with a unique ID, and the antennas on site capture the packets sent from it and deliver this data to the server, where the positioning calculations will be performed. Their paper focuses on providing a solution for rescue teams to navigate the building using Bluetooth 5 and 3D reconstruction of buildings using augmented reality glasses. In their design, battery-powered landmark nodes are either present in the building from the beginning or are scattered throughout the building by the rescue team. The data of these landmark nodes are collected in a gateway (which is the infrastructure of the building). However, to ensure a safe gateway, the rescue team needs to have a sample of these extra gateways with them. There is also a radio connection between AR devices. Finally, the system provided by them consists of 3 components: 1- An Indoor positioning system 2- Smart glasses to offer augmented reality for each member of the rescue team 3- An operation management system.

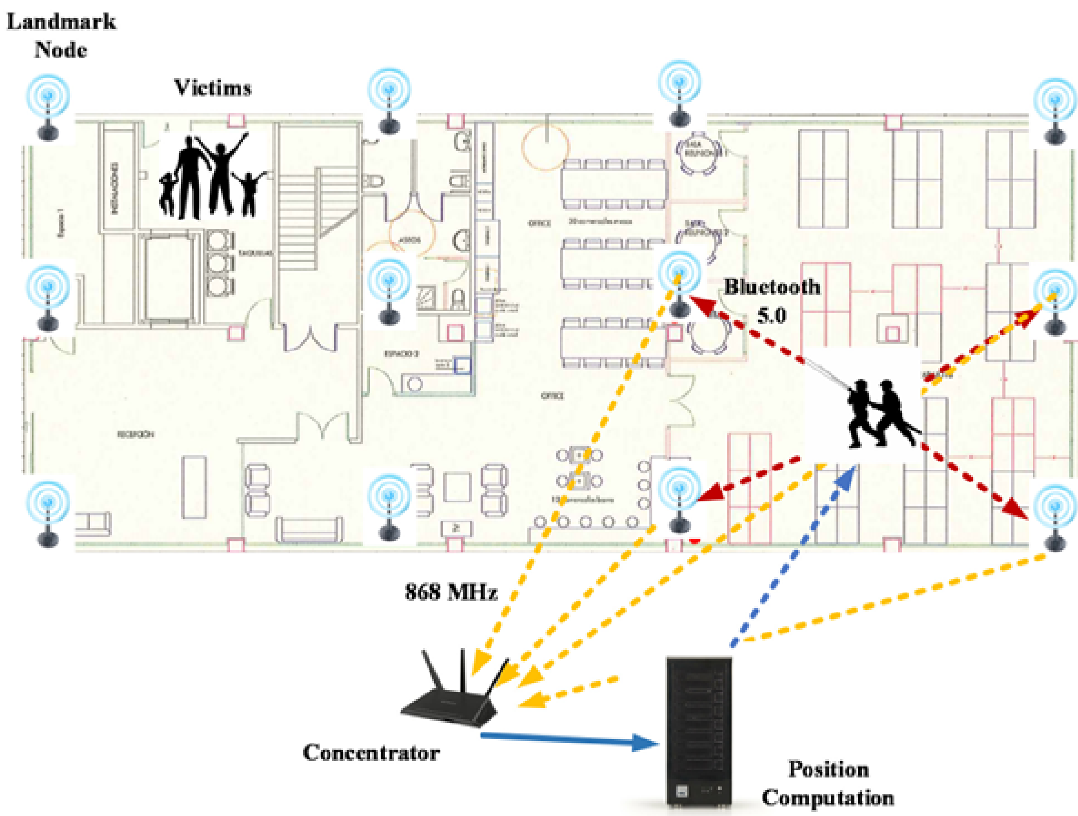


Figure 2.15: The hallmark nodes in part of the construction system are shown on a map of the building. The concentrator and location computing device can be used to aid rescue operations in the case of an emergency.

Rescue workers need to have a Beacon BLE (Bluetooth Low Energy) device with them to be able to track. In their positioning system, each member of the rescue team carries a Beacon device with a humidity and temperature sensor and Bluetooth 5 that sends radio signals. Landmark nodes receive these signals and then send the 868 MHz long-range protocol signal, which is received by the gateway, which sends this information to the central location system. Also, the central system itself needs to always send them the location of other rescue forces and information on existing routes. They have proposed and designed a special fire helmet with their desired specifications, beacon, Bluetooth, temperature and humidity sensor, and smart glasses.

Figure 2.16: A suggested firefighter helmet with an embedded smart see-through AR

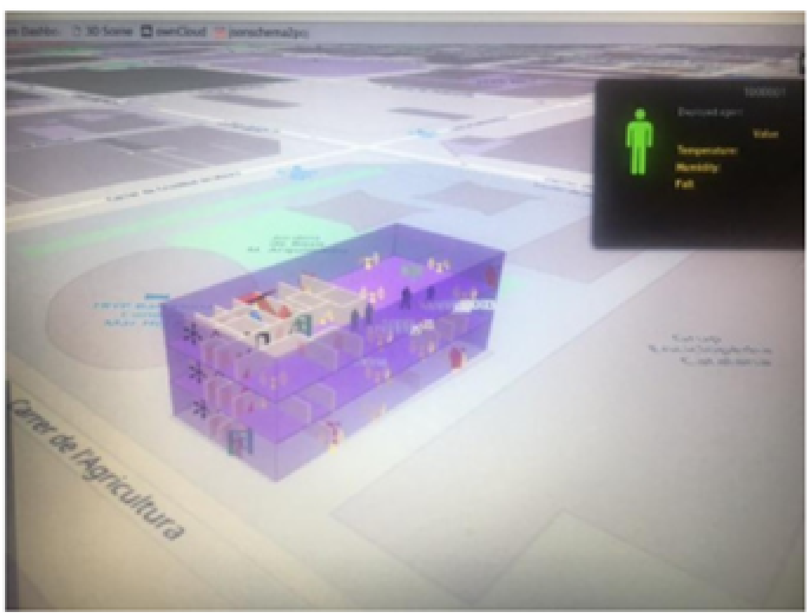


Figure 2.17: A reconstructed building' 3D model

Their considered beacon has a small PCB, each with a unique identifier, that locates the person in real-time. Each rescue member's smart glasses are connected to this beacon and show the member's current temperature and humidity to prevent temperature shocks. Landmark nodes have known coordinates. These nodes can receive Bluetooth signals and send them to the gateway on the 868MHz channel for communication. The values of the RSSI and IDs received from the beacons are obtained in the Landmark nodes, and these nodes also send this information to the gateway and from there to the location server. This data is stored in a database, and every 5 seconds, the program will calculate new RSSI values for each ID and through the triangulates method, the new coordinates of that beacon will be calculated. These new coordinates are stored in another table and communicate with other parts of the system through an MQTT queue. The control management unit is a web interface that connects to the Core Server and is responsible for providing information to the control center located in a truck outside the building. All data generated by agents is visualized in real-time on a web interface.

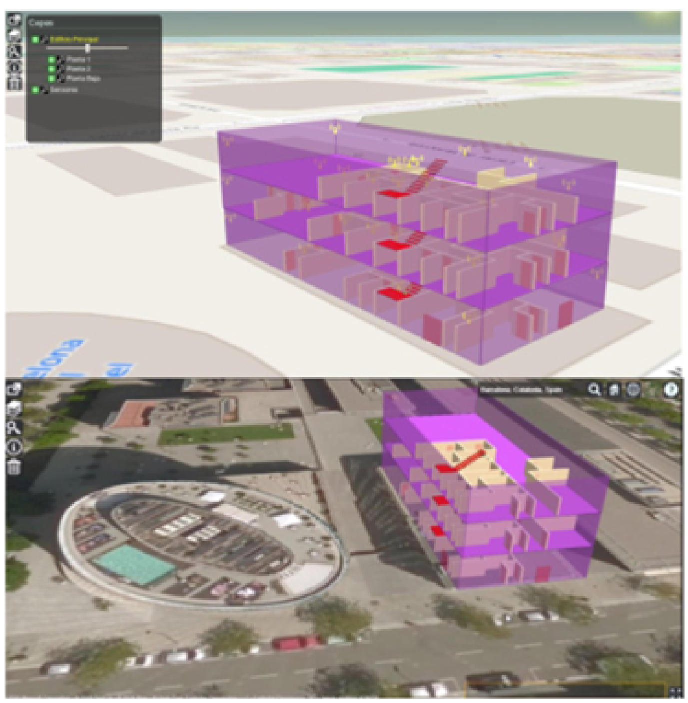
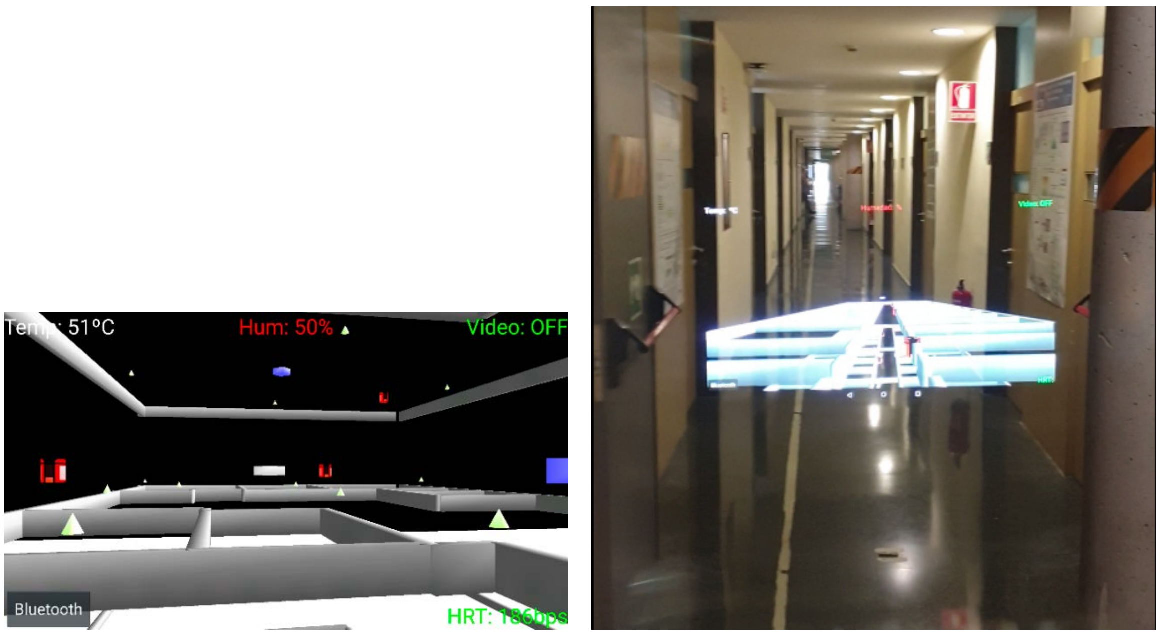


Figure 2.18: The data from the building is visualized using a web interface

The rescuer can carry other wearable Bluetooths, such as a heart rate sensor, and view the information on their smart glasses. In this way, the rescue agent can watch all the necessary information for his operation and avoid possible risks in his smart glasses. Also, the video and voice of the agents can be sent via Wi-Fi and viewed in the management center using their smart glasses. Authors have conducted several tests with virtual and real-world scenarios to test their proposed model.



(a) (b)

Figure 2.19: (a) A 3D immersive scene with various components. (b) The real-world scenario is seen through the smart glasses, with the virtual scenario overlayed.

In their experiment, despite 20 Landmark nodes on two floors, they reached 1.5 meters in positioning accuracy. One of the advantages of this method is the combination of Indoor positioning and AR, which will significantly enhance the speed of rescue operation and reduce possible injuries for rescue team members by displaying real-time environmental information. The use of the 868 MHz channel, a long-range protocol, will also provide access to information over long distances, which is a positive point due to the variety of different environments in transmitting radio signals.Disadvantages of this method include the need to create infrastructure and the almost high cost required for its equipment. Also, using RSSI to locate according to their tests has an accuracy of 1.5 meters, which does not seem to be the best option for rescue operation and emergency cases.

The next research belongs to Campos et al.[21]. In their paper, the researchers presented a mobile application based on a georeferenced system integrated with augmented reality techniques to meet the needs of emergency rescuers. This article and the mobile app are a continuation of the previous prototype prepared by them. In emergencies such as natural disasters, early responders must have clear and appropriate access to environmental information to respond quickly and efficiently. The purpose of their paper has been to develop a mobile application that assists early respondents in their decisions and tasks using augmented reality and information gathered.The mobile application will be integrated with the intelligent systems distributed by the Ministry of Defense and the Navy to facilitate the exchange of information between rescue forces in the event of a natural disaster or rescue operation. This article discusses the development process of this mobile application and how to use augmented reality technology in it. The diagram below illustrates the development process of this mobile application. The cycles in this process are to improve the application's features.

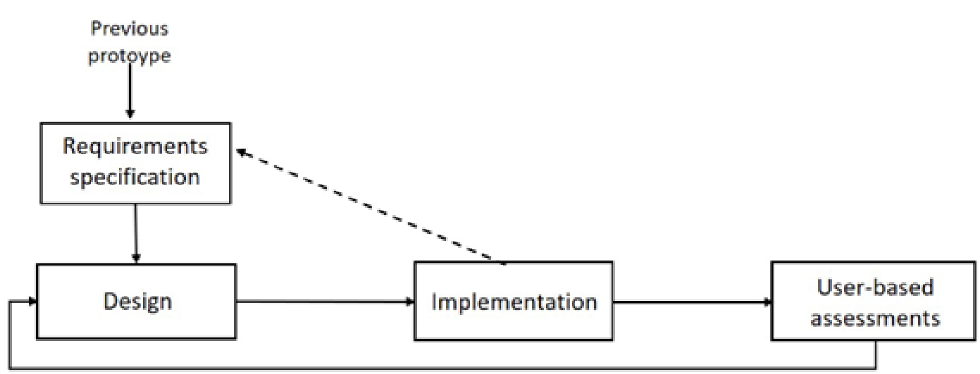


Figure 2.20: The new prototype's development process

This program allows first responders, as a member of a special operations team, to report and access information according to points of interest (POI), and similar to operations command centers or advance medical stations, be able to divide events that occur during an emergency into four categories: Person, Infrastructure, Security, and Hazard. All POIs and events are related to one geographic coordinate. All information about different events (POIs, events and operational teams) is centralized on a server and shared between different teams to better understand the state of the environment. In this program, each object that is displayed represents an event or several events. By selecting any object, the user can view the description of that occurrence. As shown in the diagram above, the Requirements Specification has been adapted in collaboration with Navy representatives to create a project data model and requirements. To represent some events centered at one point in the original prototype, they were displayed at different heights. Their written program runs on the Android operating system and is connected to the remote server via HTTP. The Wikitude SDK is also used to implement augmented reality.

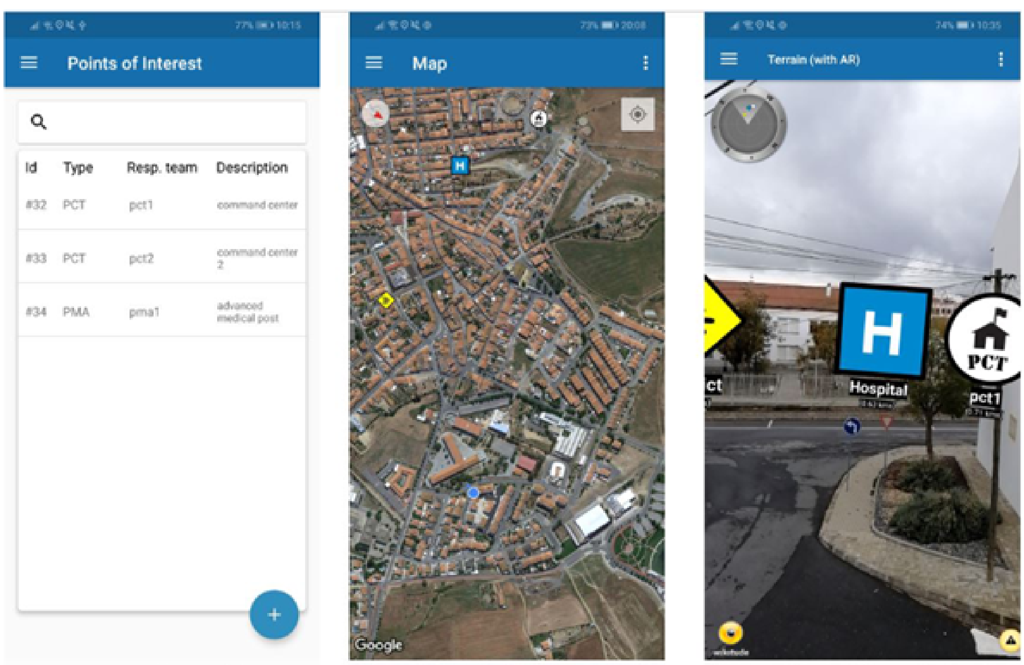


Figure 2.21: Left-Search page & Center-Map view & Right-Augmented Reality view

Figure 2.22: (Top-Cluster of Occurrences & Bottom- Enlarged cluster of occurrences

In the pictures above, the markers are based on georeferenced data, which indicate different points of interest, events, and operational teams. In their final version, common events are displayed as a cluster at one point. In the first image, the events are shown as clusters (cubes) that the user will select and view the events of this cluster in an extended form for 10 seconds.

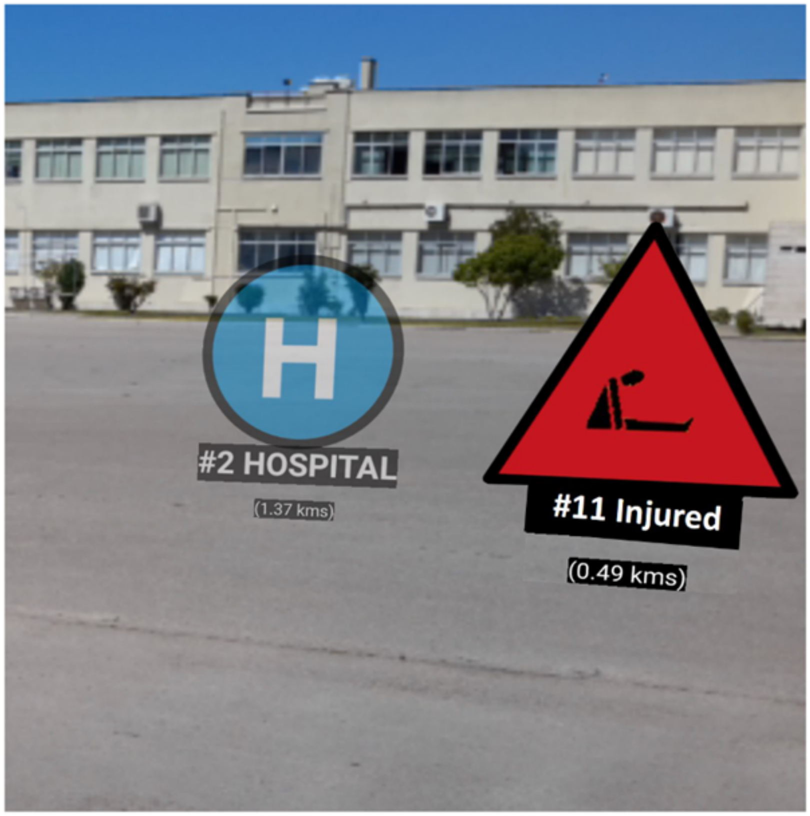


Figure 2.23: Varying opacity values in the AR view

In their application, events that require more immediate action are displayed with greater transparency. The user can click on any event to select it. Clicking on the same event will deselect that event.

Navy members were used to evaluating the proposed program. Various evaluations have been done on this program, and mixed feedback has been taken from the members of the evaluation team. In this article, this feed backs have been evaluated well, and the usefulness of this tool for the rescue operations is claimed. In conclusion, it can be said that One of the advantages of the proposed application is the creation of an integrated infrastructure for rescue operations and emergencies, as well as presenting two different types of views; one n the form of maps and another in AR. But one of its disadvantages is the manual addition of incidents, command centers, and hospital data. Moreover, limiting the types of events to a few static and fixed types. Based on the knowledge acquired in this section, the methods to implement the project objectives will be discussed in the next section.

CHAPTER 3: METHODS

In this chapter, the model proposed by Yin & Lan, which currently applies only to a simple big closed space, will be extended to complex hospital plan and a model with the important variable that will influence the possibility for infection, is proposed. These variables can be adjusted to reflect new epidemiological evidence about the infection potential remaining after a patient is in the space, the spread of the inflection rate in space, and how long and with what virulence does the infection potential remains; furthermore, these variables are subject to the epidemiological data.

3.1 Developing Process

By creating a more realistic infection spread modeling that simulates real-world scenarios,and applying the present dissertation's implemented model, there will be no limit to simulating the spread model in any environment with any plan.

In the first part of the developing process, the desired model will be presented,and in the next part, according to the calculated probable possibility of inflection, the safe short route and the optimized safe route, will be generatedto assist the navigation of susceptible (healthy) people in a hypothetical hospital. All simulations were performed in Unity.

In the first phase of simulations, an attempt was made to implement the simulation performed in the discussed article in Unity. To do this, a grid of squares with sides of 6 meters was considered and this grid forms a simulation environment with a length and width of 100.

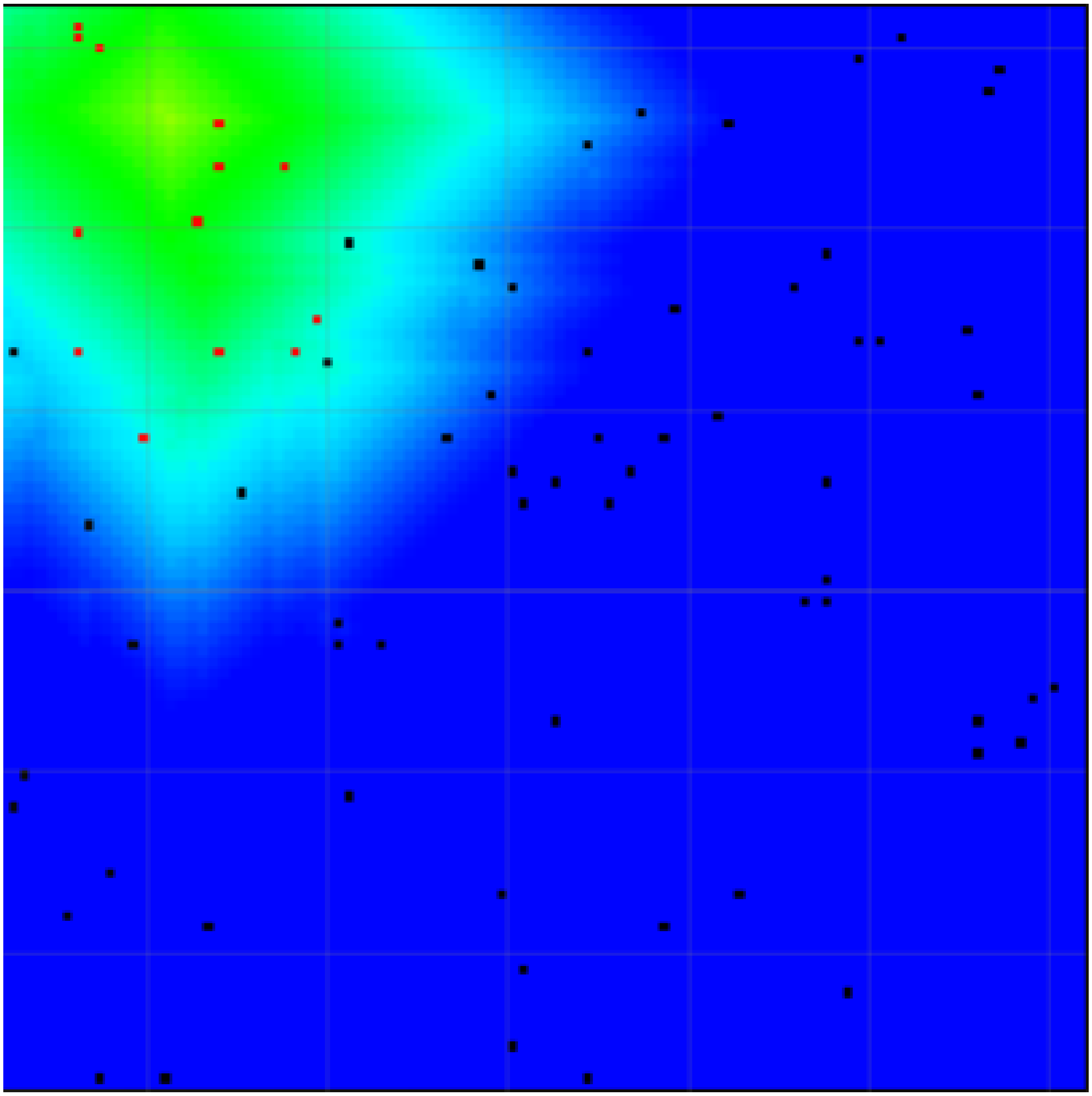


Figure 3.1: Simulation of the model presented by Yan & Lan in the Unity environment

In this simulation, the black dots are susceptible people, and the red dots are infected people. The following image illustrates the state of the environment after 24 days which was initiated with the presence of only one infected person. The movement of people, as mentioned in the article, is done using the Gillespie algorithm. In this way, for each person, four different movement directions (up, down, left, and right) were considered as different reactions with equal probabilities of occurrence. Of course, these probabilities for the edges change in proportion to the possible movements and not exiting the people from the environment. In the simulation, the movements of people are supposed limited and random. It is assumed that people move in a small range or even, most of the time, are stationary. This makes the simulation a bit far from reality. The heat map displayed in the blue to yellow color spectrum illustrates the intensity of contamination anywhere in the environment. In this way, blue indicates the no-contamination, and yellow, the maximum contamination.

To determine the value of contamination at each point, each point is checked once in the contamination spread model in each update. According to the proposed model for spreading the infection, every point where the infected person is located becomes infected based on the rate of virus spread by that person. The infection also spreads to surrounding areas. In fact, in the study of each point, if there is an infected point in the adjacency of the point understudy, a portion of its contamination,is transferred to this point.

According to the model presented in the paper, the spread of contamination in the environment and the possibility of spreading the virus to surrounding points in the grid and carrying the virus by individuals are simulated.

To draw a heat map, a network of nodes consisting of two triangles is used. The offset of the texture points of each point of this grid, according to the severity of the contamination of that point, is an offset of a gradient image between blue and yellow.

Figure 3.2: The Used Texture to render the heat-map

In the second phase, given that one of the contributions of this dissertation is to perform this simulation on an actual building (hospital), a hypothetical map of a hospital was generated by coding. To do this, a matrix with the dimensions of the length and width of a grid (70 by 45) was formed, each element of which was determined with a value of zero or one. This binary value will determine whether or not it is possible to cross that point on the grid. Thus, if an element of this matrix was 0, it means that it would be possible to cross the node corresponding to that element on the hospital plan grid; otherwise, it would not be possible to cross that point (walls or other obstacles and architectural elements). For generating this matrix, the following pseudo-code was implemented.

Algorithm 1 Filling Matrix of plan grid

```
function GeneratePlan(bool [ ][ ] matrix, int width, int height)
    for i ← 1 to width do
        for j ← 1 to height do
            if j > 0 AND j < 20 AND i > 25 AND i < 45 then
                matrix[i][j] ← true
            else
                if i%5 == 0 OR j%5 == 0 then
                    matrix[i][j] ← true
                else
                    matrix[i][j] ← false
                end if
            end if
        end for
    end for
end function
```

Finally, this matrix was used to find the route between the entrance and exit doors using the Dijkstra algorithm. In this way, for the elements with the value of 1 in this matrix, the cost of reaching the desired node will be very high and will not have an additional cost for the nodes corresponding to the elements with value of 0. In this way, the safe short path proposed by the Dijkstra algorithm will be a passable path according to the desired plan.

As illustrated in the Figure below, the gray circles are nodes whose corresponding element in the generated matrix is 0, and the green circles are nodes whose corresponding element in the generated matrix is 1. Furthermore, Orange dots indicate exit doors.

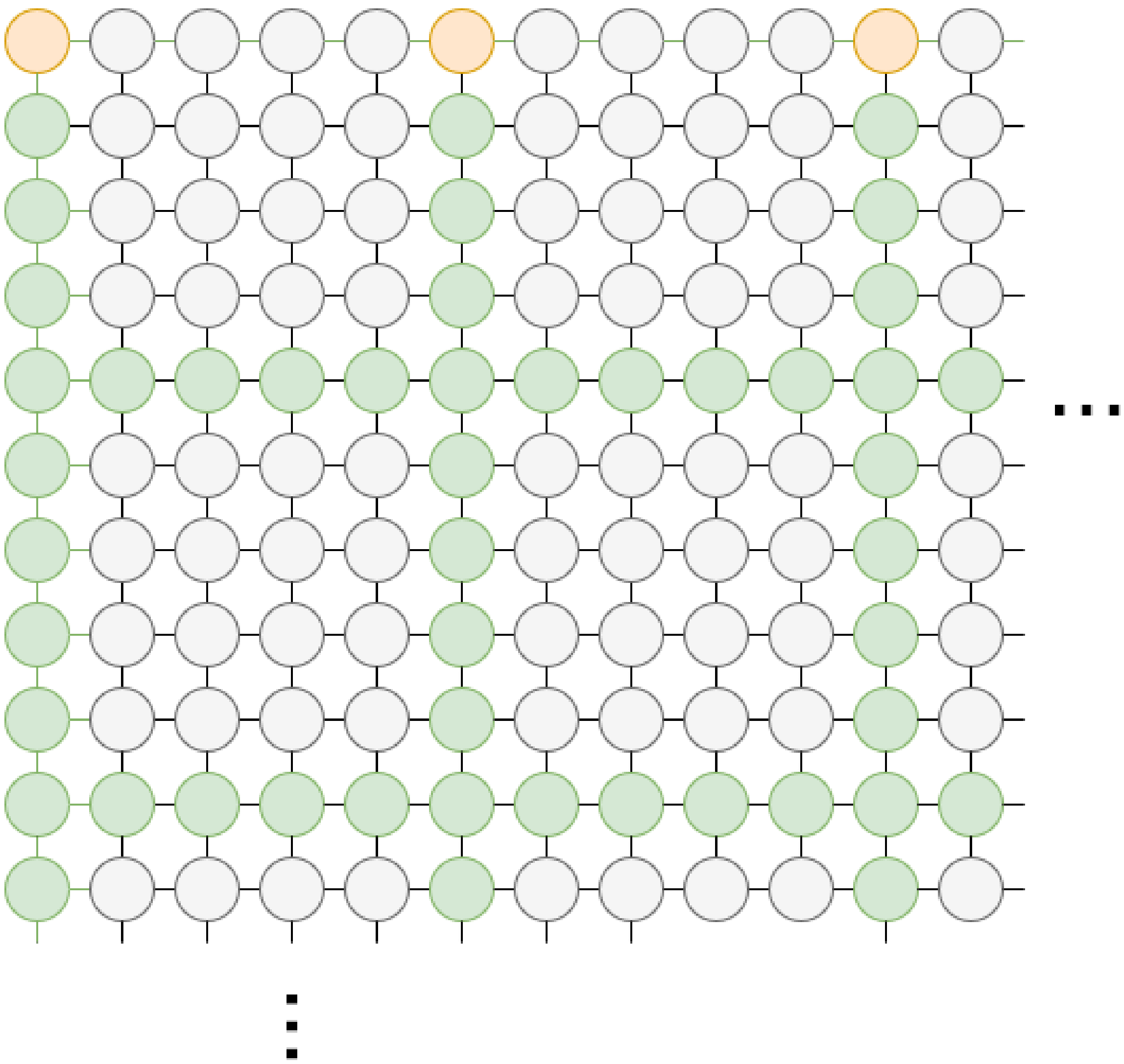


Figure 3.3: The Network of Nodes Constructing the Grid

To use the Dijkstra algorithm in this simulation, the calculation of edge weight for shortest path's each adjacent node pair is equal to the following equation:

$$Weight = (1 - PlanMatrix(x_2, y_2)) * MaxInteger + \sqrt{(x_2, x_1)^2 + (y_2, y_1)^2} \tag{3.1}$$

$MaxInteger$ is equal to the largest possible integer within the defined variable type. The $ContaminationMatrix$ is the equivalent of the COVID-19 contamination distribution matrix in the environment, which, based on the article described in the previous section, values the corresponding element for each point in the environment, which Indicates the intensity of the contamination at that point. Actually, this matrix is the same matrix related to drawing heat-maps which, with the high value of each element, the color of the heat map of that point will also turn yellow.

Based on this weight calculation model, the Dijkstra algorithm does not select paths leading to points where the corresponding element in the matrix of the plan is one because the weight of this type of edge will be infinite.

In this phase, the ends of all vertical corridors are considered as hypothetical exits, and randomly three patients with COVID-19 choose one of the entrance doors and one exit door for their passage.

Routing of these patients is also done using Dijkstra algorithm. In the simulation environment, 20 susceptible individuals were also considered to be present, which by passing infected people according to the model presented in the article, contamination is spread in the environment, and some susceptible people become infected.

Ultimately, after the passage of these three infected individuals,using the Dijkstra algorithm, the safe short path from one non-contaminated entrance and one safe random exit is determined and is illustrated in red in the environment (Figure 3.6). In this simulation, the red dots are infected people, and the green dots are susceptible people. Similar to the previous phase, to illustrate the intensity of the contamination, the gradient spectrum between blue and yellow in the heat-map was considered.

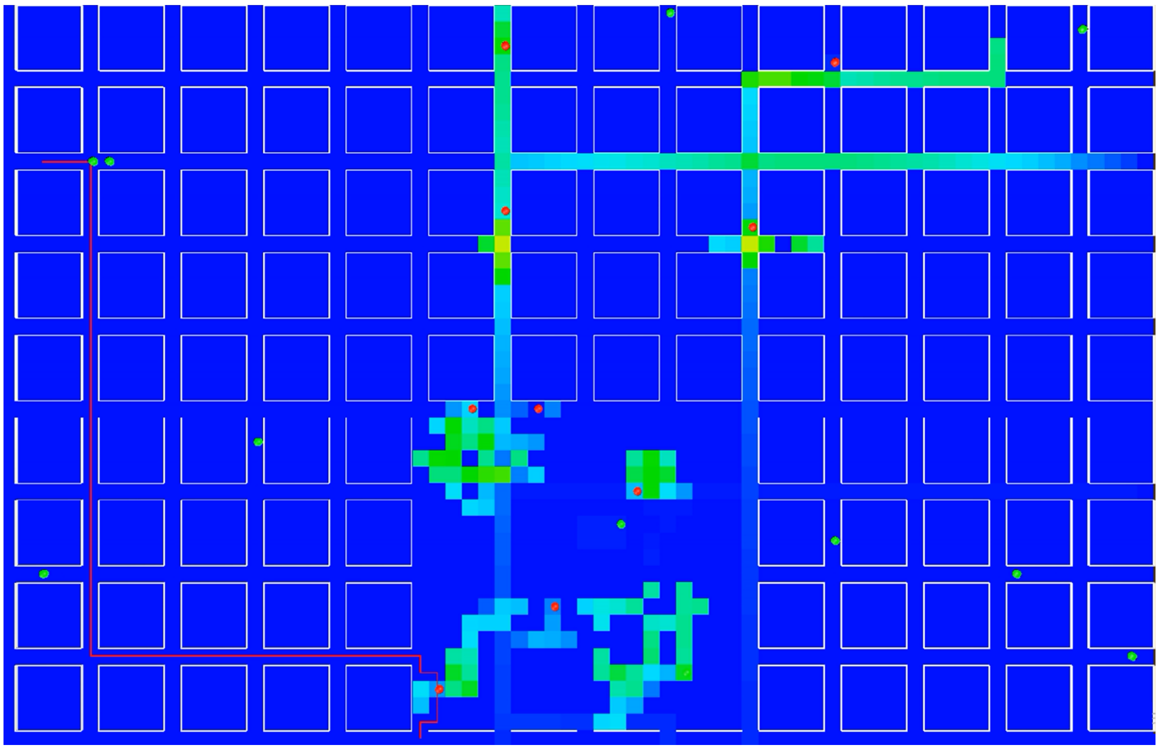


Figure 3.4: Simulations performed on a hypothetical building

In the next phase of the simulation, instead of generating the matrix of the plan, a plan designed by Rhino software was used for the hospital plan.The process of simulation is presented in the following diagram (fig.3.5).

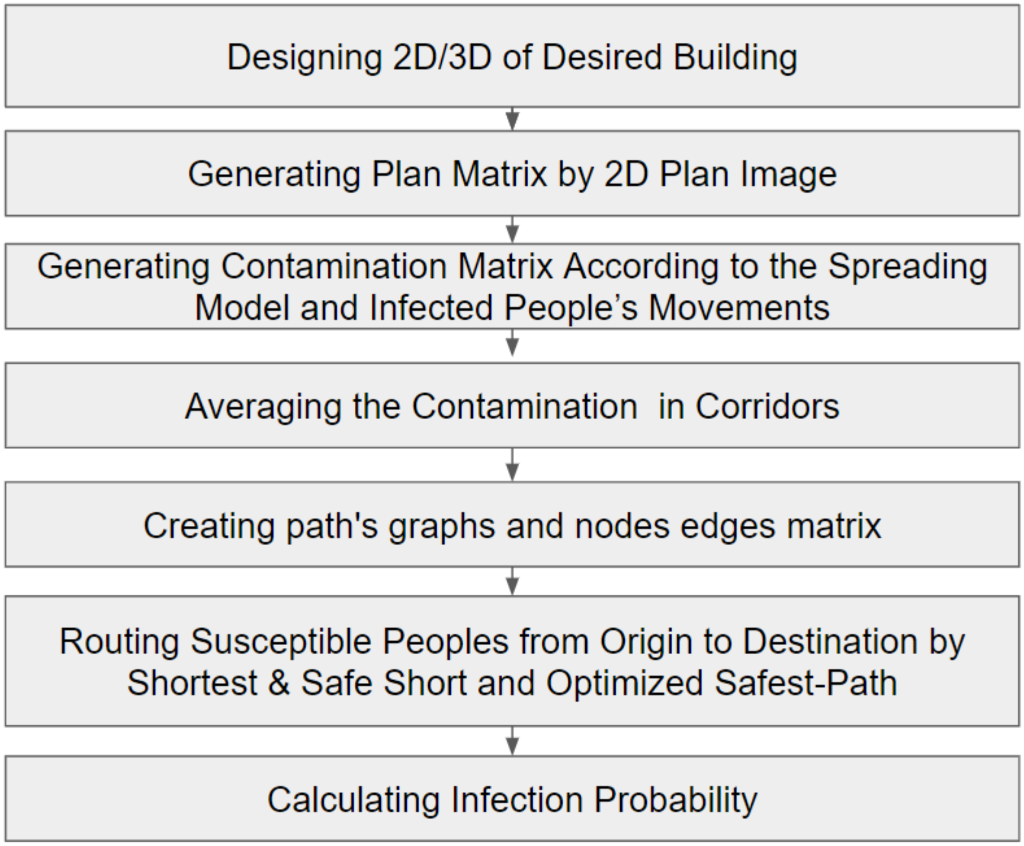


Figure 3.5: Final Simulation Process

In the designed plan, 3 doors were considered for the entrance and 4 for the exit. In this plan, several corridors were considered to create variety in passable routes. A primary 3D model was also created for this plan using Rhino.

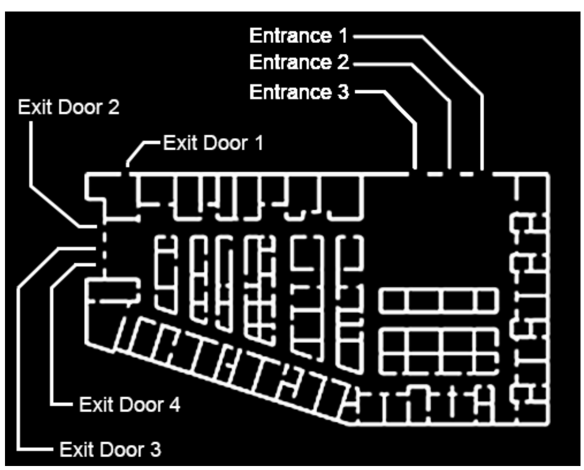


Figure 3.6: Hospital Plan

To create a plan matrix, black-and-white photo output was made from the designed plan. This image was then converted to Binary values of 0 and 1, by the online tool "Image to Binary Converter"[22].

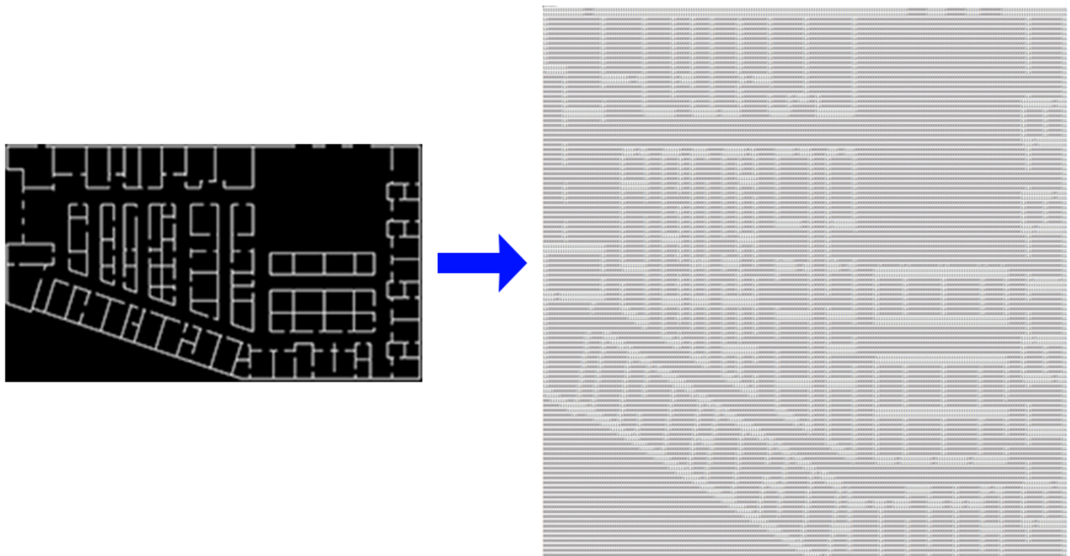


Figure 3.7: Binary Plan

These binary values were stored in a file, and in the program developed for this step's simulation, this file was read and its values were placed in a matrix as a plan matrix. With this matrix, it is possible to find the shortest path between two points. In this simulation, in addition to the safe short route, the optimized safe route was also suggested. Figure3.9 illustrates the optimized safes route in green and the safe short route in black. Dijkstra algorithm was used for both types of routing.

The difference between these two routes is in the equation for calculating the weight of the edges in the Dijkstra Algorithm. To calculate the edge weight of the safe short path, the equation presented in the previous step was applied. But to calculate the edge weight of the optimized safe path, the distance effect was removed from the routing calculation, and instead, an α factor was added to the corresponding element of the contamination matrix, to increase the contamination effect at each point. Because in this type of proposed routing, the length of the route does not matter, and contamination value is the critical factor in determining the route.

$$\begin{aligned} Weight = & (1 - PlanMatrix(x_2, y_2)) * MaxInteger \\ & + ContaminationMatrix(x_2, y_2) \end{aligned} \tag{3.2}$$

And the Weight Calculation model of the safe short path in Dijkstra Algorithm is:

$$\begin{aligned} Weight = & (1 - PlanMatrix(x_2, y_2)) * MaxInteger \\ & + ContaminationMatrix(x_2, y_2) \\ & + \sqrt{(x_2, x_1)^2 + (y_2, y_1)^2} \end{aligned} \tag{3.3}$$

This simulation scenario was that three infected people randomly choose their entrance and exit doors and use the Dijkstra algorithm (only considering the plan matrix and the distance of points as the weight of the edges) to determine their paths. And according to the proposed model for contamination spread, the values of the $ContaminationMatrix$ elements change in corresponding to the path points and contamination spread relationships. Next, the optimized safe route and safe short route between the entrance and exit doors are generated; In this simulation, the susceptible people in the environment whose movements were simulated by the Gillespie algorithm were eliminated because of the high run-time and the narrow corridors that restricted their movement, the contamination were increasing dramatically, which finding a safe route was very unlikely.

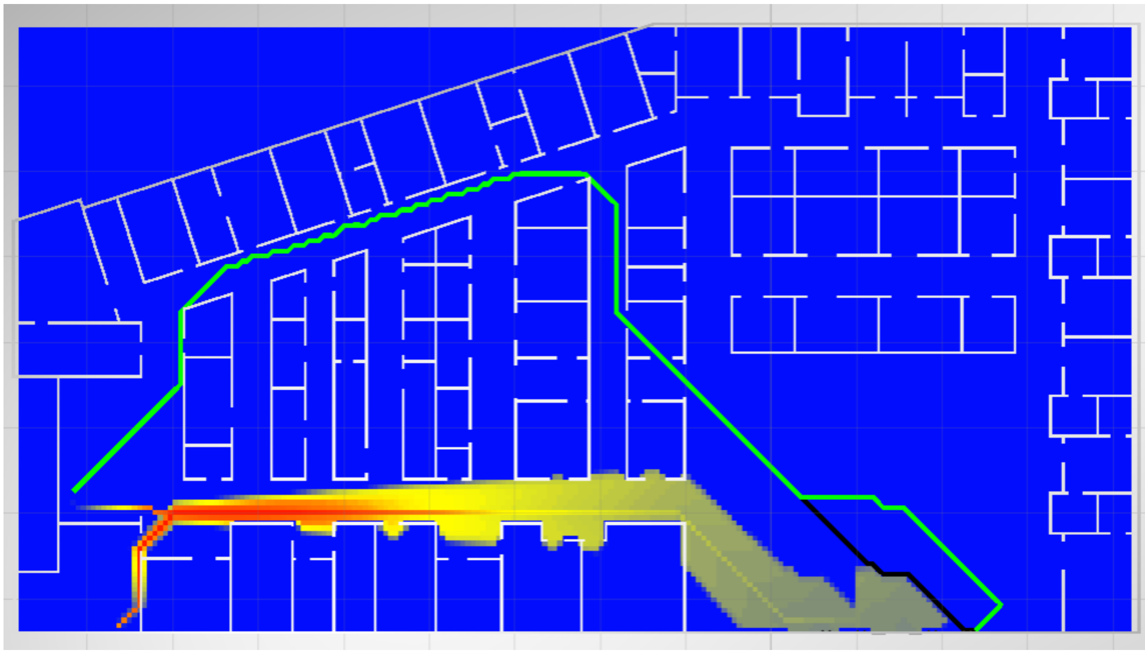


Figure 3.8: Safe Short Route & Optimized Safe Route

In this simulation, because the network of nodes is a grid, and each node is connected to its eight adjacent nodes. The green and black paths that overlap in the upper corridor are zigzagged. The reason for this is that the path from each node to the other node will be a multiplication of an angle of 45 degrees. While the upper corridor has a different angle, the Dijkstra algorithm has to constantly change the angle of the path nodes in this corridor in order to generate the safe short path.In this simulation, the gradient spectrum of the heat-maps was placed between blue and red.

Figure 3.9: Heat-map Gradient

The most significant problem of this simulation was the time-consuming routing by the Dijkstra method due to the very high number of nodes (25606). Because it was assumed that the heat map nodes and the plan graph nodes were the same for the Dijkstra.

To solve this problem in the final simulation, based on the hospital's plan, an optimized graph was designed as a plan graph for being applied in the Dijkstra algorithm. This generated graph was based on corridors, intersections, and passable routes on the plan. There are 33 nodes in the resulting graph, the edges of which show the navigable paths. In Figure 3.10, the blue nodes are the entrance doors, and the red nodes are the exit doors.

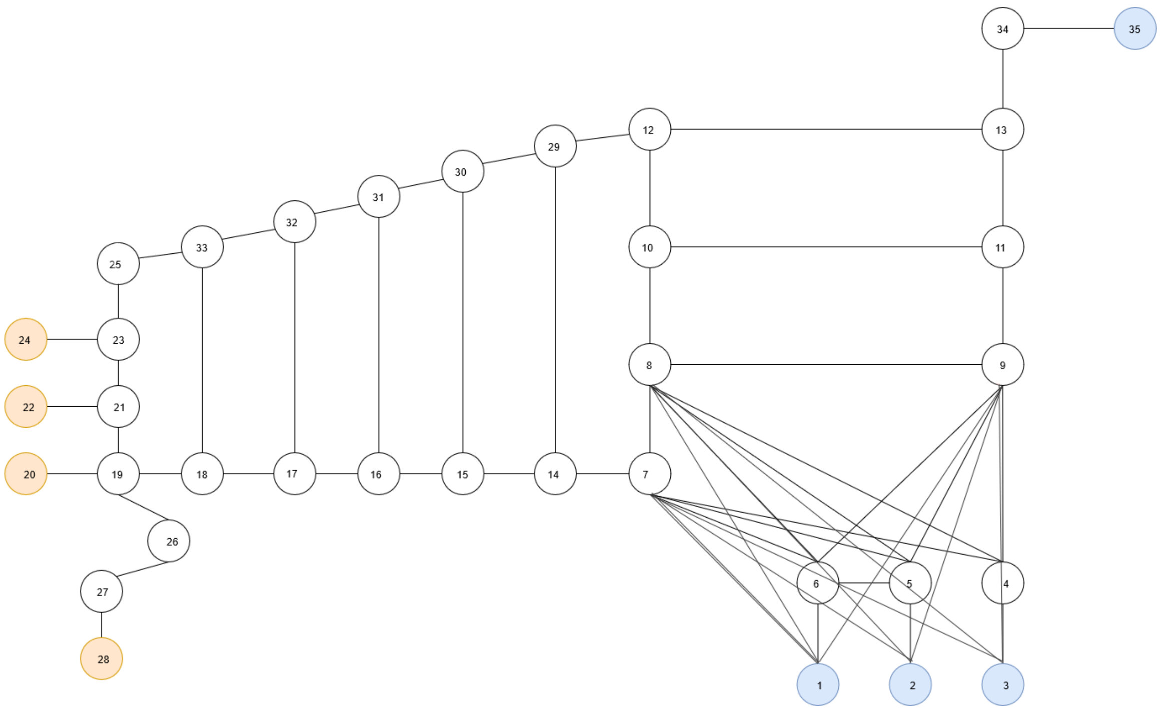


Figure 3.10: Optimized Graph for the Hospital Plan

To apply this graph in the Dijkstra algorithm, a 33 by 33 matrix was designed whose rows and columns are nodes 1 to 33. For each edge between different nodes, the corresponding element of those nodes is considered 1; Otherwise, this element is regarded as 0, which means that there is no edge between the two nodes. The Dijkstra algorithm uses this matrix to detect the adjacent nodes of each node (as mentioned earlier, the Dijkstra algorithm needs to update the set of distances of the neighboring nodes of each node in each step). This matrix is illustrated in Figure 3.11.

	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
1	000001000000000000000000000000000
2	000010000000000000000000000000000
3	000100000000000000000000000000000
4	001010111000000000000000000000000
5	010101111000000000000000000000000
6	100010111000000000000000000000000
7	000111010000010000000000000000000
8	000111101100000000000000000000000
9	000111010010000000000000000000000
10	000000010011000000000000000000000
11	000000001100100000000000000000000
12	000000000100100000000000000010000
13	000000000011000000000000000000000
14	000000100000001000000000000010000
15	000000000000010100000000000001000
16	000000000000001010000000000000100
17	000000000000000101000000000000010
18	000000000000000010100000000000001
19	000000000000000001011000010000000
20	000000000000000000100000000000000
21	000000000000000000100100000000000
22	000000000000000000001000000000000
23	000000000000000000001001100000000
24	000000000000000000000010000000000
25	000000000000000000000010000000001
26	000000000000000000100000001000000
27	000000000000000000000000010100000
28	000000000000000000000000001000000
29	000000000001010000000000000001000
30	000000000000001000000000000010100
31	000000000000000100000000000001010
32	000000000000000010000000000000101
33	000000000000000001000000100000010

Figure 3.11: The Matrix of Plan Graph

Additionally, in the final simulation, after the infected people passed through the environment, each corridor is considered filled up uniformly by the contamination . This is because if part of the corridor is infected with the virus, that corridor will not be reliable and navigable. To consider this, after the passage of infected people, the value of contamination in any part of the corridor was considered the average of the contamination in the entire corridor.

To perform the averaging operation, it was first necessary to identify the nodes inside each corridor. To do this, a rectangle of a specific color was drawn for each passable corridor on the hospital plan image. This image was then converted to a text file using an online tool [23] in which the number assigned to it was placed for each color. Finally, in the written code, each number is correspond to a separate corridor space, and the average contamination values of the nodes corresponding to those numbers were calculated.

Figure 3.12: Corridors Detection Matrix

Need to be mentioned that in the simulations, the plan view in Unity was considered to export 2D PNG images of the performed simulations. To present the final simulations, the significant variables and their values on the left side of the image of the simulation was listed. These variables are discussed and tested further in the Result and Findings section. In addition to this change, in the final simulation, the path taken by each infected person is generated as lines with a range of purple colors in the plan, and blue was considered for the safe short path, but green is still applied for the optimized safe route. Another improvement in this simulation is the smooth line of the proposed routes (unlike the previous simulation, where the routing lines were zigzagged in the corridors) and also faster routing. This is because there are fewer nodes in the graph used in Dijkstra.

A color spectrum ranging from yellow to red was used for the gradient of the final simulation heat-map. Red indicates the areas with the high values of contamination and yellow with the low values. An essential change of this gradient compared to previous simulations is that its first column is transparent. This makes the heat map clear and unobtrusive in places where there is no contamination yet (unlike previous simulations where non-contaminated areas were displayed in blue).

Figure 3.13: Final Heat-Map Gradient

As was explained, The change in the edge weight calculation between two adjacent nodes will change the routing strategy. The values of the contamination matrix, which are calculated according to the proposed model for the spread of the virus, are shown as a heat map in the following image. It should be noted that in this simulation, two infected people entered through two different doors, and one of them exited from the exit door, and the other entered one of the rooms.

So in this illustration, three routes are generated, green is the optimized safe path that just considers safety, the blue line is the safe short path, which considers contamination and distance, and the shortest path considers just distance.

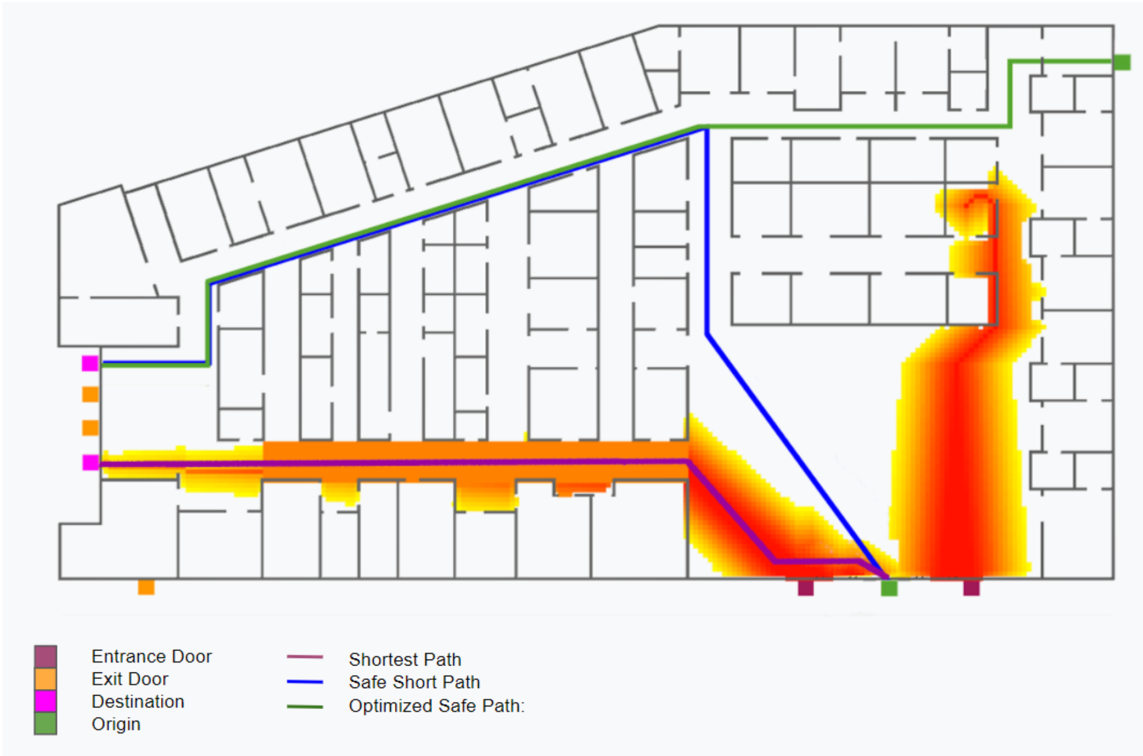


Figure 3.14: Shortest, Safe Short & Optimized Safe Routs'

3.1.1 Variables

In this dissertation, to evaluate the results and performance of the proposed method, several input and output variables are considered. Input variables have a direct impact on the results and output variables.

- **The number of infected people:** One of the essential variables in modeling the contamination spread in a hospital is the number of patients infected by the COVID-19. by entering into the hospital; they spread the virus in the environment.

- **Speed:** Speed is another variable that is considered for the modeling. Below is a table that shows the speed of different types of patients in a hospital.

- **Stop time:** stop times of the patients is another variable that was considered in the simulations. Like a real-life scenario, the infected people probably do not leave the environment directly after they entered it and passed through it, and may stop somewhere along the path. These stops are effective on the contamination value in the infected people's standing spot and as a result the contamination of the environment.

- **The rate of virus spread from one point to the surrounding:** Some of the contamination from each point in the space is transmitted to the surrounding areas and contaminates the surrounding environment

- **Decay rate:** This variable indicates how long the virus lasts in the environment.

In addition to these factors, which are based on the model of virus spread, there is another category of variables that are based on the specific location one studies with the model. These factors are:

- **The layout and size of the building plan:** Building plans will also have an important impact on the model of virus spread and routing in the environment. How the building is designed and the layout of design elements will play an important role in safe and short routing. In the open space(like a lobby), it is possible for people to pass by the contaminated area, but in a narrow space, if a person enters this space, even if there is no contamination at first, and there would be some amount of contamination along the way. because there is no way to pass It by, the person will most likely get infected, so routing for these two types of space is considered differently in this dissertation.This will be discussed further in the next chapter.

- **The number of nodes on the graph:** Another important variable in this category is the number of nodes on the graph intended for the Dijkstra routing matrix.The number of nodes determines the accuracy and detail of the routing.

- **The number and the locations of the entrance and exit doors:** The doors are the access and entrance to the building. It is the point from which individuals, including infected and uninfected, enter the building, so the infection of the infected people can be transmitted to the susceptible people. The same is for the exit doors.

- **The number of corridors and their intersections:** It should be noted that contamination of even a part of a corridor affects the probability of a susceptible person becoming infected by crossing that corridor.

  The number of intersections affects the ability to select and redirect between corridors. Finally, considering that the contamination value at each relative node is considered and based on this ratio, the color of each node is determined. This ratio itself, and in fact, the maximum contamination value calculated for each node, will affect the color of the heat-map.

  The variables discussed so far were input variables. In this simulation, there are an output variable that is directly affected by the input variables, and the final conclusion of the simulation is based on its values.

- **The infection probability (The probability percentage of getting infection):** One of the output variables is the probability of infecting a susceptible person by crossing the suggested shortest, safe short or optimized safes routes. This variable depends on the all the input variables.

- **Shortest, safe short & optimized safe routs' length:** The lengths of the shortest,safe short or the optimized safe paths are other outputs of the model Which are generated according to the amount of contamination in different places and fast routing.

  The following formula was defined to obtain this infection probability:

$$n_v = \sum_{i=0}^{m} \left(\left(\frac{L}{V} \right) \times P_t\,(i) \times \gamma_b \times \gamma_c \right)$$

$$InfectionProbability = \frac{n_v}{InfectionThreshold} \times 100 \tag{3.4}$$

In this formula, L is the path length of the shortest, safe short or optimized safe path that is offered. V is the speed of movement of an individual, which is considered 1.38 meters per second as default. Pt (i) is the amount of contamination at the point i. γ_b and γ_c the infection rate and the rate of viral attack on the body, respectively, (which were introduced in the Yin& Lan's article). Finally, by the division of obtained n_v, which is the total amount of contamination in the proposed path by contamination threshold [9], the percentage of contamination can be obtained.

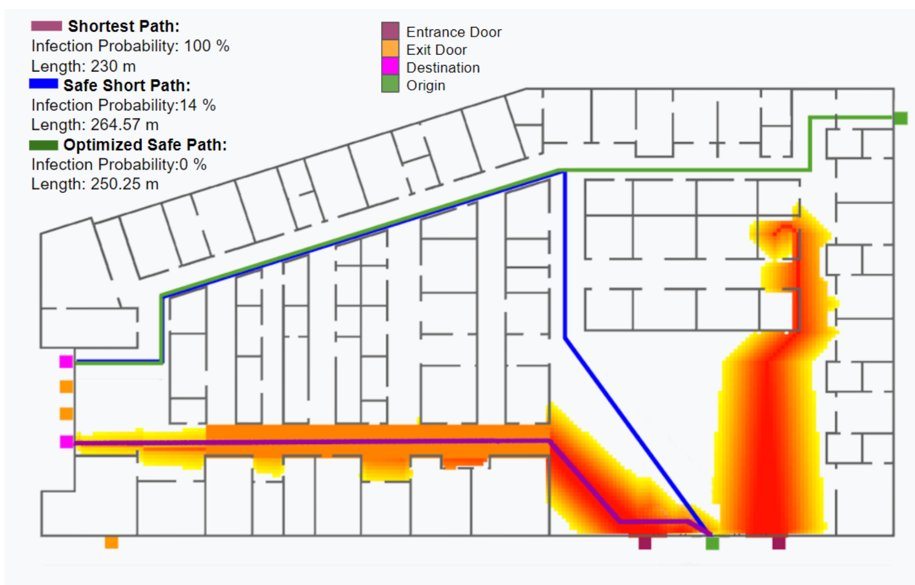


Figure 3.15: The Shortest, Safe Short & Optimized Safe Routs' Infection Probabilities

The defined input and output variables and their types and Categories are summarized in the below table

Table 3.1: The types and categories of variables that influence the possibility for infection

Variable	Type	Category
Number of Infected People	Input	Virus Spread Model –Based
Speed	Input	Virus Spread Model –Based
Stop Time & Numbers	Input	Virus Spread Model –Based
Rate of Virus Spread	Input	Virus Spread Model –Based
Decay Rate	Input	Virus Spread Model –Based
Layout and Size of the Building Plan	Input	Location–Based
Number of Nodes on the Graph	Input	LocationBased
Number and the Locations of the Entrance and Exit Doors	Input	Location_Based
Number of Corridors and Their Intersections	Input	Location –Based
Infection Probability	Output	–
Shortest, Safe Short & Optimized Safe Routs' Length	Output	–

CHAPTER 4: RESULTS & FINDINGS

The methods explained in the previous chapter will be tested and analyzed in this chapter. Some selected independent variables in two categories one based on the virus spread model and another based on the location of the studding the model and the results of each change on the output variables will be examined. Input variables include the number of paths taken by infected people,decay rate, the number of entrance and exit doors in the building, the location of entrance and exit doors, and the number of corridors. The output variables will also include the lengths and the contamination probabilities of passing through the Shortest, safe short and optimized safe paths.

Needs to be mentioned, If the contamination probability of passing through the safe short path is less than 10 %, it would be an optimized safe path too. Also, if the contamination probability differences of the optimized safe path and short safe path are less than 10%, the optimized safe path will not generated.

In the following, based on the goals of the thesis, the effect of each of the input variables on the results and output variables will be discussed.

4.1 Variables Base on the Virus Spread Model

4.1.1 The number of Infected Patients' Paths

Indeed, a person who is a carrier or infected with the COVID-19 virus, bypassing through any closed space, causes contamination in that environment. In this part of the review of the simulation results, the effect of the number of routes traveled by patients on the contamination probability of the hypothetical hospital will be analyzed.

In the figure 4.1, two patients enter the building, one enters a room and the other exits in front of the corridor. The two patients used two of the left entrances to enter. In this way, the third door remains uninfected and safe. According to the implemented method, the safe short path starts at this door and ends at a safe and uninfected exit door. Since the probability of becoming infected as a person passing through the safe short path will be zero, there will no longer be a need to suggest an optimized safe path, this route will not be generated. In the figure 4.1 , the movement paths of infected people, and in the figure 4.21 the shortest, safe short paths are illustrated. Given that it is still found in safe entrances and exits and safe corridors in the building, it can be assured that the person will cross the proposed route both quickly and away from contamination.

As the shortest route passed through the contaminated areas, the contamination probability is 100%. In contrast, the safe short route, which considers both the shortness of the route and the level of contamination, has zero infection probability. So is a safe path to take.

Figure 4.1: The simulation of virus spread by two infected patients to investigate the effect of the number of infected patients' paths on the infection probability in a hospital

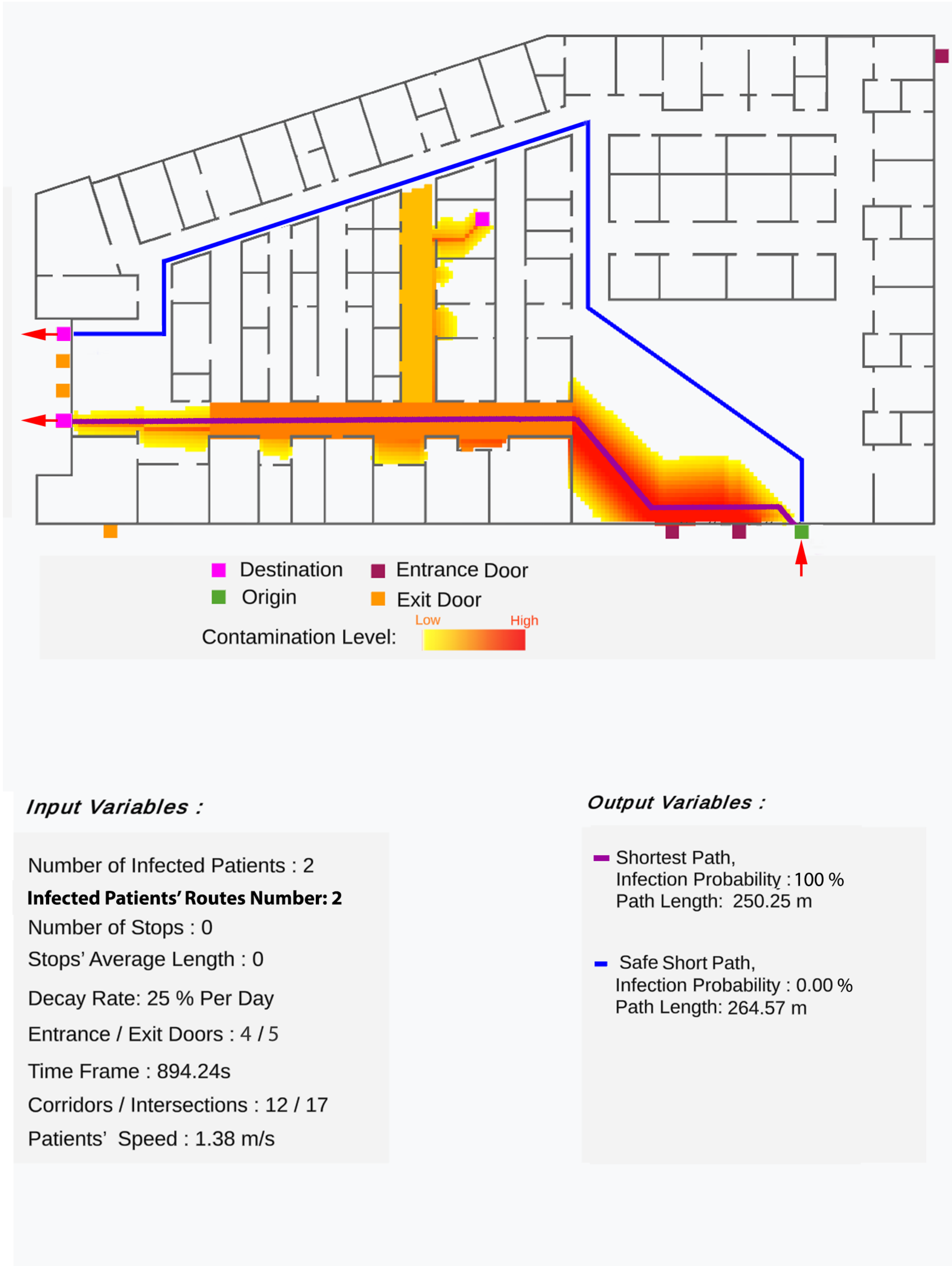


Figure 4.2: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

In the following simulation, the entry of 2 infected patients in the main entrance of the hospital has made these doors infected and unsafe. The shortest path has the contamination probability of 100% and the safe short path 14.45 %. As the infection probability of short path is more than 10 % , the optimized safe path is generated from the back door; In such a situation that the main doors are contaminated, if there are side doors, they can be used, like the one on the upper left side of the hypothetical hospital in the figure. This simulation proves that in addition to the main doors, it is better to consider several side doors in the design of hospital buildings so that if the main doors are not usable in terms of contamination, the side doors can be used. Furthermore, having patients traveled in different directions and areas, more spaces of the hospital have been contaminated and fewer choices have remained for the safe entrance and navigation for the susceptible people.

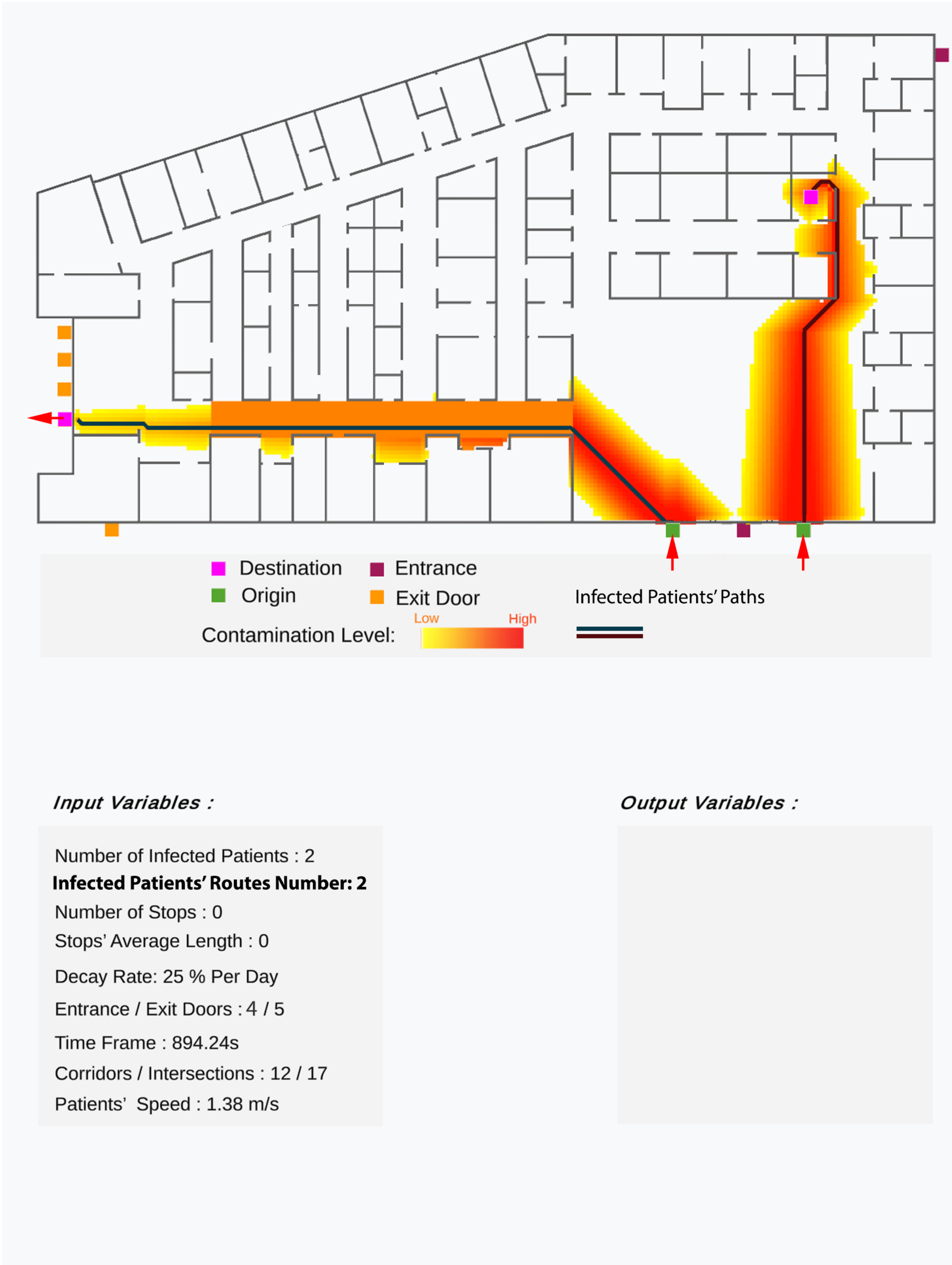


Figure 4.3: The simulation of virus spread by two infected patients to investigate the effect of the number of infected patients' paths on the infection probability in a hospital

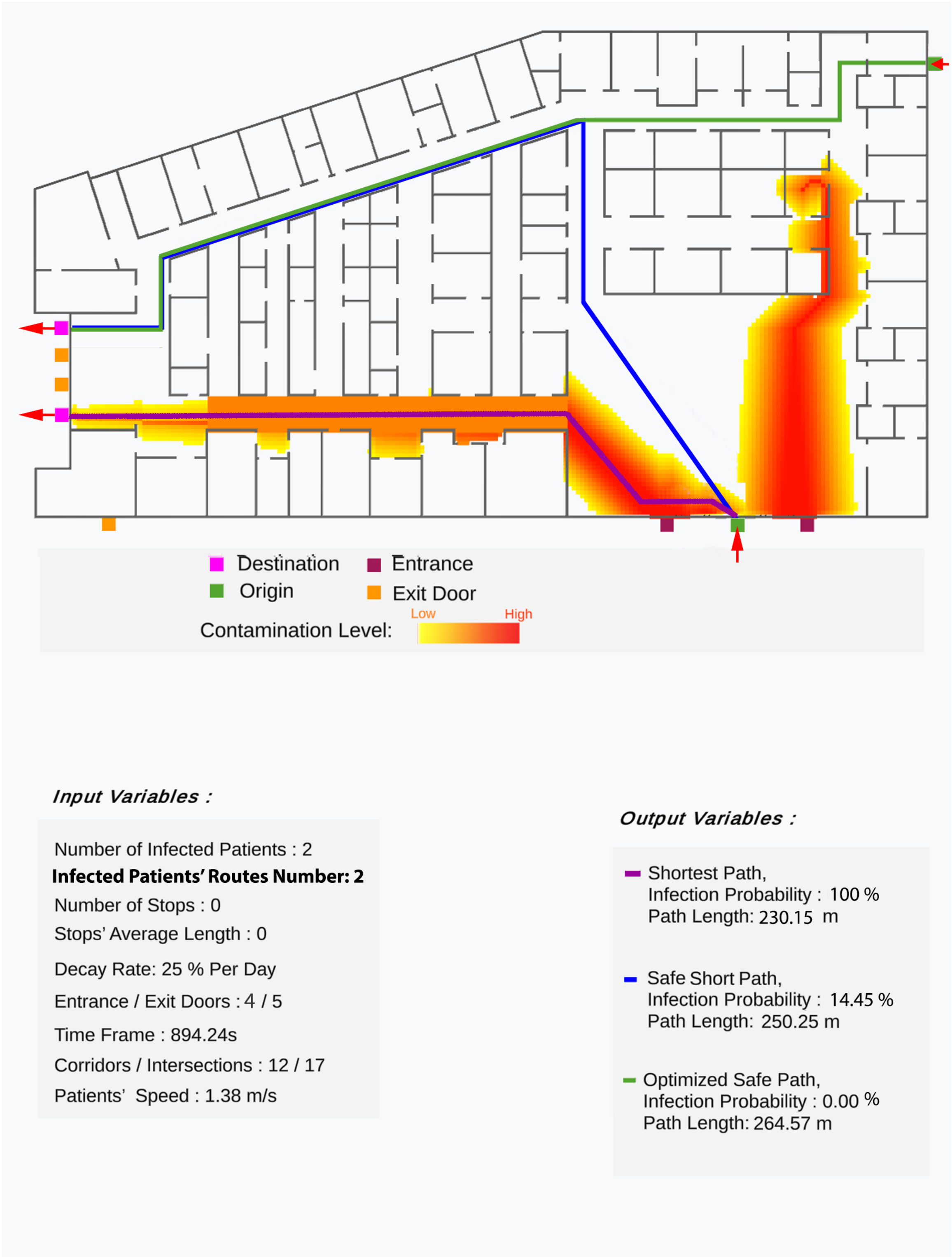


Figure 4.4: The illustration of the generated shortest, safe short, and optimized safe paths and their lengths and infection probabilities

In the following simulation, three infected people enter the hospital, with the difference that that they choose only one corridor to cross. As a result, two other main doors will remain safe and uncontaminated. Furthermore, because all three have taken one corridor to path through to their destination, other corridors have remained uninfected. This simulation demonstrates well that restricting the entry of people who have tested positive for the disease into a limited number of entrances and a limited number of corridors to cross, as well as focusing all the parts needed for these patients to restricted areas of a hospital, can keep the rest of its spaces safe and uncontaminated.

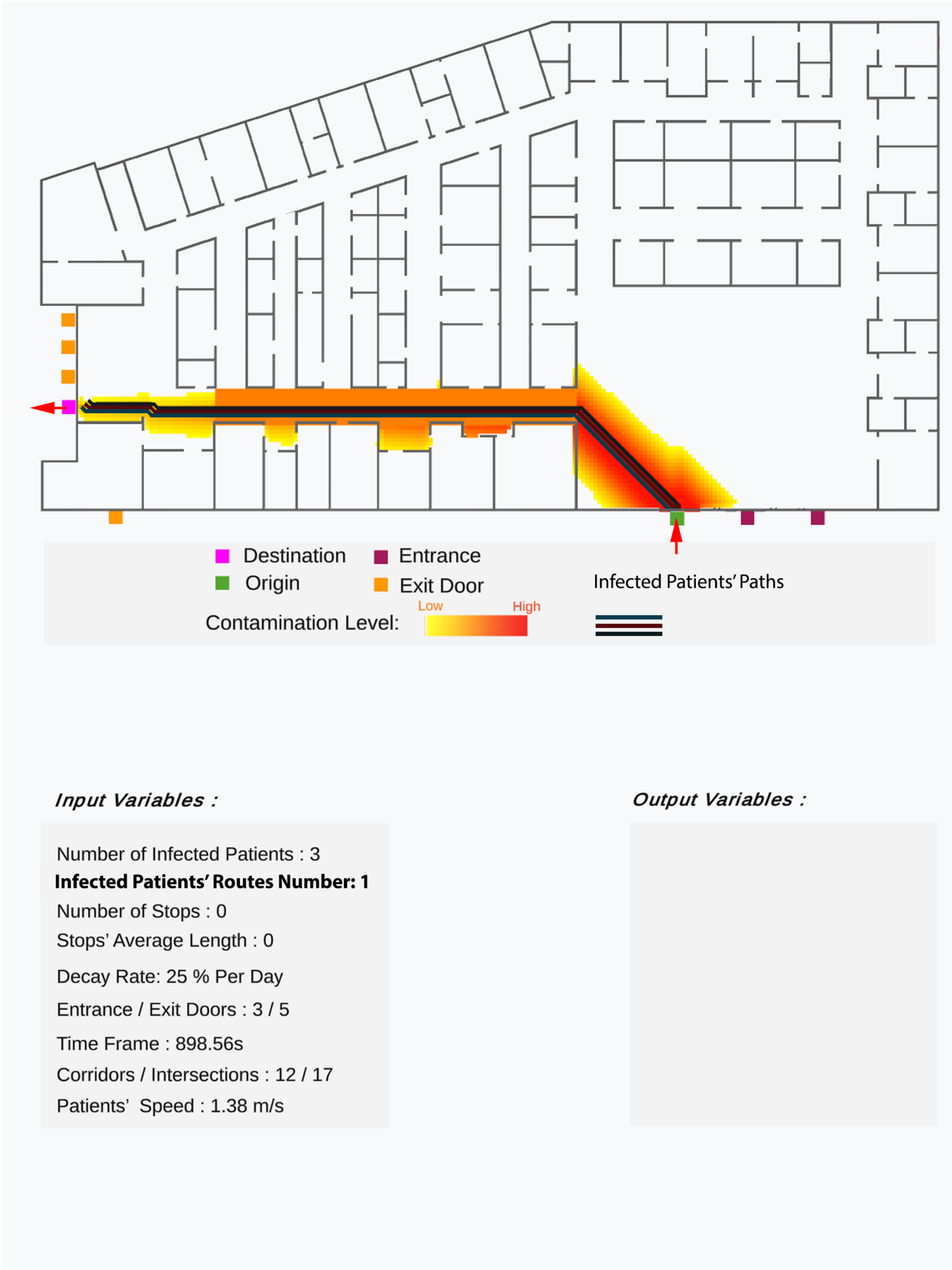


Figure 4.5: The simulation of virus spread by three infected patients to investigate the effect of the number of Infected Patients' Paths on the infection probability in a hospital

Figure 4.6: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

According to the simulations performed to examine the variability of the routes traveled by patients, it can be concluded that the diversity of the patients' path would increase the risk of infection of susceptible people and causes more contamination in the hospital environment. The best possible way, as shown in Figure 4.5, is to allocate a specific corridors of the hospital for the passage of infected people. The rooms in this corridor can also be administered to these patients. In this way, other corridors will remain uncontaminated and safe and can be used by other uninfected people. This experiment demonstrates that infected people's unlimited navigation in the whole hospital could cause more contamination spread, affecting the whole people who enter the hospital. Access limitation for the infected people to a specific and small part of a hospital could help to keep the rest of the spaces safe and uninfected. Moreover, demonstrating the spread of contamination from different routes taken by infected patients can help hospital administrators make better decisions to reduce the amount of contamination, such as restricting patients to a small part of the hospital, or allocating a specific entrance or exit for infected people.

4.1.2 Decay Rate

According to the proposed model for the spread of Covid-19 contamination in the environment [9], Decay Rate determines the rate of destruction of viruses in the environment per day. The higher this value, the faster Covid-19 contamination is removed from the environment. Different experiments have shown that the lifespan of the virus varies on different materials that they lands on. According to various tests, Coronavirus lasts 24 hours on cardboard, 72 hours on steel and plastic, and 4 hours on copper. As a result, the Decay Rate is directly related to the type of materials used in the interior of buildings. Thus by choosing suitable materials for the hospital interior design, it is possible to increase the rate of Coronovirus eradication.

In the simulations performed for this variable, with 2 rates of 25% and 60%, changes in the amount of virus in the environment during 3 days were investigated. Heat maps obtained with different decay rates and the passage of days showed a reduction in the infection probability.

In the first series of simulations, the Decay Rate is assumed to be 25%, and the contamination is simulated for 3 consecutive days. As illustrated in the simulations, on the first day, the infection probability of an individual who chooses the shortest path will be 100% due to the passage of the infected person of the same path and the low Decay Rate. This value drops to 65% and 25% in the second and third days, respectively, over time and decreases the amount of virus in the environment. These simulations indicate the importance of proper material to counteract the spread of infection through different surfaces.

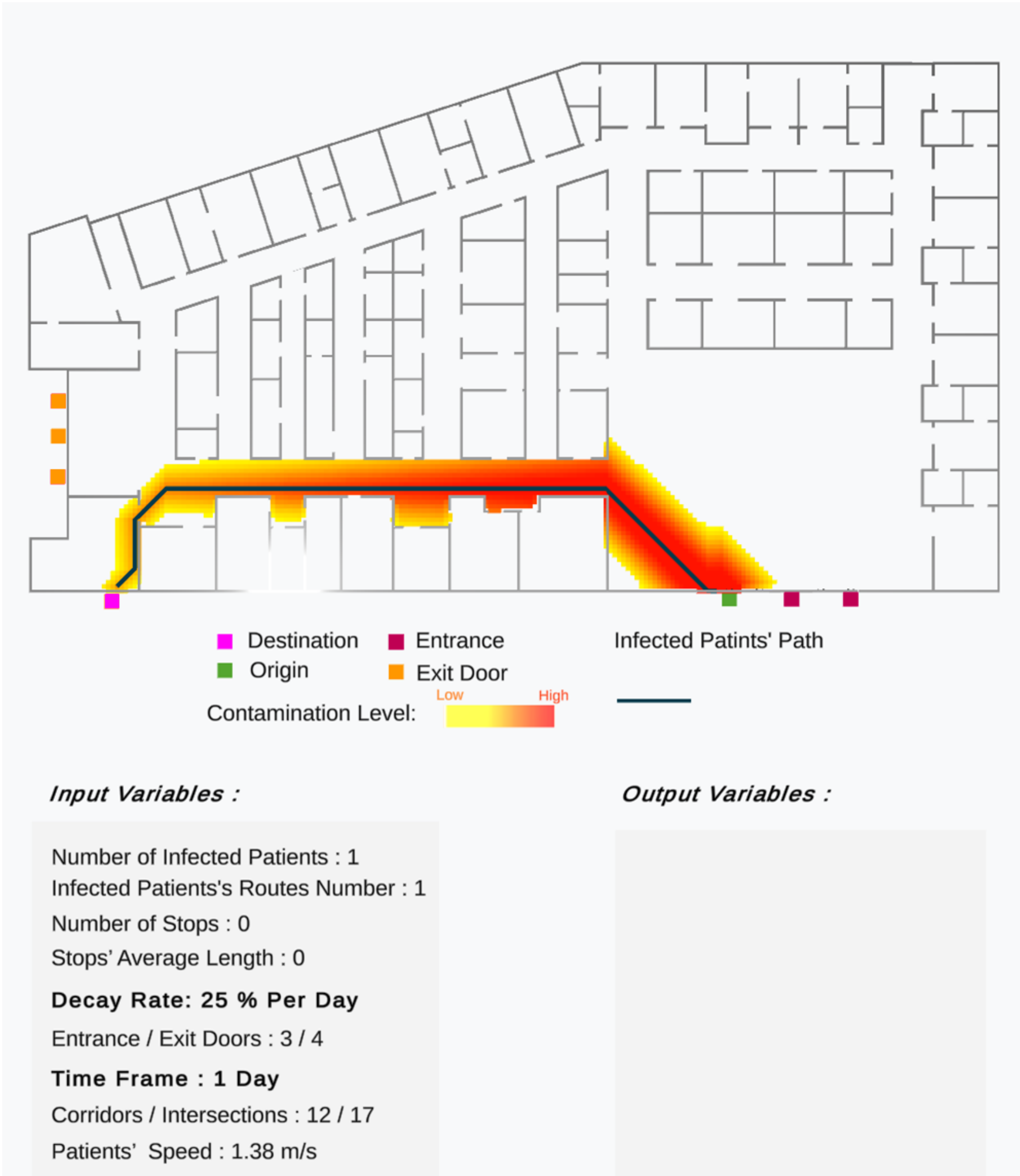


Figure 4.7: The simulation of virus spread by an infected patients to investigate the effect of the 25% decay rate of Coronavirus the on the infection probability in a hospital, on the first day

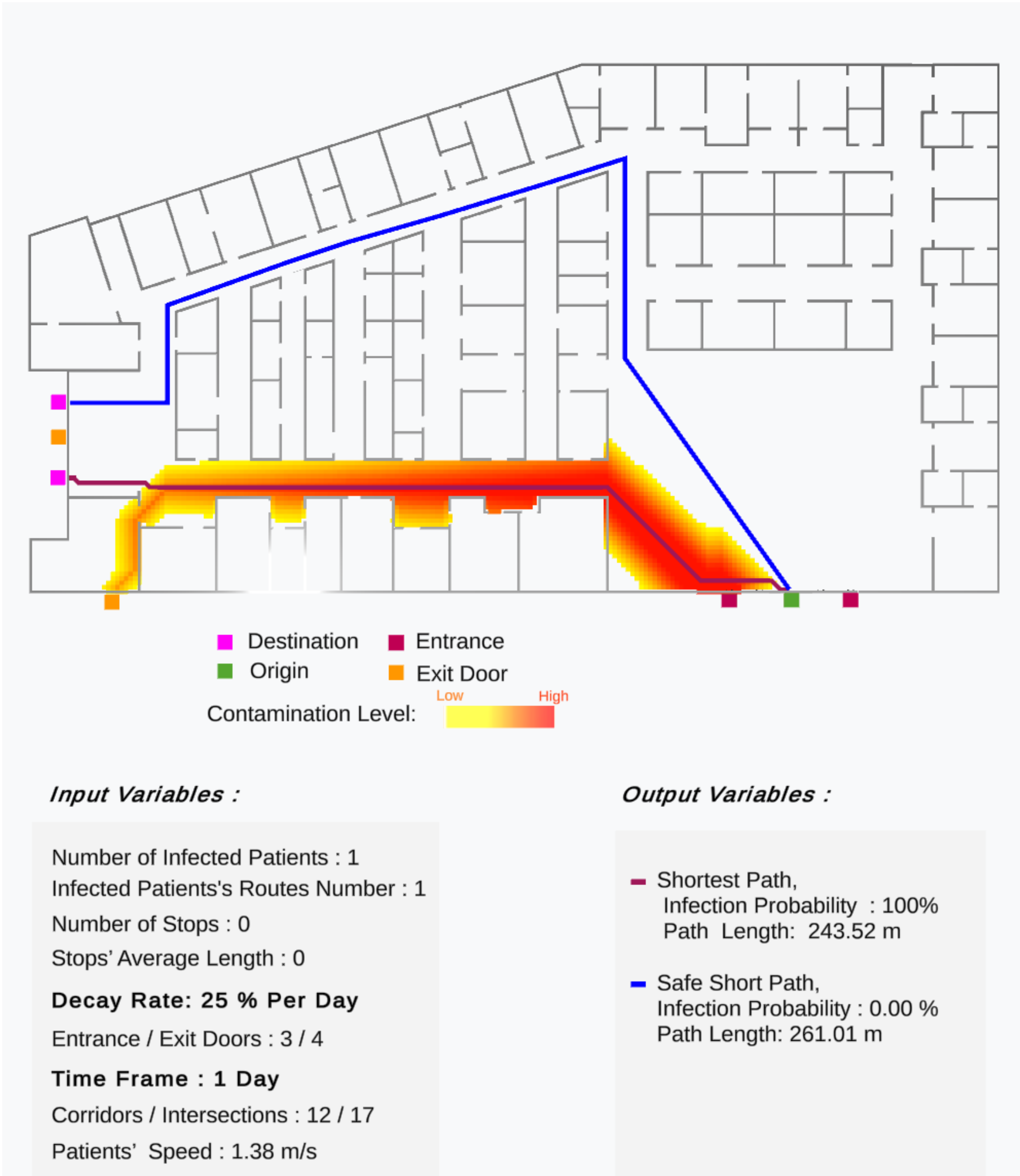


Figure 4.8: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

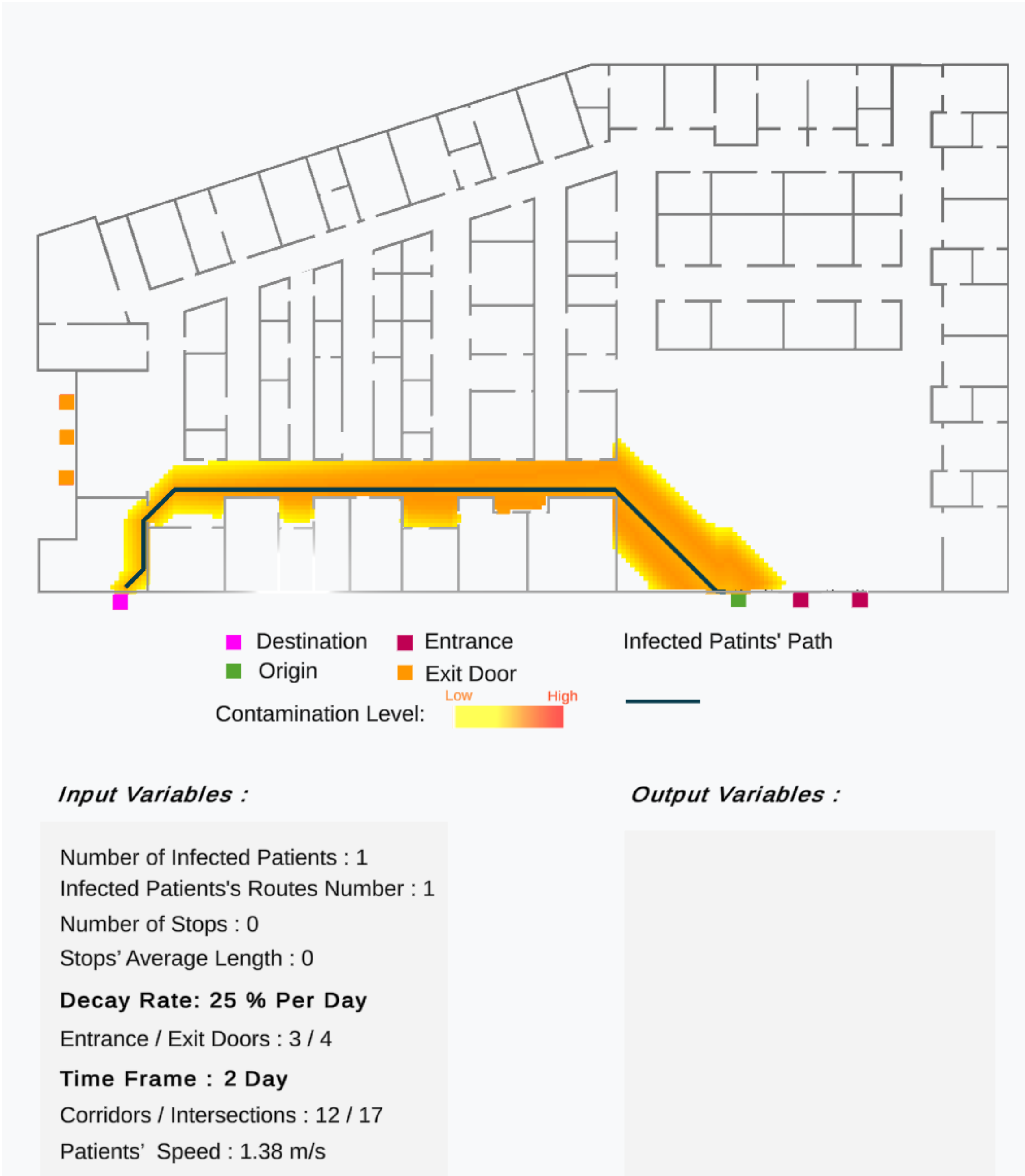


Figure 4.9: The simulation of virus spread by an infected patients to investigate the effect of the 25% decay rate of Coronavirus on the infection probability in a hospital, on the second day

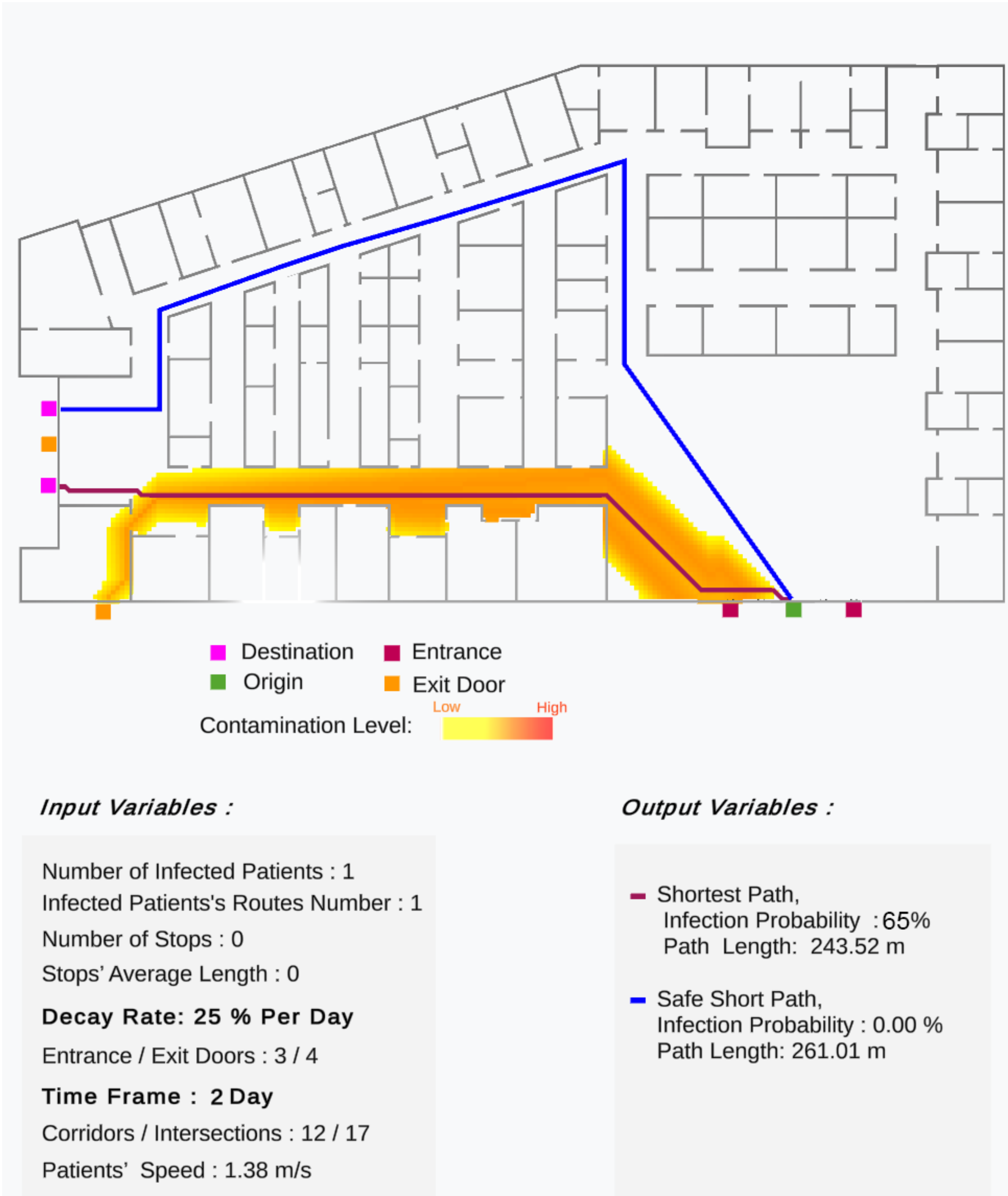


Figure 4.10: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

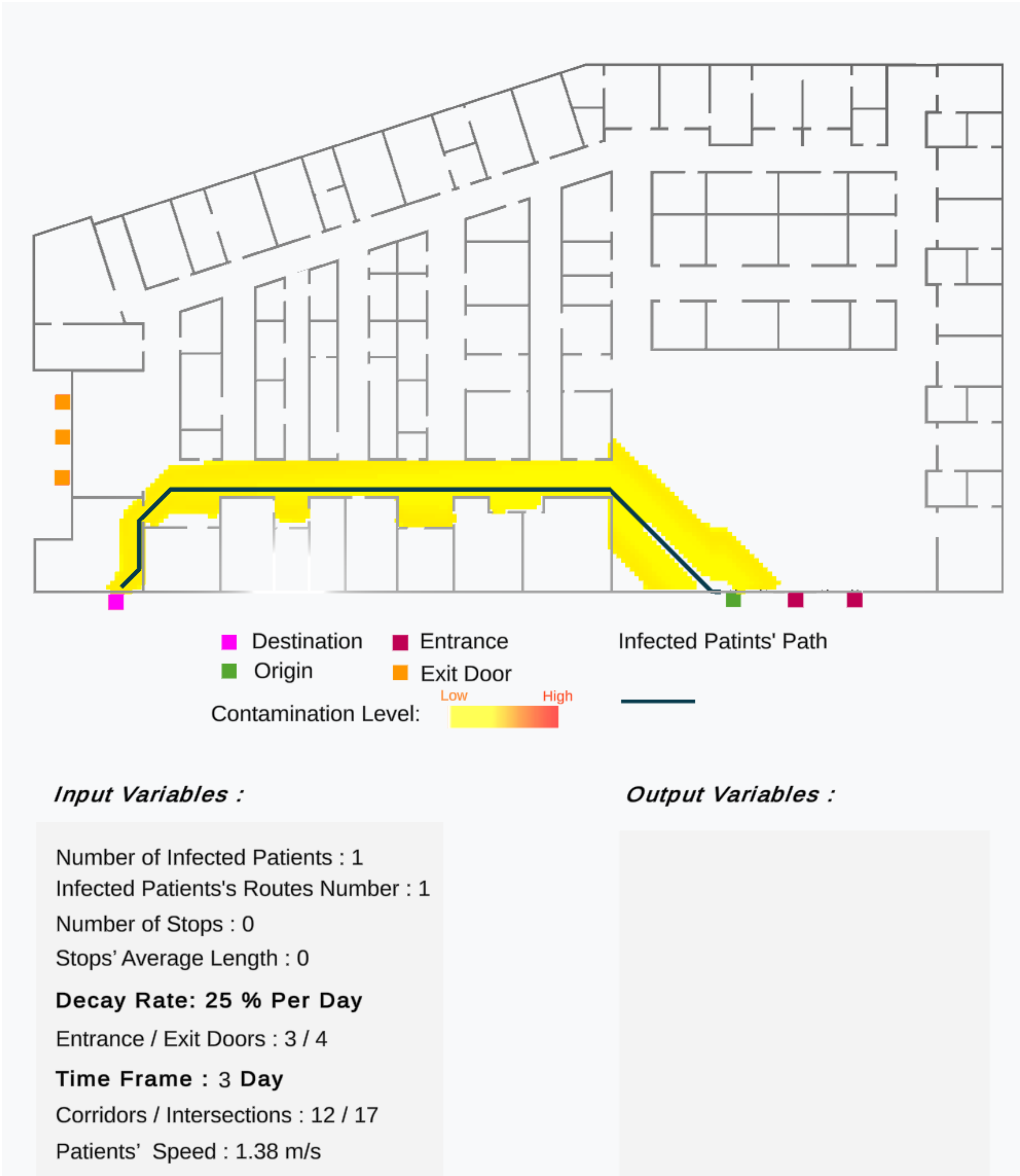


Figure 4.11: The simulation of virus spread by an infected patients to investigate the effect of the 25% decay rate of Coronavirus on the infection probability in a hospital, on the third day

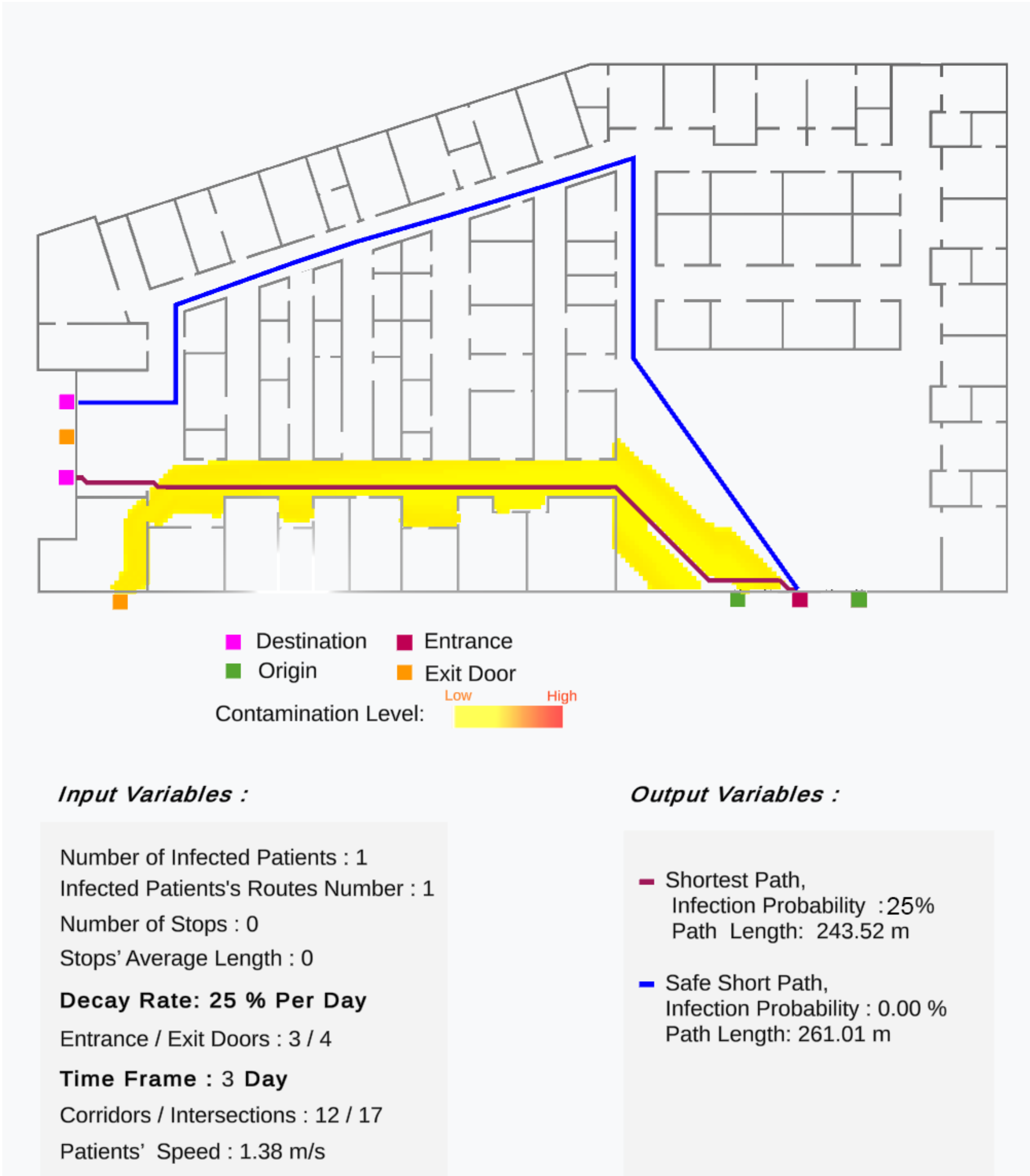


Figure 4.12: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

In the second series of simulations, the Decay rate was assumed to be 60%. Thus, on the first day, the individual crossing the shortest path, which is similar to the route taken by the infected person (because both paths are generated based on the shortest path of the Dijkstra algorithm), was equal to 87%. Over time, the probability of infection reached 53% on the second day and 13% on the third day. Thus, on the third day, the hospital will be in good condition. These changes in the decay process of the virus indicate the importance of the material used in the interior. Also, by selecting the appropriate ventilation system the Decay Rate can be increased.

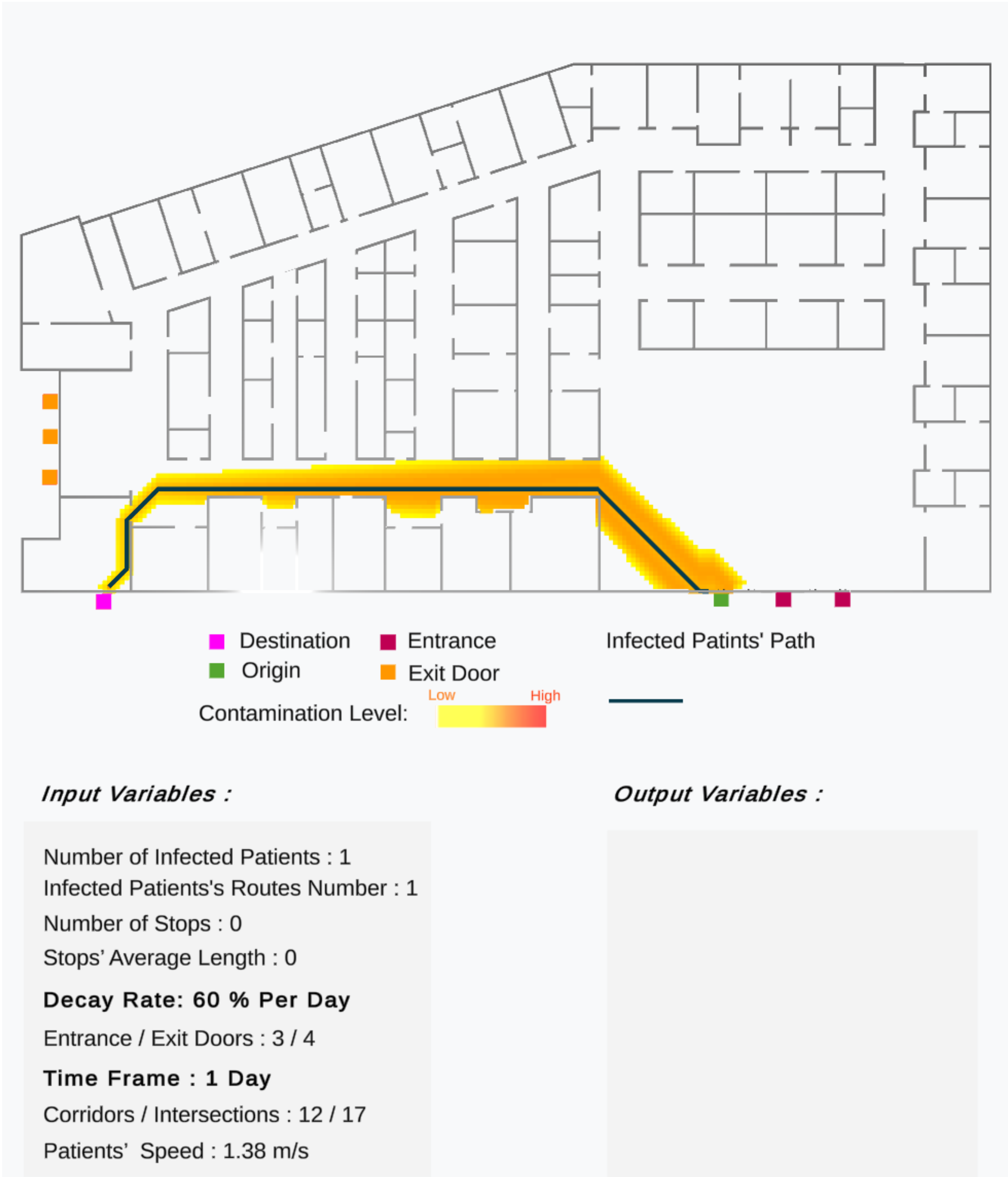


Figure 4.13: The simulation of virus spread by an infected patients to investigate the effect of the 60% decay rate of Coronavirus the on the infection probability in a hospital, on the first day

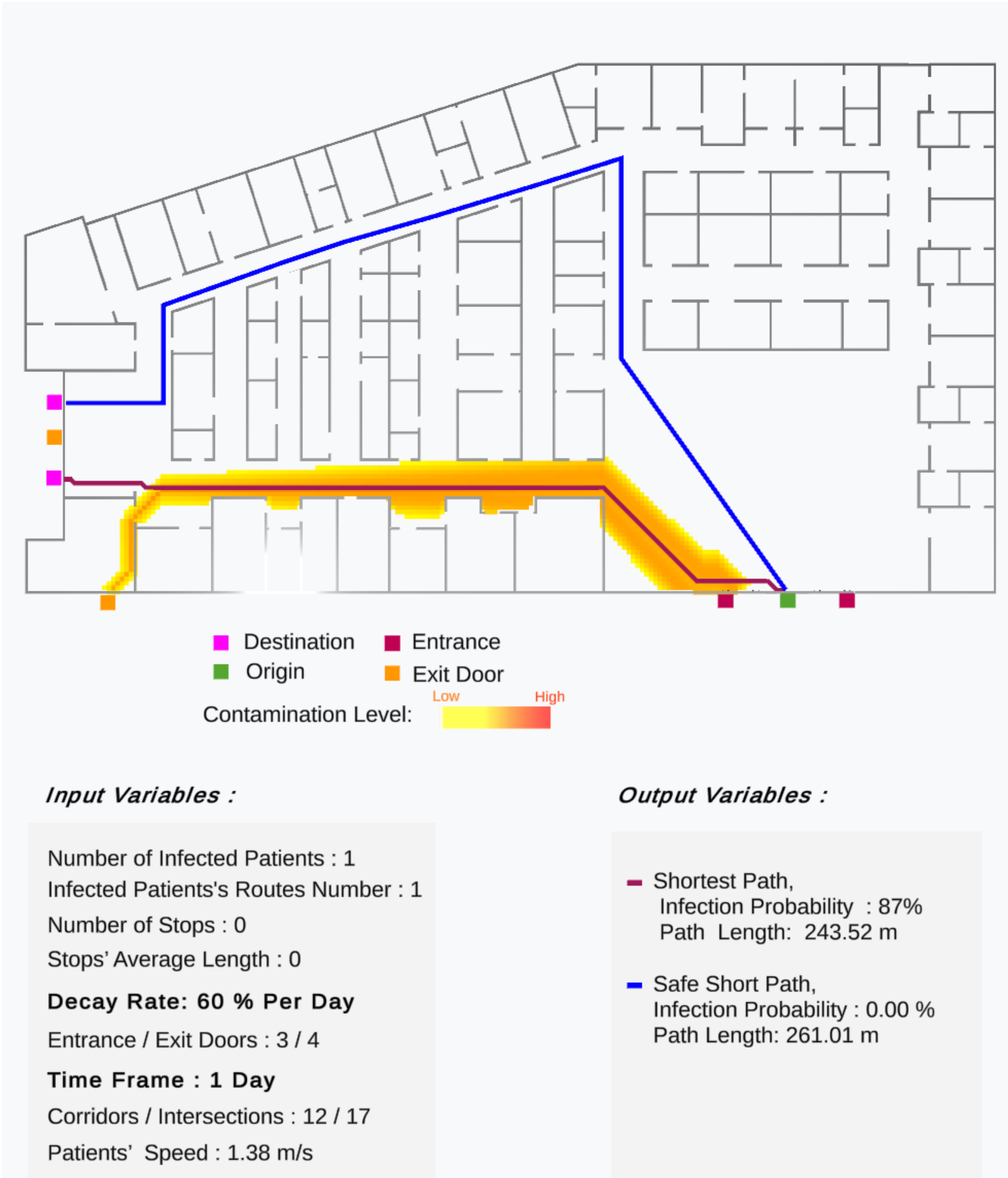


Figure 4.14: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

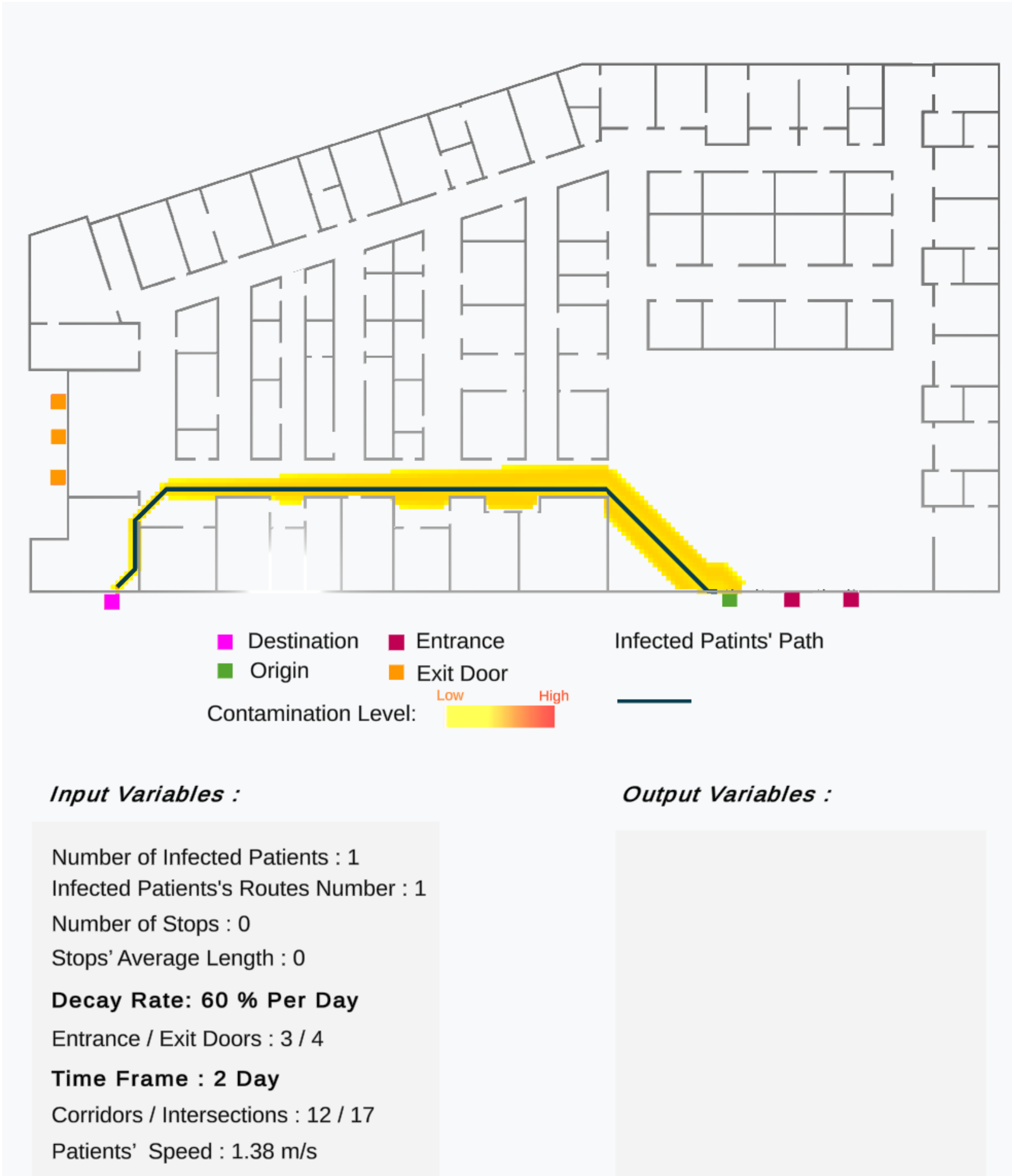


Figure 4.15: The simulation of virus spread by an infected patients to investigate the effect of the 60% decay rate of Coronavirus the on the infection probability in a hospital, on the second day

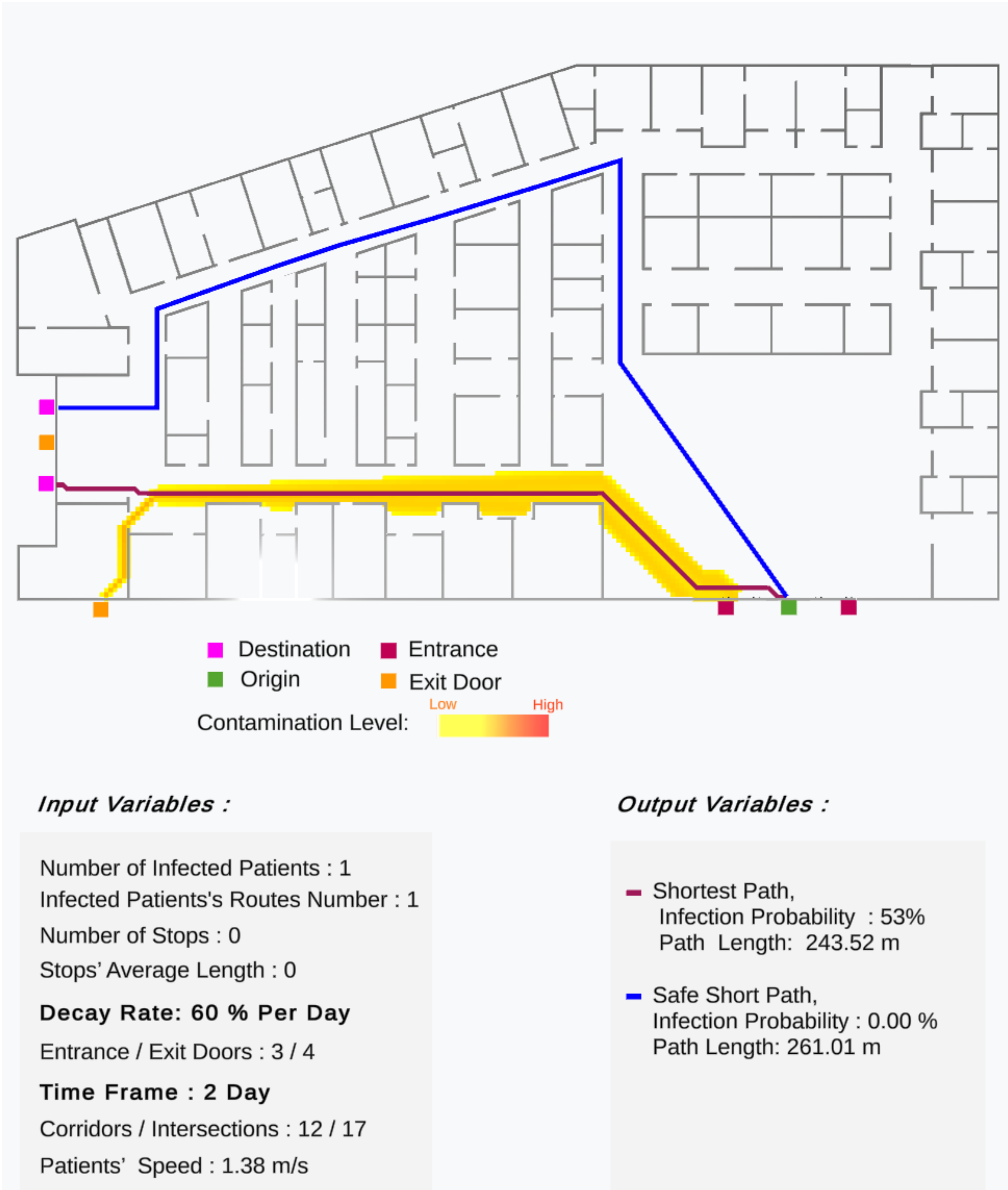


Figure 4.16: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

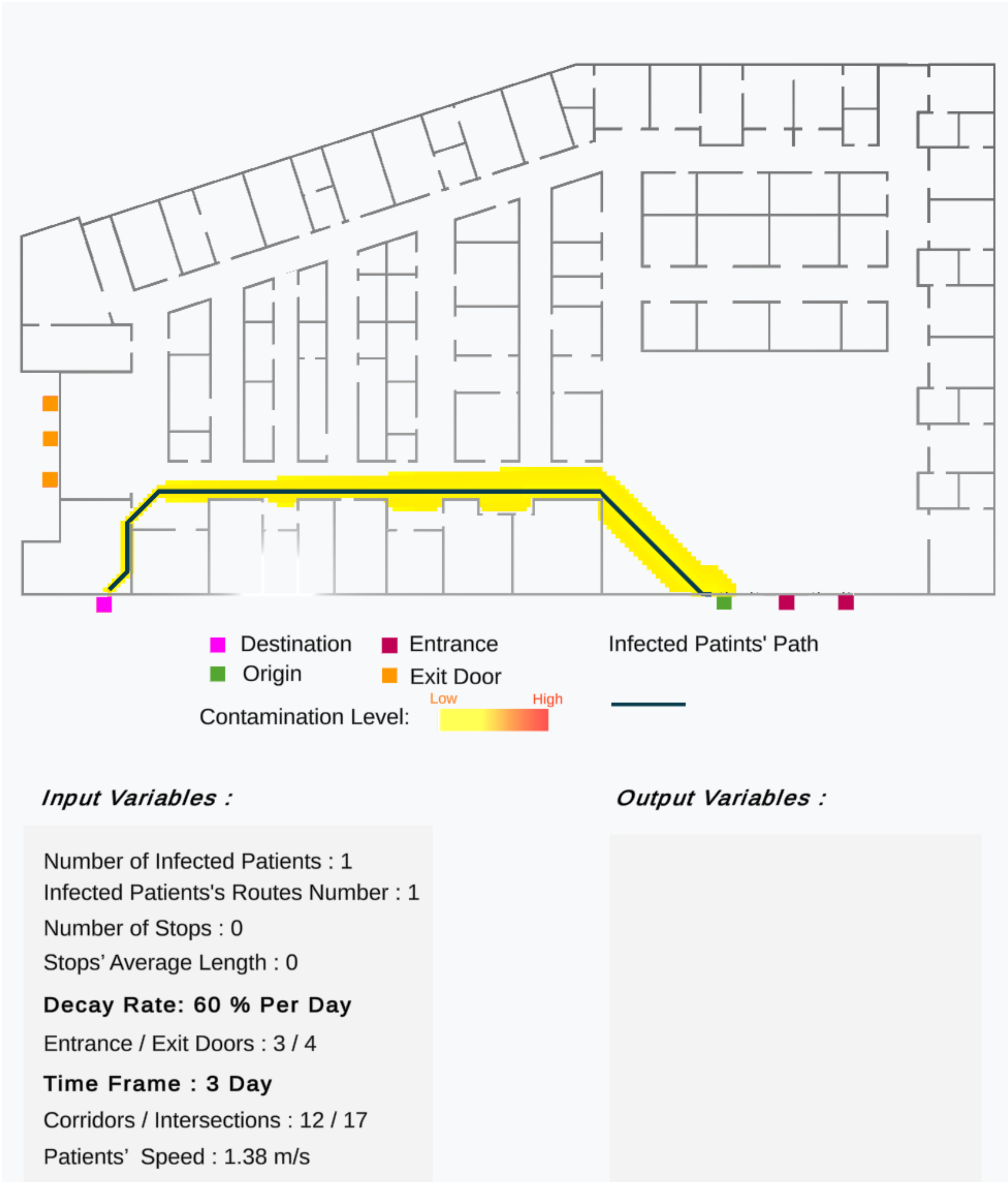


Figure 4.17: The simulation of virus spread by an infected patients to investigate the effect of the 60% decay rate of Coronavirus the on the infection probability in a hospital, on the third day

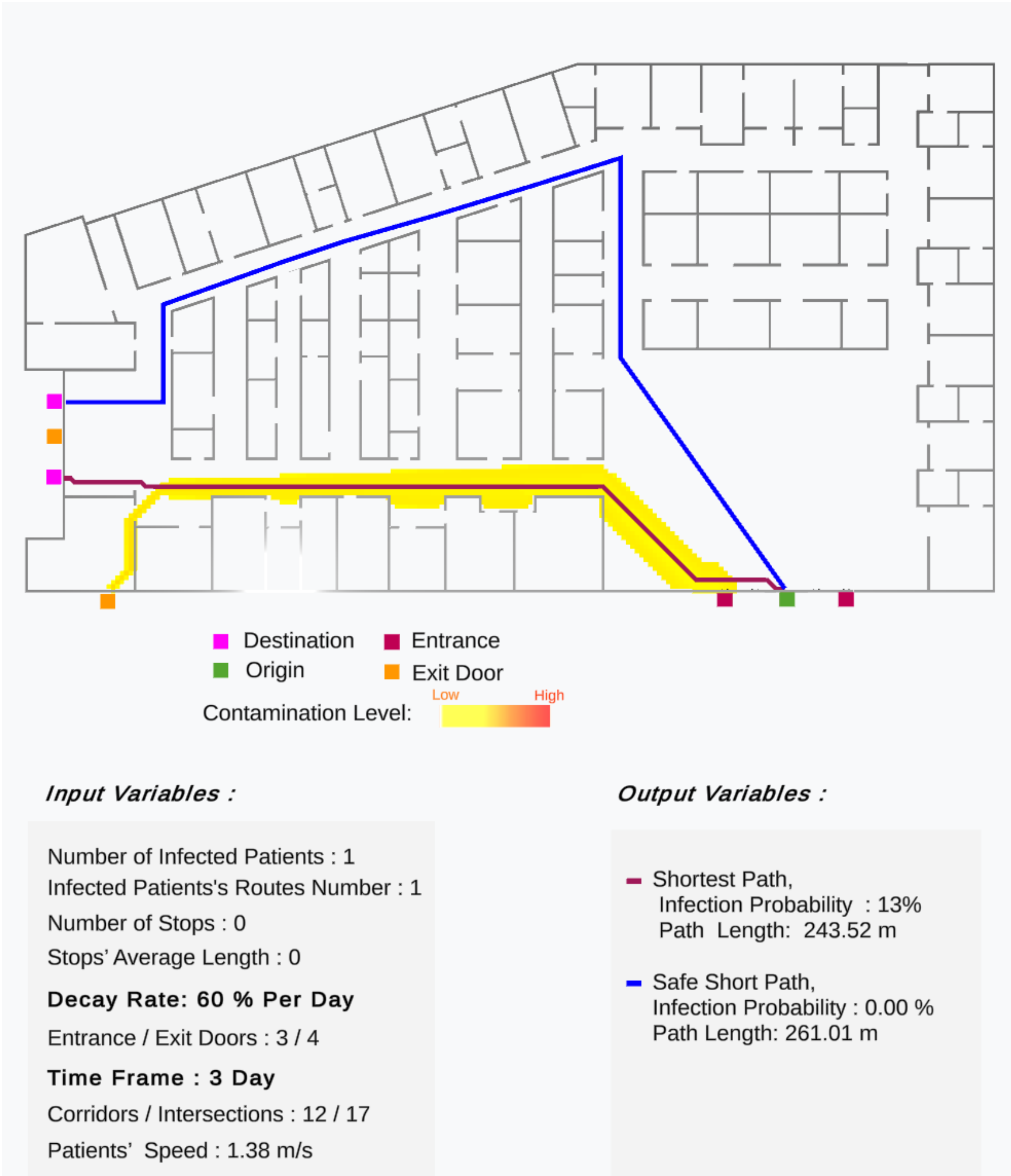


Figure 4.18: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

4.2 Variables Based On The Specific Location Of The Studying The Model

4.2.1 Location & Number of Entrance and Exit Doors

The location of entrance and exit doors in the hospitals is one of the effective variables in the infection probability of individuals with the Coronovirus. In the following, this variable will be examined.

If in the hypothetical hospital, one of the doors would be a back door and separated from the other main doors, this door will be more likely to remain safe if it is not the main entrance too. This is because if an infected person enters through one of the main doors, his / her entrance area becomes infected and may spread virus to other close entering doors areas. In addition to another reason for infection of the doors which is the hand contact with the door nobs. To investigate the effect of the door location variable, in the simulation (Figure 4.19), two infected people enter through two entrance main doors and exit through one of the exit doors. The doors of their choice in this scenario are two doors with one door in the middle. With the passage of these two infected people, the door in the middle will be infected too and the result of this passage is a 30% chance of infecting the person who enters through the middle as the safe door (Figure 4.20). However, by changing the location of this door (Figure 2), a completely safe path is created for the susceptible people, which reduces the contamination probability to 0% (Figure 4.22).

Figure 4.19: The simulation of virus spread by two infected patients to investigate the effect of the location of entrance and exit doors on the infection probability in a hospital

Figure 4.20: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

Figure 4.21: The simulation of virus spread by two infected patients to investigate the effect of the location of entrance and exit doors on the infection probability in a hospital

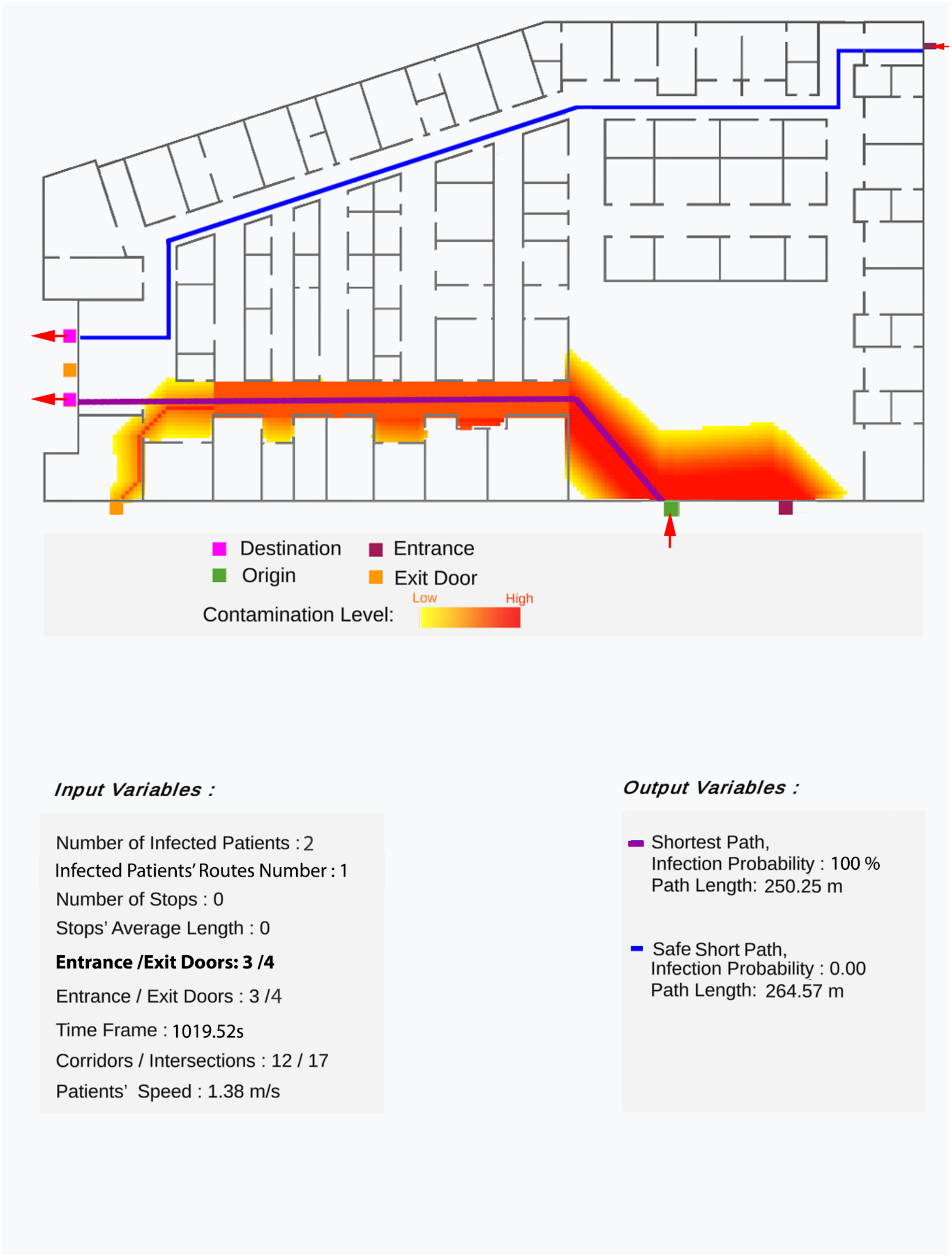


Figure 4.22: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

To analyze the effect of number of doors on the infection probability, in the following simulation, initially (figure 4.23) there are three doors for the entrance which one is blocked and four doors for the exit that two of them are blocked. In this way,due to fewer options for entrance and exit, an individual who wants to enter through the entrance door and exit through one of the exit doors may have to choose between the contaminated entries. This coercion will increase an individual's chance of getting infected with the virus up to 42% (Figure 4.24).

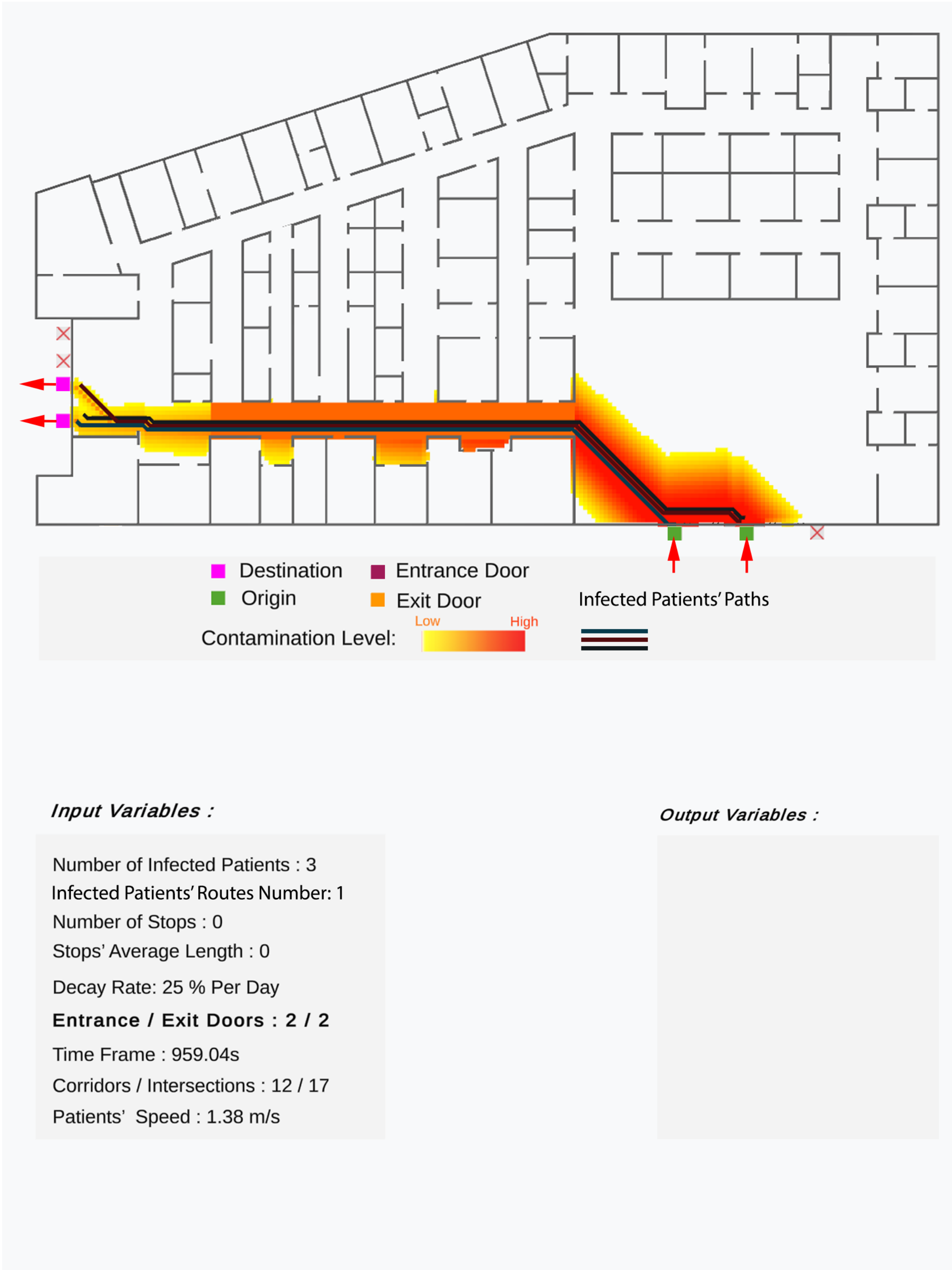


Figure 4.23: The simulation of virus spread by two infected patients to investigate the effect of the number of entrance and exit doors on the infection probability in a hospital

Figure 4.24: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

In the next simulation, 3 entrance and 3 exit doors are considered and 3 infected people enter and exit through only one of these doors (Figure 4.25). The entry of these 3 people from the first door, in addition to the first door, has also contaminated the second door to some extent. A susceptible person who wants to enter the hospital chooses the third door and enters and leaves through one of the safe doors. The probability of infection of this person will be 0 % (Figure 4.26). Thus, because of having more options, there was an uninfected entrance for safe navigation. From this simulation, it can be concluded that the more entrance and exit doors there are; The options for the susceptible people to enter and exit safely will be larger. Also, the smaller the number of entrance and exit doors allocated to infected people, the greater the options of susceptible people to choose.

Figure 4.25: The simulation of virus spread by two infected patients to investigate the effect of the number of entrance and exit doors on the infection probability in a hospital

Figure 4.26: The illustration of the generated shortest and safe short paths and their lengths and infection probabilities

In the following simulation (Figure 4.27), five entrance doors and five exit doors are considered. In this scenario, three infected people enter through two of the doors, and all three leaves the same exit door. The entry of these three people from three different doors causes contamination in the other two doors close to them. A susceptible person entering the hospital can enter through one of these three remaining doors; However, one of them which is in the middle of the two entry doors of the infected people, has been contaminated completely, so the other two entry doors on the right hand side are the better options. The proposed safe short route (blue route) selects the fourth entrance door, which is closer to the exit doors. However, due to the adjacency to its left side entrance which was used by one of the infected people, it has got some contamination. If a susceptible person chooses this safe short path, there is a 14% chance of getting infected. While the proposed route for the optimized safe route (green route) selects the far-most right door (which is the farthest from the entrance doors of 3 infected people) to enter. The probability of contamination by selecting this suggested route will be 0% (Figure 4.28). However, its length is longer than the other proposed route.

This simulation illustrates that by increasing the number of doors, the possibility of safe entry is increased. However, due to the proximity of the entrances to each other, contamination has been transferred from one's space to another, which has increased the possibility of contamination. Perhaps this simulation contains instructive points to consider in designing a hospital to reduce the spread of infection, which the greater the distance between the doors, the less likely it is to become infected.

Figure 4.27: The simulation of virus spread by two infected patients to investigate the effect of the number of entrance and exit doors on the infection probability in a hospital

Figure 4.28: The illustration of the generated shortest, safe short, and optimized safe paths and their lengths and infection probabilities

The number of entrance and exit doors is a determining factor in the contamination probability. The experiments in this section illustrate that the greater the number of entrance and exit doors, the more the individuals' choices and the higher the chance of safe entries.

Furthermore, these experiments may have this lesson for the administrators that if there are multiple doors in a hospital, allocating some for infected patients would keep other doors safe for the uninfected people and subsequently prevent the spread of the virus.

In the following simulation, to test the influence of the number of the corridors on the infection probability, one of the corridors has been blocked. As is illustrated in the figure 4.29 even though one infected patients has passed through the hospital, and one entry space is contaminated, and there are two safe entrances, in the continuation of the route, because the safe corridor is blocked, the safe short route has been forced to be generated along the contaminated corridor, which has increased the infection probability up to 70% (Figure 4.30). From this simulation it can be concluded that the more corridors and their intersections there are, the less likely it is to be contaminated because uninfected people will have a greater choice of route to take.

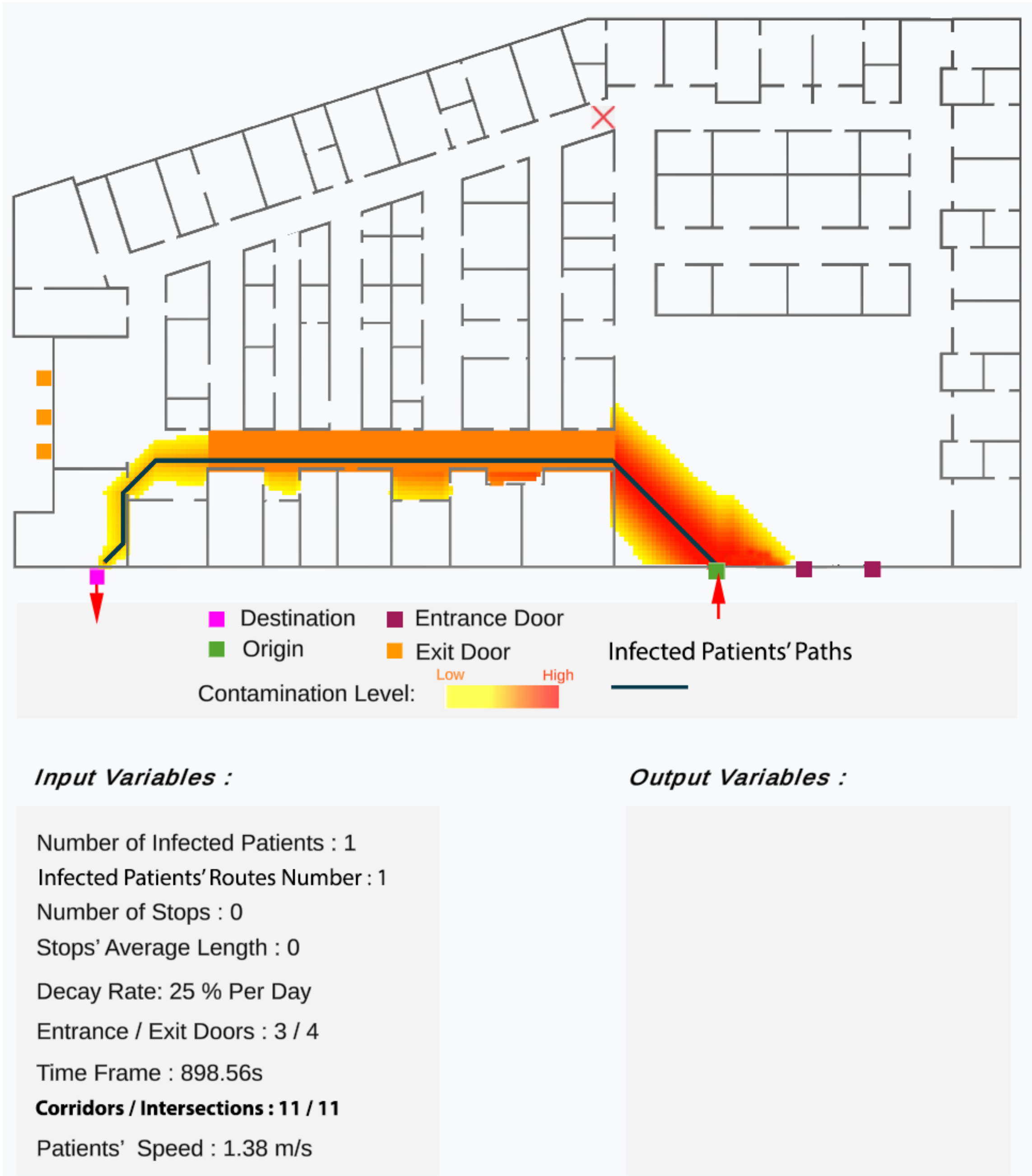


Figure 4.29: The simulation of virus spread by two infected patients to investigate the effect of the number of corridors on the infection probability in a hospital

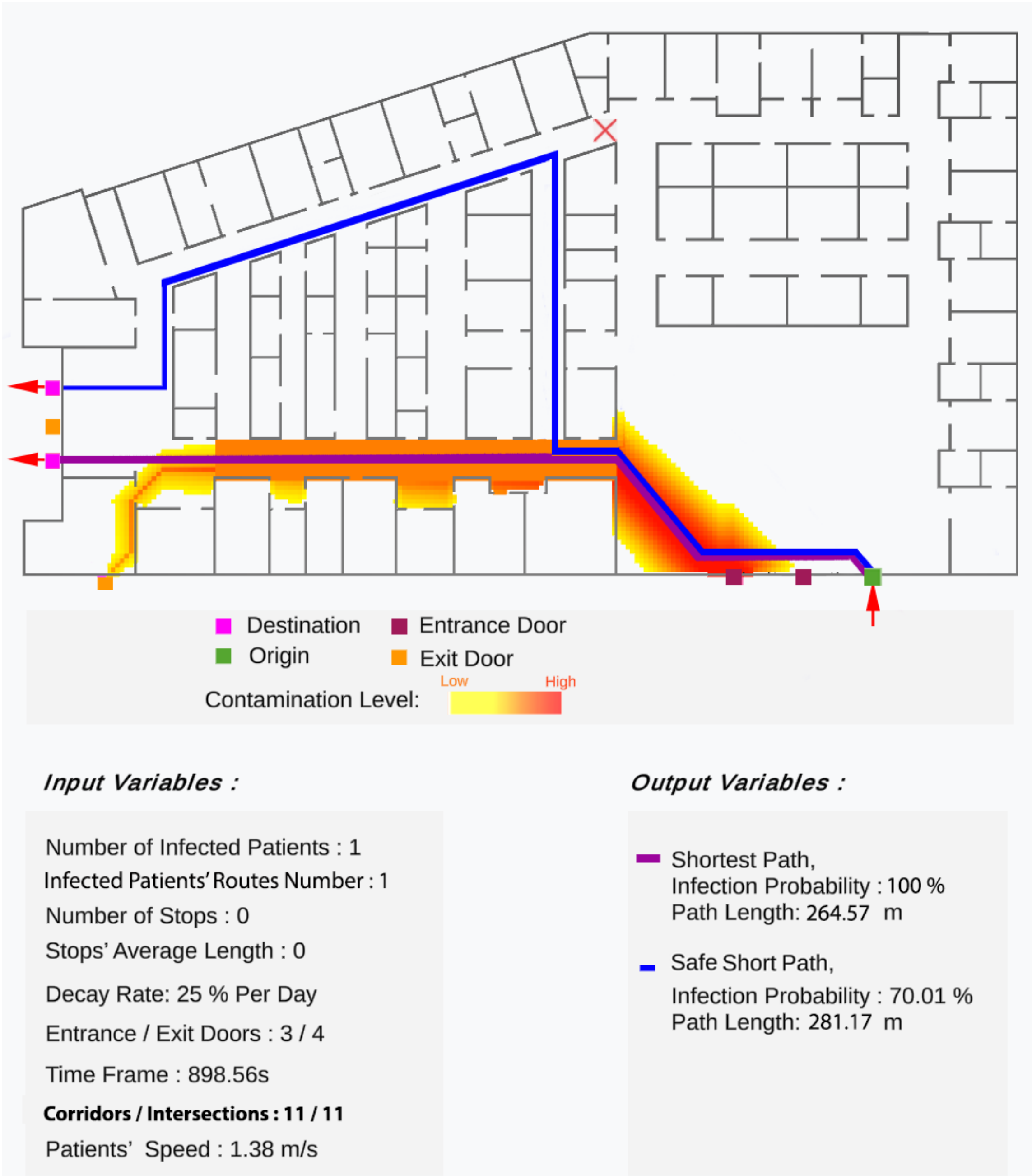


Figure 4.30: The illustration of the generated shortest, and safe short paths and their lengths and infection probabilities

These simulations provide a very limited number of scenarios applicable to the model. Numerous scenarios with different purposes can be implemented with this model, which can examine various variables in the hospital that are effective in spreading the infection. A variety of users can benefit from this model, such as hospital managers in their decision making or hospital clients in safe navigation in the environment, which will be through the AR application; this case is further explored in the Future Work section.

CHAPTER 5: CONCLUSION AND FUTURE WORK

This thesis made an attempt to understand the current situation affected by the COVID-19 in a hospital, as one of the vital buildings, that is struggling with the current pandemic, and provide collaboration, albeit a small one, to improve it.

In order to understand the epidemiological model of virus spread in the closed spaces, Yan%Lan's research was used [9]. One of the aims of this dissertation was to expand their model by introducing variables that are missing in the initial model to provide more realistic simulations of what is happening in the real world.These variables influence the possibility of infection and can be adjusted to reflect new epidemiological evidence and include the infection decay rate, Virus spread rate, infection rate after an infected person is in a space.Having involved variables in the contamination simulation, the infection probability was calculated in various scenarios to examine the different layout conditions in the hypothetical hospital. This probability was depend on the paths that infected people were taken, average speed and the number of stops that they had, and the resulting infection rate that caused, as well as the origin and destination of the new patients' paths through the hospital. Moreover, In experimenting and testing the change of infection probability by changing the defined variables, another goal of the research was addressed which was to provide the shortest and optimized safe routes for the susceptible people to navigate securely through the hospital.

One of the variables examined in the infection spread simulation is the number of routes that suspicious or infected people travel to get to their target place in the hospital. According to the results, the more passable routes and freedom of movement to different places for the infected or suspected people, the more contamination in the hospital spaces will be. Due to the various scenarios that were implemented, some practical solutions to prevent the spread of the virus are traffic management and classification of people into three groups: susceptible, suspicious and infected. Therefore, by examining the plan and layout of the hospital, setting the rules, and guiding the people, one or more specific routes can be assigned to the suspects and infected people to reduce the number of paths used by these individuals. The result of this change, as discussed in the Result & Findings chapter, is a significant reduction in the infection probability.

In addition to the previous variable, the Decay rate of the virus has a direct effect on the endurance of this virus in the environment. In fact, this rate determines the number of viruses eliminated each day. A high value of this variable will make the hospital environment faster clean in terms of contamination with the COVID-19 virus. In contrast, the lower its value, the longer the virus lingers in the environment.

According to [24], the value of the Decay Rate depends on the environment and the materials used in it, and the ambient airflow. For example, copper has a high Decay Rate and destroys COVID-19 viruses at high speed. According to the purpose of this dissertation, the effect of Decay Rate in the hospital environment was investigated and analyzed using simulations.According to the results obtained in the mentioned simulations, a high Decay Rate will make the hospital conditions more suitable for people to travel and reduce the possibility of infection in a shorter period of time. Although the optimization of this variable will be very effective by selecting the appropriate ventilation and materials used in the hospital interior, this variable alone will not be enough to deal with the spread of the virus, and other variables are needed to optimize the environment.

Another identified influential variable in the spread of infection in hospitals and the incidence of COVID-19 in people, according to this study, is the number of entrance and exit doors of the hospital. Any infected person passing through one of the entrance or exit doors will contaminate the entrance area and increase the infection chances of a susceptible individual passing through the door.Especially since opening most doors requires hands and doorknobs, which increases the spreading probability of contamination. In the simulation performed in this dissertation, the effect of the number of the hospital entrance and exit doors was investigated and analyzed. According to these results, access to the back entrance door and back exit door for the movement of susceptible people, in the case that all the main doors have been contaminated, significantly reduces the risk of infection. In addition to the number of entrance and exit doors, the location of these doors in the hospital is also essential.

According to the simulation, the proximity of the entrance or exit doors will spread the contamination around these doors. It will increase the probability of contamination of a susceptible individual by passing through any of these proximate doors. Moreover, in the hospital design, there may be only one door to enter a high-traffic ward (such as a laboratory or emergency room) from outside the hospital.

This increases the travel rate of people from this door, and this increase also raises the probability of infecting susceptible people. However, there may be two or more entrances to the other ward of the hospital that these doors lead to a low-traffic ward (such as the general surgery ward).

A suitable solution for infection management for entrance and exit doors is to increase the number of entries, increase the distance between them, connect them to different corridors, and network these corridors by creating interaction between them. This increases the variety of routing and reduces the chance of infecting susceptible individuals.

The last variable studied in this dissertation is the number of corridors. In the simulations performed, as the number of corridors increases (and consequently the number of intersections, which is a variable depending on the number of corridors), the variety of routing for individuals will increase. This diversity reduces the probability of different routes being contaminated. The hospital administrators also could regulate the movement of suspected and infected people to specific corridors in order to reduce the possibility of contamination of other routes and susceptible people traveling in these routes. According to a simulation performed in a hypothetical hospital, if the number of corridors is sufficient, the probability of infection in susceptible people will be almost zero.

In experimenting and testing the change of infection probability by changing the defined variables, another goal of the research was addressed which was to provide the shortest and optimized safe routes for the susceptible people to navigate securely through the hospital.

For the implementation of the scenarios relating to the explained variables, the Unity engine was used to simulate and perform calculations related to the contamination spread model in the environment, and the 3D modeling of the hypothetical hospital plan was designed through Rhino software. The camera view in this simulation is Top View, and the camera was placed in Orthographic mode for exporting 2D images. Initially, a scenario was developed for each simulation, and infected individuals were routed and moved according to the scenario through the Dijkstra algorithm. Finally, when the infected people reach the destination specified in the scenario, the shortest route and the optimized safe route based on the distance between the origin and destination (defined in the scenario) were generated.

5.1 Future Work

For reducing the effects of the virus, various measures have been taken. One of them is the social distancing; Health authorities have introduced the measures to restrict the spread of COVID-19, asking people to maintain a safe distance from each other, Before discovering the novel coronavirus, social distancing was never considered a model to be practiced when out in public [25]. Another example of a framework for change, was proposed for medical education, discussion about monitoring hospitals and clinics through technological methods; This proposal has been the inspiration for the future proposed project in this research.

So far, the scientific community has attempt to develop multiple technological methods that can serve society amidst these difficult times. AR is one of those technologies that can be advantageous for navigating life during this crisis. One of instances for this claim is Sodar, an AR application that supports social distancing by helping individuals maintain a distance of $2m$ from each other. this application has been launched by Google[26].

Figure 5.1: Sodar Application, an AR application helping in social distancing

Due to fact that the number of mobile devices world wide in 2020 stood at 14.02 billion, they are the best tool to inform and assist people with. By spatializing information, the information would be part of the space and urban environment. People experience the environment intuitively so the data that is supposed to be the extension of it, should be intuitive for people as well.

The first presentation(the contamination spread model) of this thesis was about simulating the current situation in the hospital. The second demonstration would be a Spatial Augmented Reality (SAR) interface to present the information gathered in the previous one to the individuals in the future.

The presented studies could be beneficial for providing a guide for individuals' navigation through the building through an AR application on the smartphones or using AR glasses to find the shortest and optimized safe routes to reach the destination in a hospital. This AR program can also be used in other sensitive locations with the potential for contamination (such as nuclear facilities and so on). Also, the combination of this AR-based routing with Indoor Positioning Systems (IPS) can provide a complete chain for routing and saving lives.

In general, some of the approaches to design an SAR application using the proposed model in this thesis are:

- Demonstrating infection heat map
- Providing a safe passage through the space for the individuals in the hospital
- Somewhere in the decision points , presenting some guide texts that would assist individuals to take the best path to travel in terms of infection

5.2 Augmented Reality Interface

The following is an interface designed in Unity, which can be deployed as an AR application: This interface uses the proposed model presented to display information.

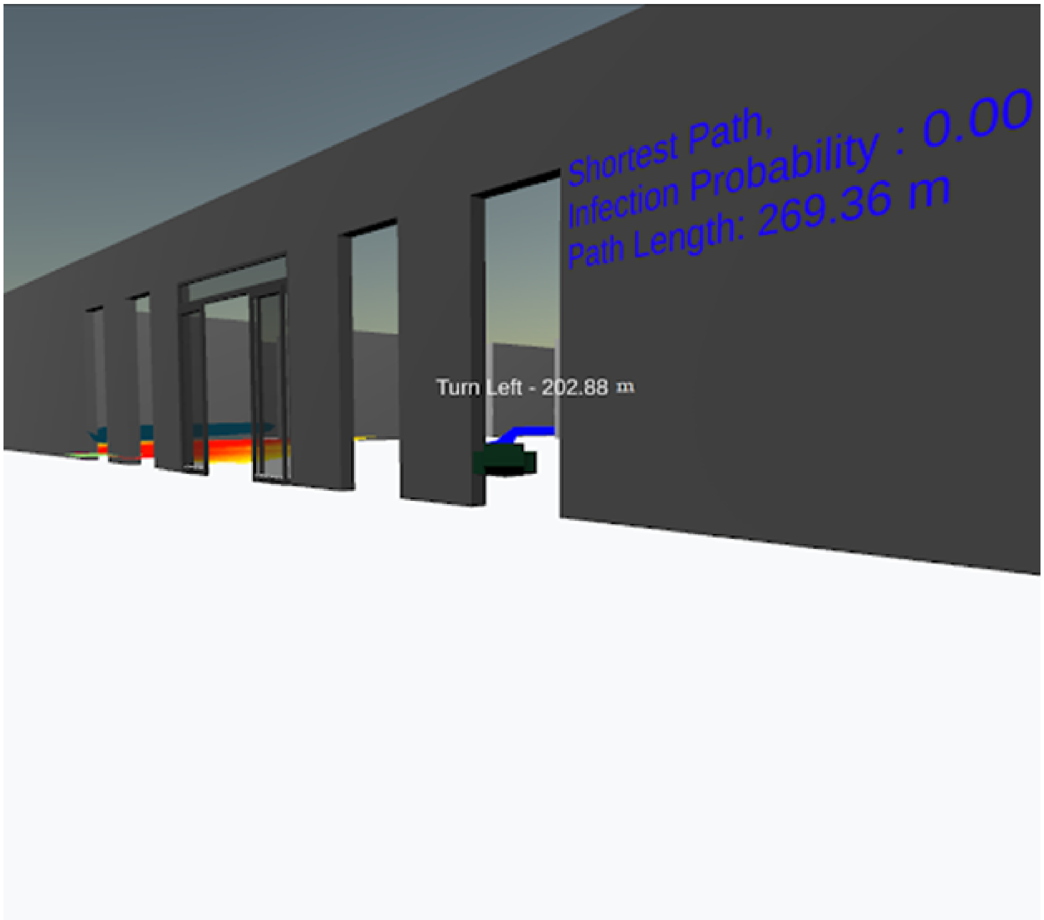


Figure 5.2: User View Outside of the Building

The image above illustrates that the infection probability and the length of the shortest path are displayed to the users before entering the hospital. If the contamination rate of the shortest path is less than 10%, the optimized safe route won't be presented similar to what is in the image. Furthermore, if the difference between the two is less than 10%, the shortest path only will be displayed. The users can choose between the two according to their desire.

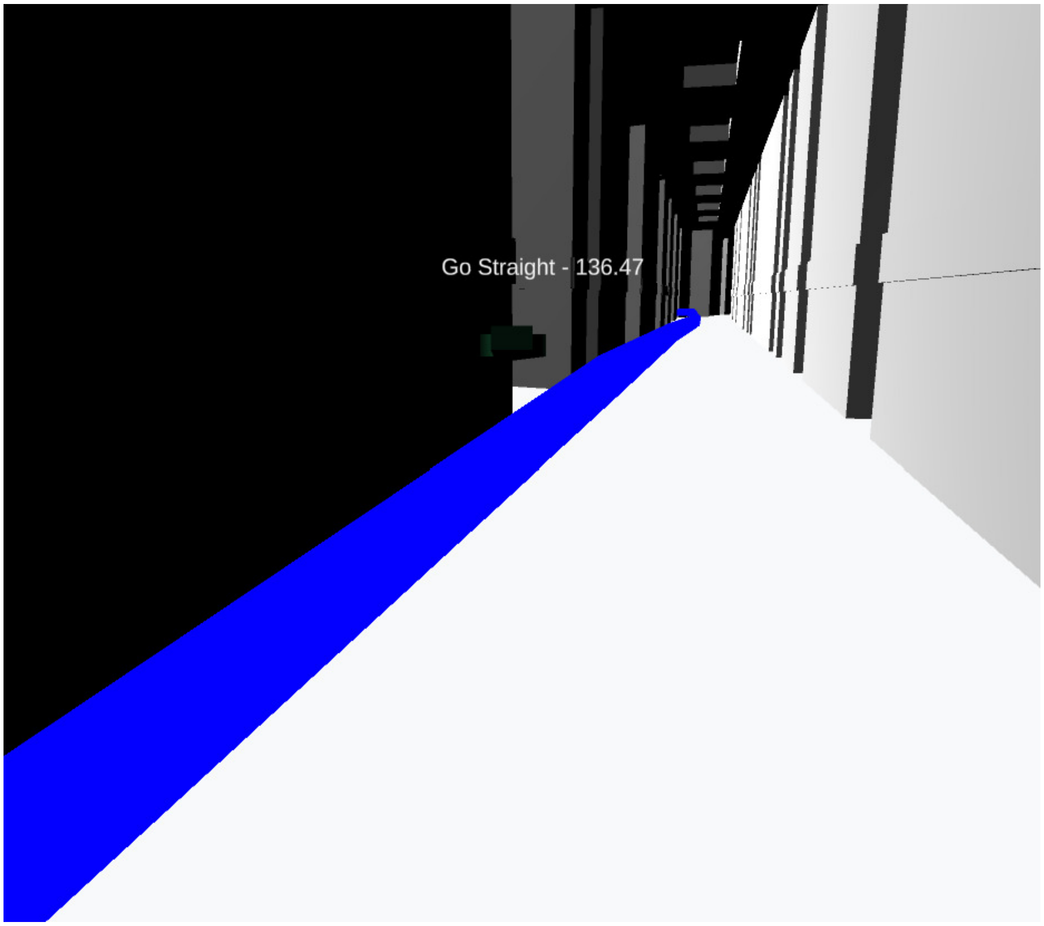


Figure 5.3: Text Guide in a Corridor

The shortest and optimized safe routes assist people to navigate.

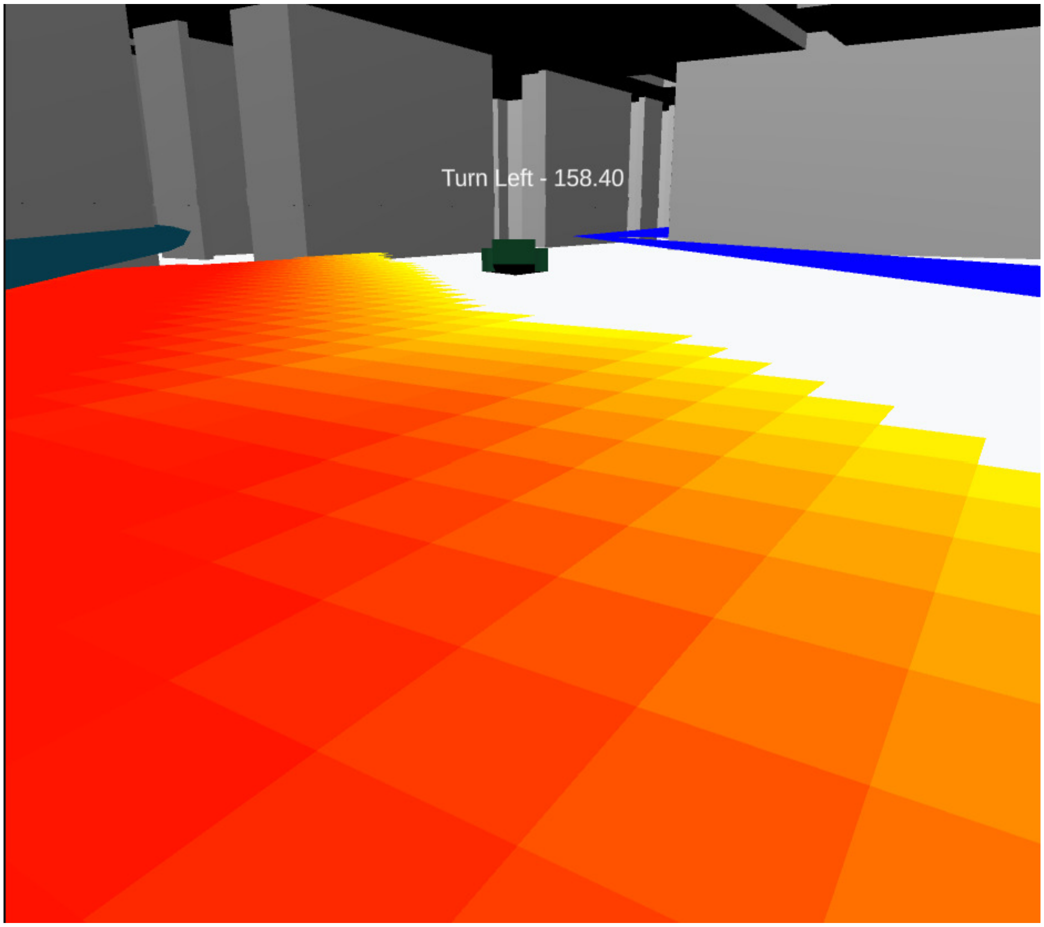


Figure 5.4: Big Space Heat-Map

The heat map illustration provided at the interface shows the infected areas in the hospital; This illustration can assist the hospital administrators to identify infected areas and disinfect them. It also helps the medical staff to beware of contaminated areas and avoid them.

REFERENCES

[1] E. Iadanza, A. Luschi, T. Merli, and F. Terzaghi, "Navigation algorithm for the evacuation of hospitalized patients," in *World Congress on Medical Physics and Biomedical Engineering 2018*, pp. 317–320, Springer, 2019.

[2] K. Samah, B. Hussin, and A. Basari, "Modification of dijkstraâs algorithm for safest and shortest path during emergency evacuation," *Applied Mathematical Sciences*, vol. 9, no. 31, pp. 1531–1541, 2015.

[3] U. Emmanuel, E. D. Osondu, and K. C. Kalu, "Architectural design strategies for infection prevention and control (ipc) in health-care facilities: towards curbing the spread of covid-19," *Journal of Environmental Health Science and Engineering*, pp. 1–9, 2020.

[4] D. Pradhan, P. Biswasroy, G. Ghosh, G. Rath, *et al.*, "A review of current interventions for covid-19 prevention," *Archives of medical research*, 2020.

[5] S. Su, G. Wong, W. Shi, J. Liu, A. C. Lai, J. Zhou, W. Liu, Y. Bi, and G. F. Gao, "Epidemiology, genetic recombination, and pathogenesis of coronaviruses," *Trends in microbiology*, vol. 24, no. 6, pp. 490–502, 2016.

[6] S. D. Pitlik, "Covid-19 compared to other pandemic diseases," *Rambam Maimonides medical journal*, vol. 11, no. 3, 2020.

[7] "Modes of transmission of the virus causing COVID-19: implications for IPC precaution recommendations." https://www.who.int/news-room/commentaries/detail/modes-of-transmission-of-virus-causing-covid-19-implications-for-ipc-precaution-recommendations.

[8] "Coronavirus disease (COVID-19): How is it transmitted?." ://www.cdc.gov/.

[9] Z. Yan and Y. Lan, "Modeling covid-19 infection in a confined space," 2020.

[10] J. Pahle, "Biochemical simulations: stochastic, approximate stochastic and hybrid approaches," *Briefings in bioinformatics*, vol. 10, no. 1, pp. 53–64, 2009.

[11] Z. A. Khan, "Comparison of dijkstraâs algorithm with other proposed algorithms," *Virtual University of Pakistan*, 2016.

[12] S.-X. Wang and Z.-X. Wu, "Improved dijkstra shortest path algorithm and its application," *computer science*, vol. 39, no. 5, pp. 223–228, 2012.

[13] "Dijkstra's algorithm." https://en.wikipedia.org/wiki/Dijkstra

[14] A. Filippoupolitis, G. Gorbil, and E. Gelenbe, "Autonomous navigation systems for emergency management in buildings," in *2011 IEEE GLOBECOM Workshops (GC Wkshps)*, pp. 1056–1061, IEEE, 2011.

[15] F. Lateef, "Hospital design for better infection control," *Journal of Emergencies, Trauma and Shock*, vol. 2, no. 3, p. 175, 2009.

[16] J. Carthey, "Reinterpreting the hospital corridor:âwasted spaceâ or essential for quality multidisciplinary clinical care?," *HERD: Health Environments Research & Design Journal*, vol. 2, no. 1, pp. 17–29, 2008.

[17] N. Pandey, V. Kaushal, G. D. Puri, S. Taneja, M. Biswal, P. Mahajan, R. R. Guru, P. Malhotra, I. S. Sehgal, S. Dhooria, *et al.*, "Transforming a general hospital to an infectious disease hospital for covid-19 over 2 weeks," *Frontiers in public health*, vol. 8, p. 382, 2020.

[18] N. A. Megahed and E. M. Ghoneim, "Antivirus-built environment: Lessons learned from covid-19 pandemic," *Sustainable Cities and Society*, vol. 61, p. 102350, 2020.

[19] J. Ahn and R. Han, "Rescueme: An indoor mobile augmented-reality evacuation system by personalized pedometry," in *2011 IEEE Asia-Pacific Services Computing Conference*, pp. 70–77, IEEE, 2011.

[20] M. Codina, D. Castells-Rufas, J. Carrabina, I. Salmon, N. Ayuso, A. Guerendiain, and G. Alvarez, "Augmented reality for emergency situations in buildings with the support of indoor localization," in *Multidisciplinary Digital Publishing Institute Proceedings*, vol. 31, p. 76, 2019.

[21] A. Campos, N. Correia, T. Romão, I. Nunes, and M. Simões-Marques, "Mobile augmented reality techniques for emergency response," in *Proceedings of the 16th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services*, pp. 31–39, 2019.

[22] "Image in Binary." https://www.dcode.fr/binary-image. Accessed: 2010-09-30.

[23] "Online Image Converter." https://lvgl.io/tools/imageconverter. Accessed: 2010-09-30.

[24] N. Van Doremalen, T. Bushmaker, D. H. Morris, M. G. Holbrook, A. Gamble, B. N. Williamson, A. Tamin, J. L. Harcourt, N. J. Thornburg, S. I. Gerber, *et al.*, "Aerosol and surface stability of sars-cov-2 as compared with sars-cov-1," *New England journal of medicine*, vol. 382, no. 16, pp. 1564–1567, 2020.

[25] D. L. J. Mataruna-Dos-Santos, "Augmented reality at dubai parks: A gaming approach to curb COVID-19," vol. 1, no. 7, p. 8.

[26] P. Parekh, S. Patel, N. Patel, and M. Shah, "Systematic review and meta-analysis of augmented reality in medicine, retail, and games," vol. 3, no. 1, p. 21.

[27] S. Feiner, B. MacIntyre, T. Höllerer, and A. Webster, "A touring machine: Prototyping 3d mobile augmented reality systems for exploring the urban environment," *Personal Technologies*, vol. 1, no. 4, pp. 208–217, 1997.

[28] D. Van Krevelen and R. Poelman, "A survey of augmented reality technologies, applications and limitations," vol. 9, no. 2, pp. 1–20.

[29] F. Zhou, H. B.-L. Duh, and M. Billinghurst, "Trends in augmented reality tracking, interaction and display: A review of ten years of ismar," in *2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*, pp. 193–202, IEEE, 2008.

[30] M. Tönnis, D. A. Plecher, and G. Klinker, "Representing information - classifying the augmented reality presentation space," vol. 37, no. 8, pp. 997–1011.

[31] F. Z. Kaghat, A. Azough, M. Fakhour, and M. Meknassi, "A new audio augmented reality interaction and adaptation model for museum visits," vol. 84, p. 106606.

[32] M. A. Livingston, A. Dey, C. Sandor, and B. H. Thomas, "Pursuit of âx-ray visionâ for augmented reality," in *Human Factors in Augmented Reality Environments*, pp. 67–107, Springer, 2013.

[33] L. Gruber, S. Gauglitz, J. Ventura, S. Zollmann, M. Huber, M. Schlegel, G. Klinker, D. Schmalstieg, and T. Hollerer, "The city of sights: Design, construction, and measurement of an augmented reality stage set," in *2010 IEEE International Symposium on Mixed and Augmented Reality*, pp. 157–163, IEEE.

[34] D. Schmalstieg and D. Wagner, "Experiences with handheld augmented reality," in *2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality*, pp. 3–18, IEEE, 2007.

[35] D. Chekhlov, A. P. Gee, A. Calway, and W. Mayol-Cuevas, "Ninja on a plane: Automatic discovery of physical planes for augmented reality using visual SLAM," in *2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality*, pp. 1–4, IEEE.

[36] G. Speiginer, B. MacIntyre, J. Bolter, H. Rouzati, A. Lambeth, L. Levy, L. Baird, M. Gandy, M. Sanders, B. Davidson, *et al.*, "The evolution of the argon web framework through its use creating cultural heritage and community–based augmented reality applications," in *International Conference on Human-Computer Interaction*, pp. 112–124, Springer, 2015.

[37] P. Lincoln, G. Welch, A. Nashel, A. Ilie, A. State, and H. Fuchs, "Animatronic shader lamps avatars," in *2009 8th IEEE International Symposium on Mixed and Augmented Reality*, pp. 27–33, IEEE, 2009.

[38] K. Kim, M. Billinghurst, G. Bruder, H. B.-L. Duh, and G. F. Welch, "Revisiting trends in augmented reality research: A review of the 2nd decade of ISMAR (2008-2017)," vol. 24, no. 11, pp. 2947–2962.

[39] J. Kysela and P. Å torkovÃ¡, "Using augmented reality as a medium for teaching history and tourism," vol. 174, pp. 926–931.

[40] T. Ha, S. Feiner, and W. Woo, "WeARHand: Head-worn, RGB-d camera-based, bare-hand user interface with visually enhanced depth perception," in *2014 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 219–228, IEEE.

[41] T. Olsson and M. Salo, "Online user survey on current mobile augmented reality applications," in *2011 10th IEEE International Symposium on Mixed and Augmented Reality*, pp. 75–84, IEEE.

[42] D. Baričević, C. Lee, M. Turk, T. Höllerer, and D. A. Bowman, "A hand-held ar magic lens with user-perspective rendering," in *2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 197–206, IEEE, 2012.

[43] T. Piumsomboon, A. Clark, and M. Billinghurst, "[demo] g-siar: Gesture-speech interface for augmented reality," in *2014 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 365–366, 2014.

[44] O. Bimber and R. Raskar, *Spatial augmented reality: merging real and virtual worlds.* CRC press, 2005.

[45] B. H. Thomas, M. Marner, R. T. Smith, N. A. M. Elsayed, S. Von Itzstein, K. Klein, M. Adcock, P. Eades, A. Irlitti, J. Zucco, T. Simon, J. Baumeister, and T. Suthers, "Spatial augmented reality — a tool for 3d data visualization," in *2014 IEEE VIS International Workshop on 3DVis (3DVis)*, pp. 45–50, IEEE.

[46] Y. Jin, J. Seo, J. G. Lee, S. Ahn, and S. Han, "BIM-based spatial augmented reality (SAR) for architectural design collaboration: A proof of concept," vol. 10, no. 17, p. 5915.

[47] D. G. W. Roberts, A. Evans, A. H. Dodson, S. Cooper, and D. R. Hollands, "The use of augmented reality, GPS and INS for subsurface data visualisation," p. 12.

[48] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, "Recent advances in augmented reality," vol. 21, no. 6, pp. 34–47.

[49] A. Ettlinger, H.-B. Neuner, and T. Burgess, "Smartphone sensor-based orientation determination for indoor-navigation," in *Progress in Location-Based Services 2016*, pp. 49–68, Springer, 2017.

APPENDIX A: BACKGROUND STUDY ON AUGMENTED REALITY TECHNOLOGY

A.1 Brief History

The first Augmented Reality (AR) prototype was created by Ivan Sutherland, a computer graphics scientist.He used a see-Through to present 3D graphics.

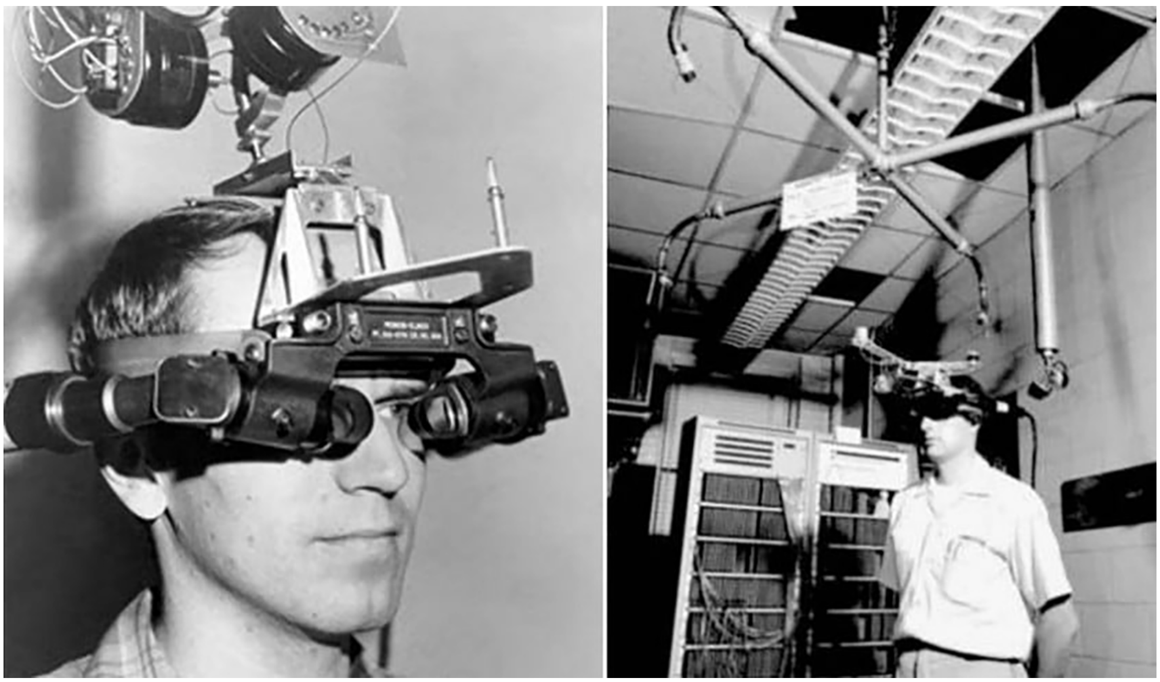


Figure A.1: The first Augmented Reality (AR) prototype.

In the early 1990s the term "Augmented Reality" was coined by Caudell and Mizell, scientists at Boeing Corporation. They were developing an experimental AR system to help workers put together wiring harnesses. Feiner et al. created an early prototype of a mobile AR system (MARS) that registers 3D visual tour guide information with buildings and artifacts the visitor sees (Figure. A.2) [27].By the late 1990s, Augmented Reality became a distinguished research area, and the conference specifically on its own title began to be held. Such as the International Symposium on Mixed Reality and the International Symposium on Mixed Reality Augmented Reality.

(a) (b)

Figure A.2: Mobile AR System (MARS) by Feiner et al.

Organizations such as the Mixed Reality Systems Laboratory (MRLab) in Nottingham and the Arvika consortium in Germany have helped improving AR technologies. Employing freely available software toolkits, e.g. the ARToolKi, has also helped to rapidly build AR applications. It was by 2001, that MRLab finished its pilot research, and after that, the International Symposium on Augmented Reality and International Symposium on Mixed Reality were united in the International Symposium on Mixed and Augmented Reality (ISMAER), which now is the major symposium in this field[28].

A.2 AR Research Topics

According to a survey by Zhou et al. all the ISMAR publications could be categorized into 11 AR research topics, including primary and secondary topics[29]. They found that the five primary topics **Tracking Techniques**, **Interaction Techniques**, **Calibration and Registration**, **AR Applications**, and **Display Techniques** are the core AR technology areas needed to deliver an AR application. The remaining topics reflected more emerging research interests. The topic categories are as follows:

- **Tracking Techniques:** Techniques for tracking a target object/environment via cameras and sensors and computing viewpoint poses.
- **Interaction Techniques and User Interfaces:** Methods and interfaces for interacting with virtual content.
- **Calibration and Registration:** Methods of photometric or geometric calibration and techniques to align various coordinate frames.
- **AR Applications:** Study on AR systems in application domains such as military, medicine, manufacturing, or education, among other techniques to align various coordinate frames.
- **Display Techniques:** Research on display hardware to display virtual content in AR, including head-worn, handheld, and projected displays.
- **Evaluation/Testing:** Research focusing on human-subject studies evaluating AR techniques or systems.
- **Wearable /Mobile AR:** Study on AR applications and methods for wearable and mobile platforms, such as tablets and smartphones.
- **AR Authoring:** Study on methods, techniques, and systems for authoring virtual content in AR.
- **Visualization:** Research on methods that use AR to make complex 2D/3D data more comfortable to navigate through and understand.
- **Multimodal AR:** Study on fusing different input (and output) modalities, such as merged speech and gesture interfaces.
- **Collaboration/Social:** Study on the interactive, collaborative systems for various remote or co-located users.

- **Reconstruction:** Study on the processes that automatically generate 3D virtual environments or objects based on images or different forms of data obtained from the real environment/objects.

- **Modeling:** research on techniques for generating virtual content via virtual primitives and tools with a human user's associations.

- **Rendering:** Research into methods for computer graphics rendering; and other sensory modalities, such as sound and haptics.

A.3 Different Types of Augmented Reality Technology Classification

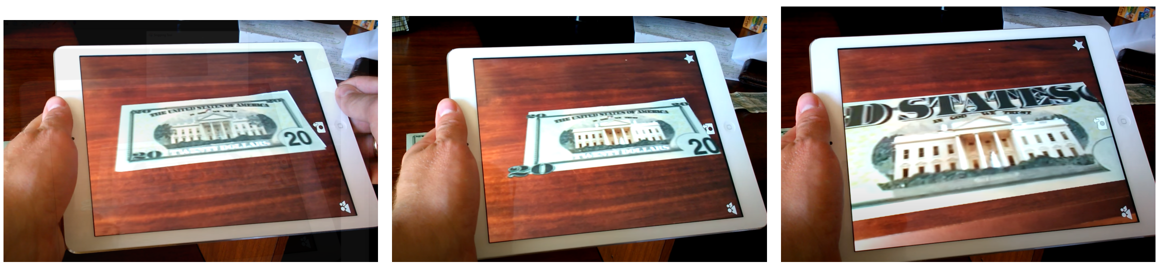
AR is often considered a kind of virtual reality, but these are two different technologies, and they are classified individually. Furthermore, applications referred to as AR can be distinct from one another, and it is beneficial to define various categories and types. Such classifications can assist researchers in considering appropriate problem areas that may fit with certain AR types.

In general, AR has six different types that fall under two overarching categories. These include *triggered* versus *view-based* augmentation. Triggers are stimuli or characteristics that initiate or "trigger" the augmentation. Triggers can be paper or object markers, GPS location, dynamic augmentations of objects, as well as a combination of dynamic object recognition with GPS location that is classified as a Complex Augmentation. Other forms of AR are view-based, which includes either digitized augmentations without reference to what is in view or augmentation of a stored/static view.

A.3.1 Triggered augmented reality technologies

The following are the four types of triggered AR technologies:

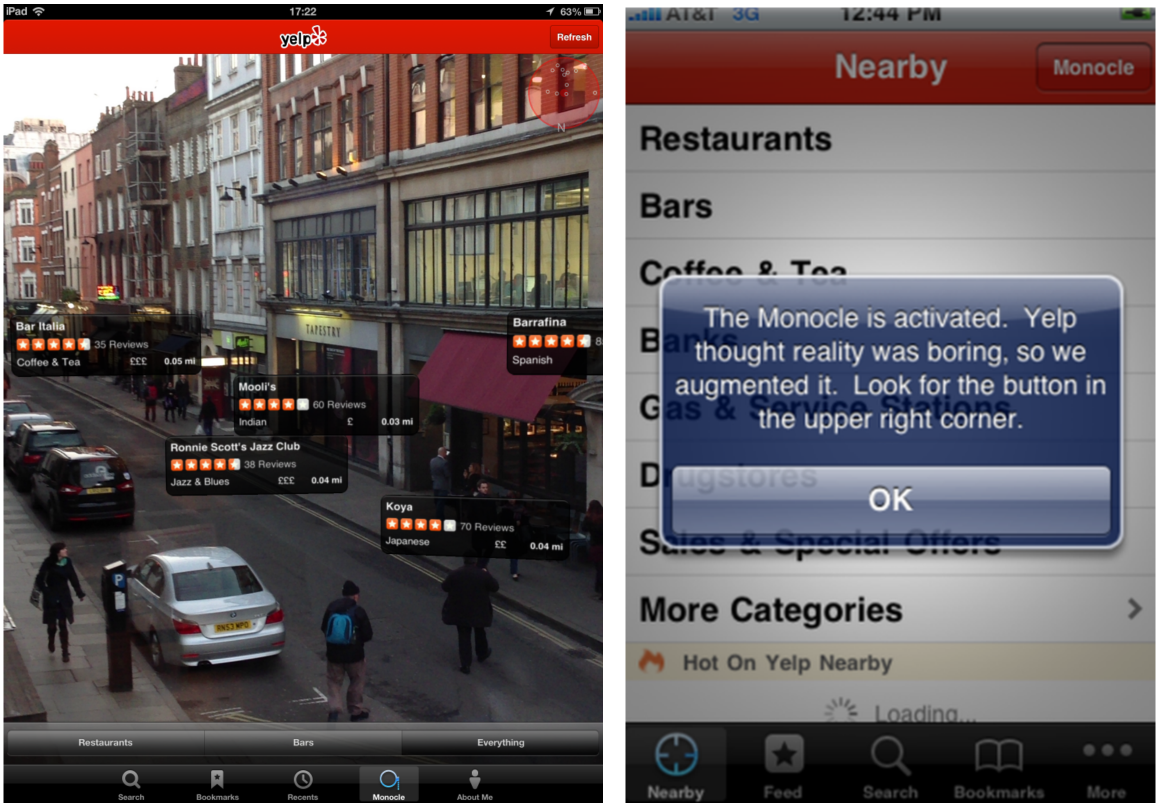
- **Marker-based** AR uses a marker to initiate an augmentation. Such markers can be paper-based or physical objects existing in the real world. Augmentations related to the marker reinforces the image or object, though some are only a means to access digital content. For example, in Figure A.3, the Aurasma app augments the appearance of a real-world $20 bill, which morphs into an animation. This example takes an object-marker and provides a meaningful augmentation of the trigger stimulus.



(a) (b) (c)

Figure A.3: Aurasma Application

- **Location** is another form of trigger. Location-based AR uses the device's GPS location as a trigger to pair dynamic location with points of interest to provide relevant data or information (e.g., restaurants in Yelp's monocle view) (Figure A.4).



(a) (b)

Figure A.4: Yelp Monocle

- **Dynamic Augmentation** is responsive to the changes of the view of the object. Dynamic Augmentation with motion tracking can also scale the augmentation to fit the identified object. For instance, Swivel is a shopping application that provides users the chance to try on clothing and accessories digitally (Figure A.5).

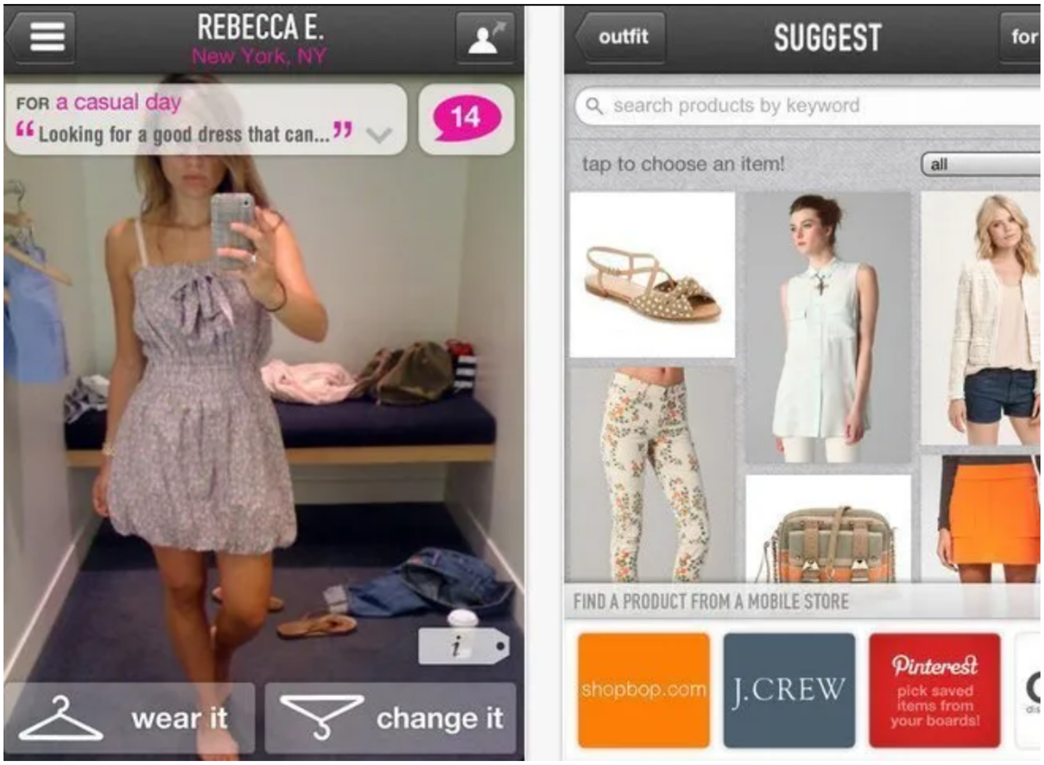


Figure A.5: Swivel Application

- **Complex Augmentation** pairs a real, dynamic view of the world with digital information typically accessed via the Internet. It is a combination of Marker/Location-based AR and Dynamic Augmentation. This can be seen in the original concept for Google Glass, wherein users see information about local sites based on their GPS location. Objects in the user's field of view are presented with helpful information about their surroundings from an internet backend. This is the AR technology that will be used in the proposed project.

A.3.2 Indirect and non-specific digital augmentation

The second category of AR is composed of Indirect Augmentation and Non-Specific Digital Augmentation. A static view of the world is augmented by Indirect Augmentation. This often involves augmenting images. The instances of this category are applications that let users take a picture of a room and then adjust the wall color of that room. The application recognizes the wall from other objects and augments just the wall. A dynamic view of the world is digitized by Non-Specific Digital Augmentation without reference to what is being viewed. This is prevalent in mobile games. Without reference to the user's environment, the users interact with the augmentation, such as tapping the augmentation when it comes into view [30]. Below is a brief summary of these categories:

Category	**Type**	**Characteristics**
Triggered	1a. Marker-based: Paper	Paper marker activates stimuli.
	1b. Marker-based: Object	Most objects can be made into markers.
	2. Location-based	Overlay of digital information on a map or live camera view. GPS may activate stimuli.
	3. Dynamic Augmentation	Meaningful, interactive augmentation with possible object recognition and/or motion tracking.
	4. Complex Augmentation	Augment dynamic view and pull internet information based on location, markers, or object recognition.
	5. Indirect Augmentation	Image of the real world augmented intelligently.
View-Based	6. Non-specific Digital Augmentation	Augmentation of any camera view regardless of location.

Figure A.6: Classification of different types of Augmented Reality Technology.

A.4 Audio Augmented Reality

Augmented Reality can also be audio or visual. Audio Augmented Reality (AAR) is already used for many years and in several domains. One common usage of AAR is as an information source. In general, it specifies the augmentation of the auditory sensory modality, usually using virtual audio with 2D or 3D spatial characteristics, individual presentation, and full position and orientation tracking extent [31]. For the future work for the proposed project, I could augment the visual effects with the audio ones to boost the conveying the information to the users. This feature will make the application usable for the blind users as well.

A.4.1 Fields of Application

To find out which research field of Augmented Reality the proposed idea falls, I studied some of them. AR covers many different research fields such as computer vision, computer graphics, interface design and more. Some areas that AR could be applied to:

- **Vision-based tracking, detection and recognition:** Vision-based tracking and/or pose estimation is an essential requirement for many AR applications. There are various approaches, such as model-based tracking and detection, such as natural features and simultaneous localization and mapping (SLAM). The central requirements for the target scene are distinct natural feature points and structures (e.g., lines), and for evaluation, varying degrees of them. Comparison with the camera pose ground truth is the most straightforward way to assess the correctness and quality of the algorithms.

- **Online/Real-time 3D modeling:** For the interactions between the real and virtual world beyond annotation, 3D models of the environment are needed (for instance, for occlusion management). Test objects should satisfy vision-based tracking and detection and consist of three-dimensional objects of varying complexity (e.g. level of detail, number of planes, type of primitives). For evaluation, the camera poses ground truth, and accurate measurements of the target objects themselves are needed.

- **Spatial AR:** This area mainly deals with the fusing the real and virtual content in a seamless manner. Because spatial AR and related applications require a virtual representation of the real-world object and real-world objects appropriate for projection, white objects are commonly used. Objects with interchangeable textures and materials provide varying challenges to different compensation methods. The setup should be both achievable and challenging for the placement of projectors and interaction with hand-held objects such as palettes and brushes. As the proposed idea falls into this field, it will be discussed in detail in the following pages.

- **Telecollaboration:** In telecollaboration, AR empowers us to leverage the benefits from both the worlds(real and virtual). Especially for interaction (tangible telecollaboration), both a physical and digital model has to exist, and for some tasks, two physical instances of the model. To support robotic telepresence, it would be advantageous to have models within reach of a robot arm.

Figure A.7: AR Telecollaboration Concept

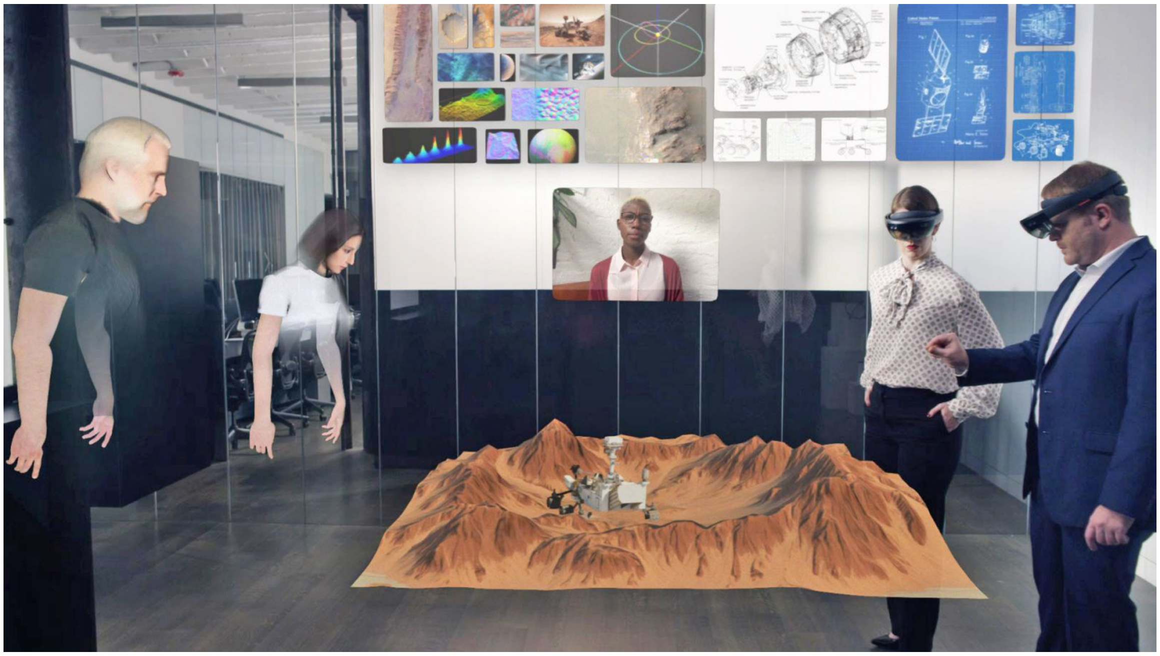


Figure A.8: AR Telecollaboration Concept

- **User interface design, Visualization in AR:** X-ray vision and label/annotation placement strategies are two commonly researched areas in visualization. Augmented Reality x-ray vision allows users to see through walls and view real occluded objects and locations [32]. Test objects should have a defined and plausible interior for X-ray visualization. They should provide 3D-referenced meta-information for labels, ideally enough in terms of complexity/hierarchy and quantity that naive display of all labels will lead to clutter, and advanced placement strategies and information filtering are needed [33].

- **Industrial/Military Maintenance:** One of the significant areas that could benefit from AR is maintenance and training in industrial or military contexts. Previously in 2007, Pentenrieder et al. presented a continuously developing industrial AR application process in a factory planning context. They employed various platforms from web-based PC to AR HMD and considered different quality measures to develop the application, such as usability and precision.

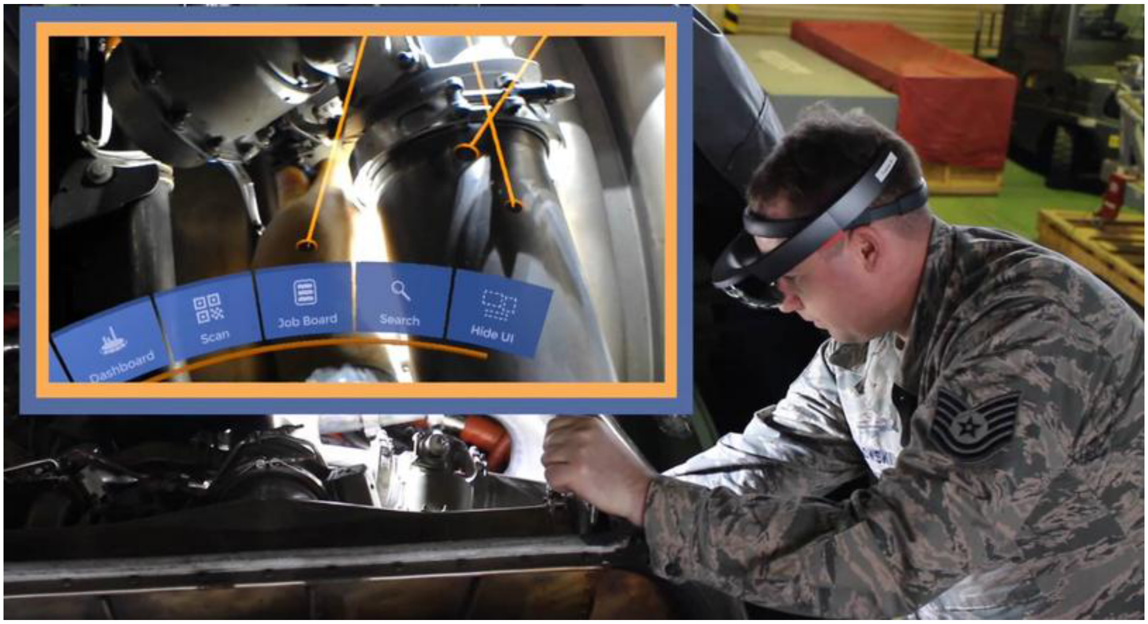


Figure A.9: AR Application in Military Maintenance

(a) (b)

Figure A.10: AR Application in Military/Industrial Maintenance

Two examples of such body of work are an outdoor AR application in a hand-held mobile platform that displays virtual redlining, which is an illustration of the underground infrastructure such as electricity or telecommunication lines, for field workers of utility companies; and an AR maintenance application for military mechanics to see visual guidelines in AR while dealing with an armored vehicle turret.

- **Medical Applications:** Another influential and popular application domain using AR is medical simulation and training. Applications in various medical or clinic contexts have continuously appeared in ISMAR. For instance, Bichlmeier et al. presented a medical AR application that superimposed 3D medical imaging data on the patient's body in real-time so that surgeons could see patient data without having to look away at different displays and also have a natural and intuitive perception of 3D medical imagery.

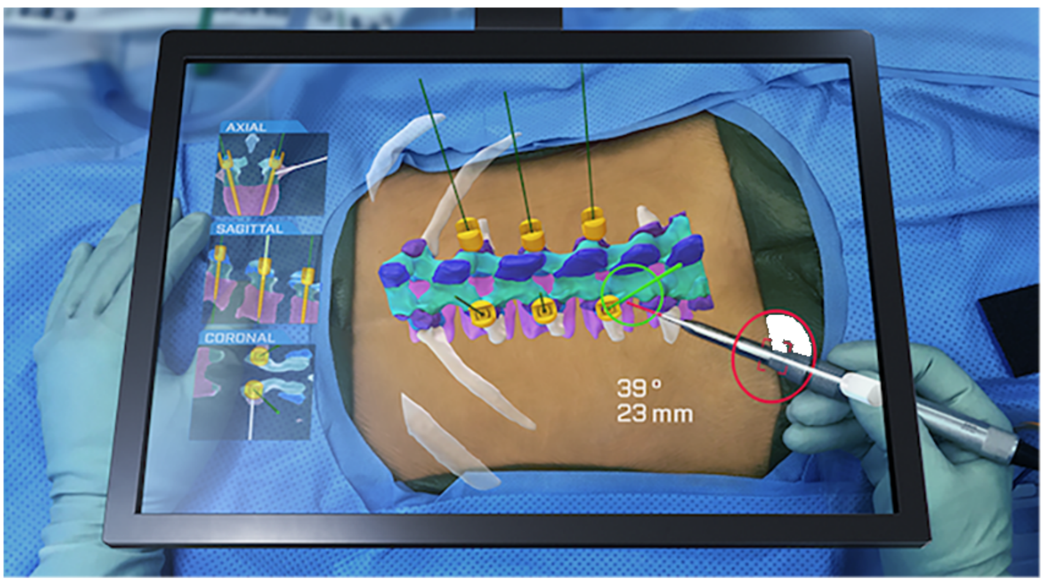


Figure A.11: AR Medical Application

In collaboration with Cleveland Clinic, Case Western Reserve University developed an AR app called HoloAnatomy, which helps medical students learn about the human body in 3D. HoloAnatomy teaches students anatomy using Microsoft Hololens. Such online educational AR apps can also be extremely useful in the current COVID-19 crisis [26].

(a)

(b) (c)

Figure A.12: HoloAnatomy Application

- **Games:** Entertainment and gaming are also considerable application domains for AR technology, as we saw from the success of Pokemon Go. Schmalstieg and Wagner introduced location-based museum game applications using handheld AR devices and fiducial markers and discussed users' positive feedback indicating the applications' practical value [34]. Chekhlov et al. proposed an automatic plane discovery method using a SLAM-based technique to build a game (fig:A.14) where a virtual character could jump around flat surfaces in the real world. Unlike typical AR applications that used a pre-defined real environment, this approach enabled the users to dynamically generate the planar surface based on the real game environment [35].

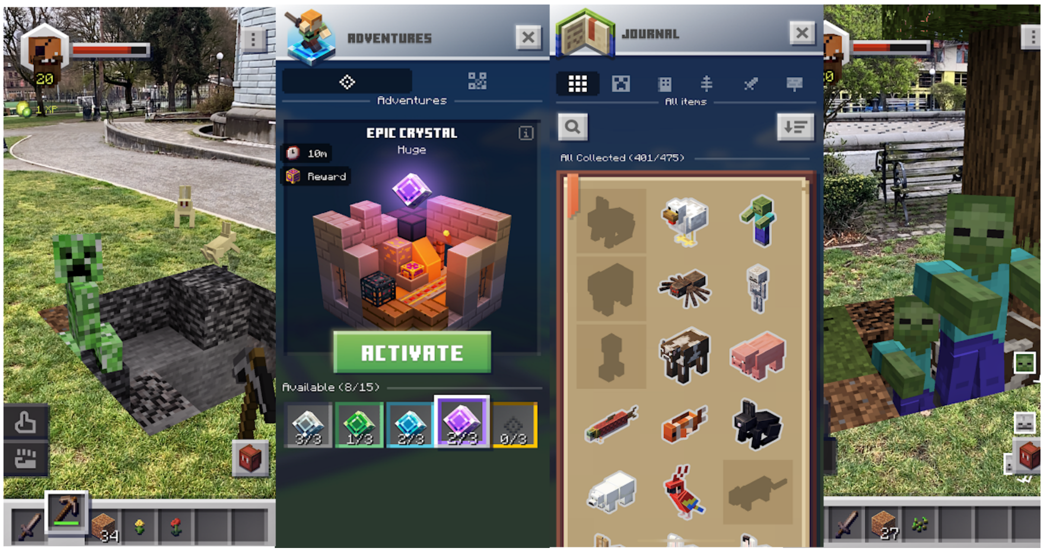


Figure A.13: AR Game Application

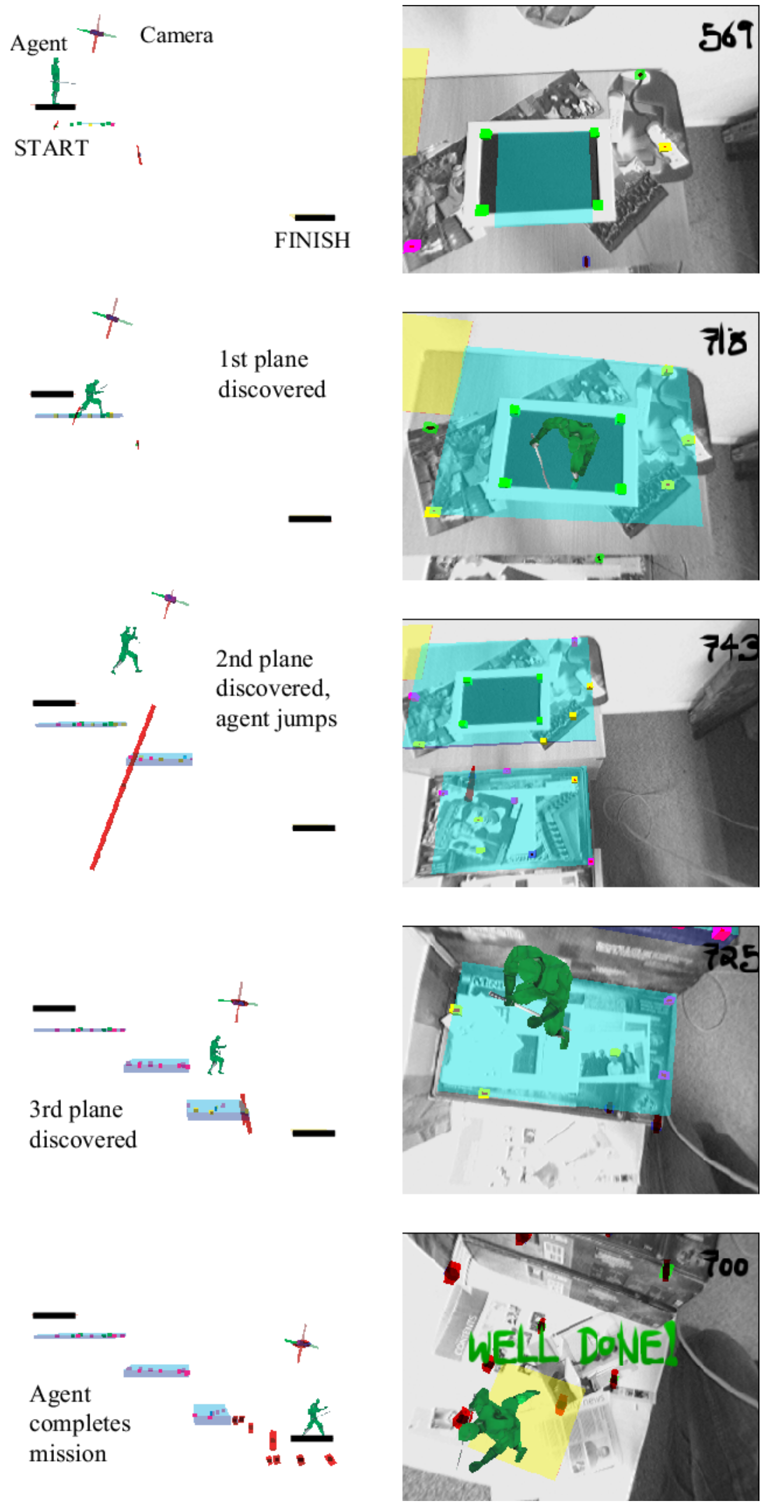


Figure A.14: "The Ninja on a Plane" Game

- **Tour Guide and AR Browsers:** A combination of AR technologies with tour guides, e.g. based on virtual agents, has been shown for museums, and cultural heritage sites, etc. For instance, Miyashita et al. presented an AR-based museum guide as an extension of existing audio guides.

In the domain of cultural heritage or city-size tours, AR browsers are a useful tool to visualize AR content. Macintyre et al. illustrated a city tour project (Argon 1) that benefited from their prototype web-based mobile AR framework, which leveraged other information available, e.g. Google Earth (Figure A.15) [36].

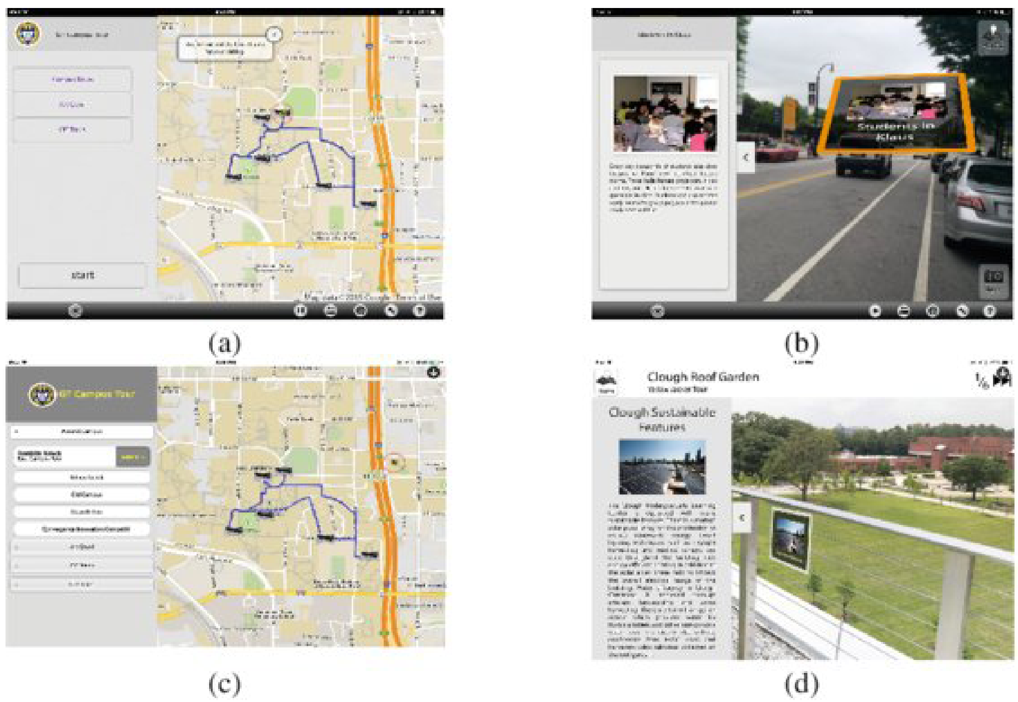
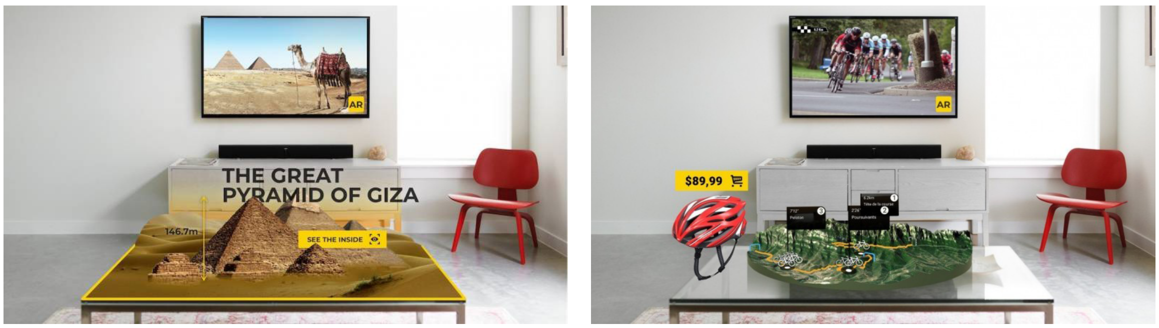


Figure A.15: Argon 1 Application

- **Telecommunication and Broadcasting:** AR could also be an excellent medium to replace or improve conventional telecommunication and broadcasting methods, such as phones, video conferencing, and televisions, because of the immersive experience that AR can provide. For instance, Fuchs et al. developed telepresence systems using animatronic Shader Lamps Avatars and commodity depth cameras like Kinect sensors for remote collaboration and telecommunication(Figure A.17) [37]. Likewise, for a broadcasting scenario, Grundhöfer et al.

described an approach employing an imperceptible coded image projected on a screen to achieve AR without harming the visual naturalness caused by ad-hoc marker patterns. They manifested the potential of this approach by adapting it for television studio situations [38].



(a) (b)

Figure A.16: AR 3D Broadcasting Application

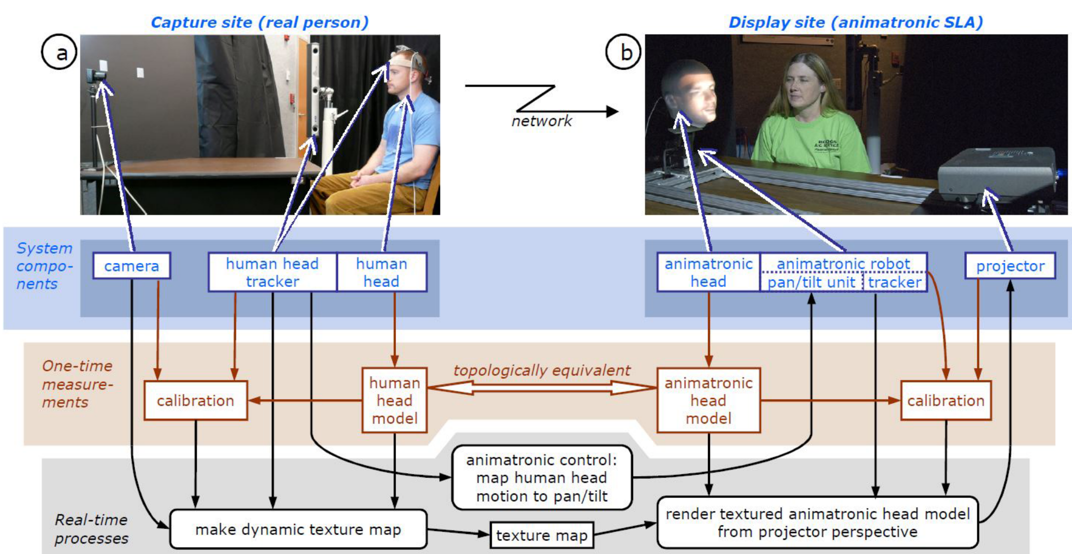


Figure A.17: Shader Lamps Avatar (SLA) User Capture and Display

- **Education:** Augmented reality is one of the most current technologies that offers innovative ideas about educating effectively and attractively. Most already available AR applications are developed for education, especially for natural sciences (chemistry, biology, physics, etc.) [39].

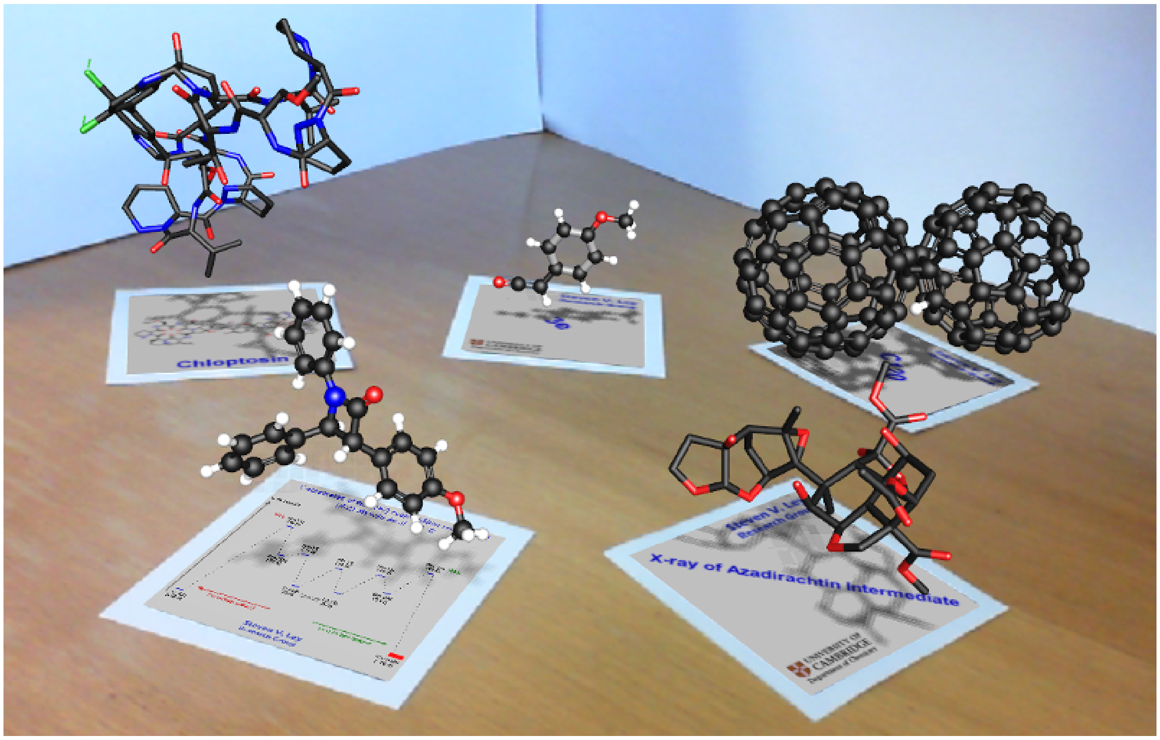


Figure A.18: AR Application for Education, e.g. Chemistry Lectures

A.5 Interaction Techniques and User Interfaces

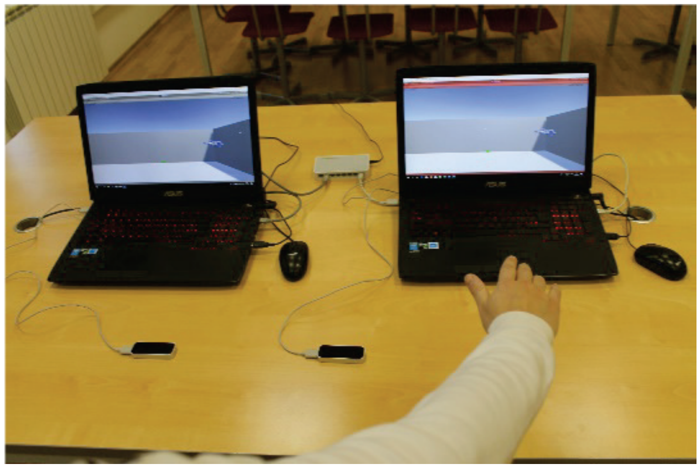
The usefulness of AR as perceived by practitioners and end-users in application domains is mainly dependent on effective and efficient user interfaces in AR. Hence, an important investigation direction is the development of interaction techniques with virtual content in AR. Some instances of AR interaction techniques are:

- **Tangible AR:** After the seminal concept of tangible user interfaces (TUIs) was presented by Ishii and Ullmer in 1997. The trend to move toward TUIs continued, and many AR research prototypes included physical objects as an intuitive way to interact with virtual content.

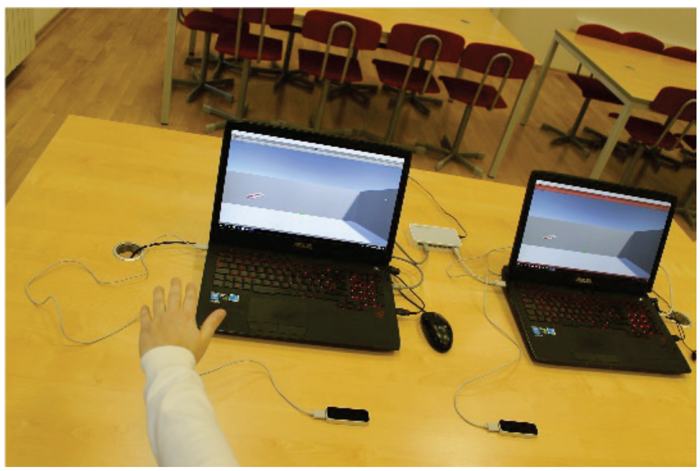
- **Mid-Air Interaction:** As an intangible alternative to TUIs, research on mid-air interaction has received wide-spread attention over the last ten years. Depictions of natural user interaction with intangible virtual content in AR have become more prominent in science fiction movies such as Iron Man (2008) (Fig. A.19), which shows a 3D user interface in AR. Moreover, advances have been made in mid-air hand tracking and gesture recognition technology such as the Leap Motion Controller (Fig. A.20).

Figure A.19: Once ideas in sci-fi movies were out of reach.

Ha et al., devoleped a user interface called WeARHand, which used a head-mounted display and depth sensors to track the user's hand in mid-air and included gestures to select and manipulate virtual 3D objects. The described method thus required no environmentally tethered tracking devices or gloves (Fig. A.21) [40]. The authors further included visual shadows and occlusion feedback with a semi-transparent virtual proxy-hand, thus addressing one persistent challenge in mid-air interaction with stereoscopic displays, the problem of users misperceiving depth.

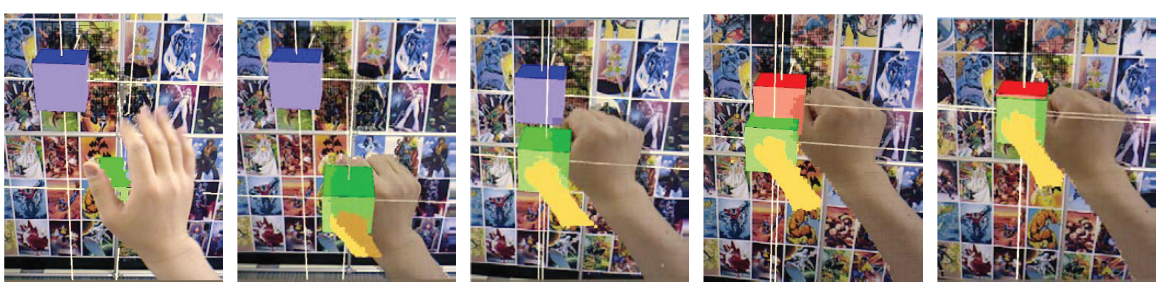


(a) Hand on the right in FOV of right sensor



(b) Hand on the left in FOV of left sensor

Figure A.20: Leap Motion Controller



(a) (b) (c) (d) (e)

Figure A.21: WeARHand User Interface: Employing AR version of the HOMER hand technique to 3D manipulation of a virtual object

3D manipulation of a virtual object using the AR version of the HOMER hand technique. The solid yellow virtual hand looks smaller

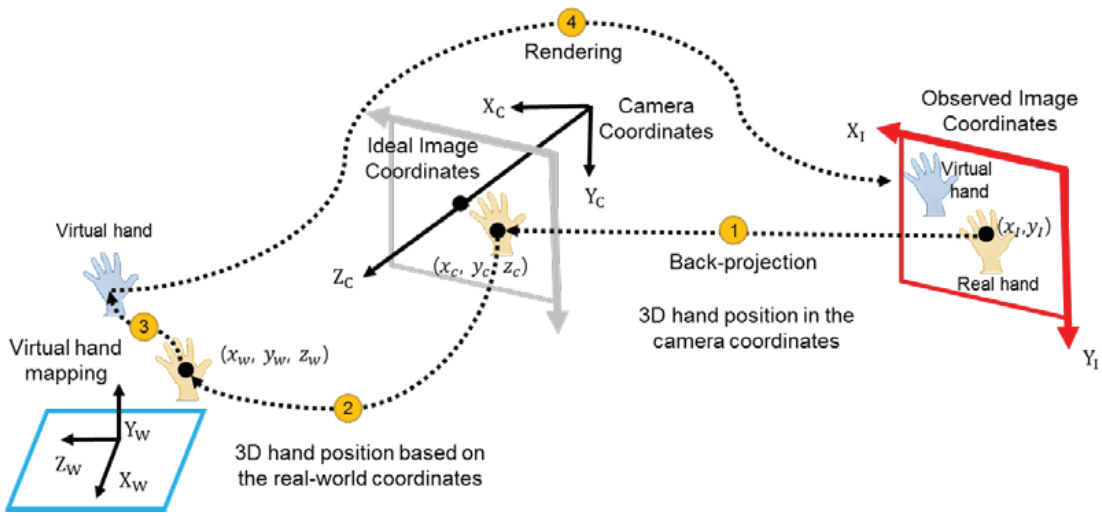


Figure A.22: Coordinate systems for image, camera, and world in the WeARHand user interface

- **Mobile Device User Interfaces:** Mobile AR devices include some form of the user interface for interaction with the virtual content. Research on such user interfaces is essential, which has been explicitly shown in an online survey on mobile AR applications presented by Olsson and Salo [41]. They found that 25 out of 90 participants in the survey commented on bad usability in general, a poor-looking user interface or a lack of user interface feedback in mobile AR applications they had experience with. Multiple papers over the last ten years presented user interfaces for mobile AR devices with improvements related to ergonomics and human factors. For instance, Veas and Kruijff, as well as Schall et al. proposed improvements to the ergonomic form factor of mobile AR devices, e.g., using one or two joystick handles attached to the AR device, which allows holding it for extended periods of time. Moreover, Baricevic et al. proposed providing a 3D of pointer for the user's dominant hand to interact with virtual objects while the non-dominant hand holds the mobile device showing an AR magic lens view (Fig. A.23) [42].

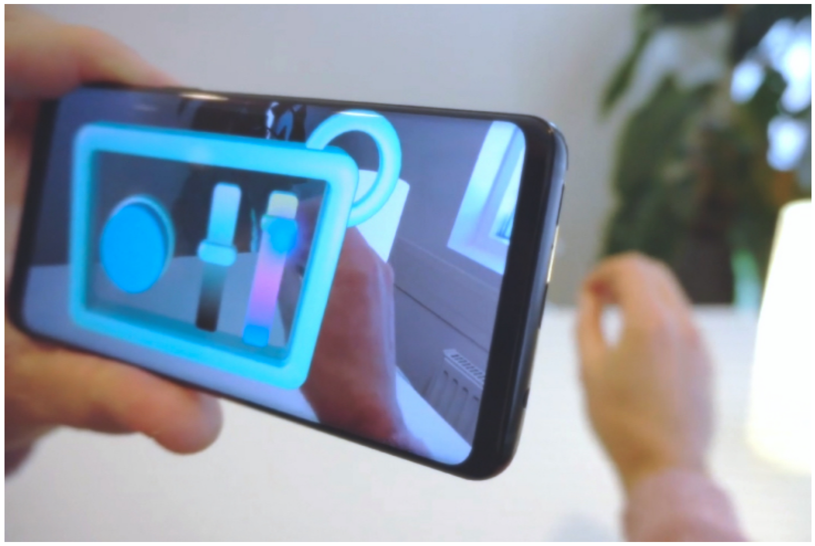


Figure A.23: Interacting with the virtual object

- **Collaborative User Interfaces** While many of the user interfaces presented at ISMAR over the last ten years are designed to be used by one user simultaneously, a small but increasing number of papers explicitly focused on ways to improve collaboration in AR or took the potential collaborative scenarios into account. Nilsson et al. received the Honorable Mention Award for presenting a collaborative AR tool for the police or military personnel for use in joint planning tasks to deal with catastrophic situations (Fig. A.24).

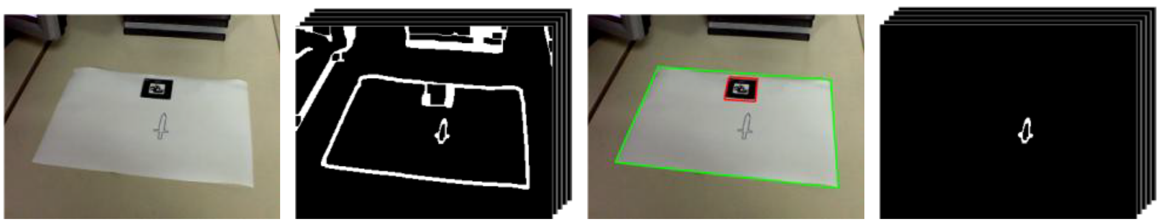
Figure A.24: The simulated natural setting (a helicopter base)

Unlike co-located collaborative scenarios, a particular challenge in remote collaborative AR systems is the physical absence of the remote users in the local collaboration space, That means one user at least should not be in the same physical space as others are. There are system and pipelines for capturing a user's head in real-time, streaming it over the network, and then projecting it onto a robotic physical head to give the illusion of seeing the remote user's head to multiple viewers.

Multiple papers have investigated eye contact during collaboration in AR and shown that eye contact is essential but challenging when using head-mounted displays (HMD) in co-located AR or remote collaboration in AR.

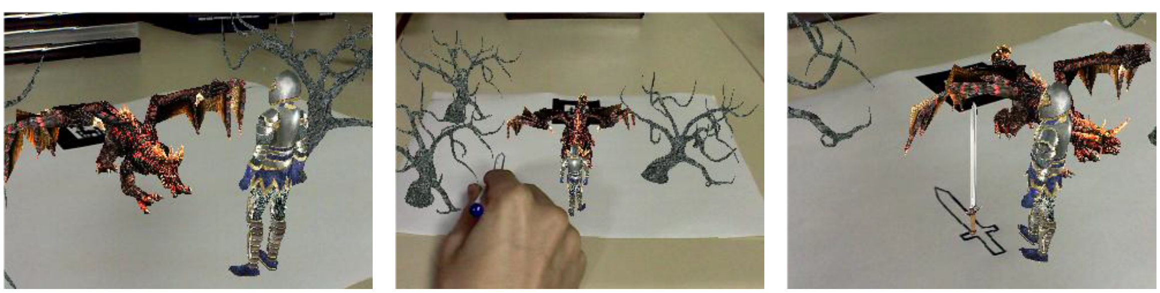
- **Authoring and Modeling:** In the field of AR authoring, the most often cited papers focused on sketching user interfaces. A paper by Bergig et al. described a framework in which a user can sketch objects on a paper sheet, which is then acquired by a webcam, and turned into a 3D virtual scene that is then augmented and simulated on top of the physical sketch. The described system stands out as it combines AR with sketching and allows users to sketch the objects in-place and modify them by editing the sketch itself. Printed sketches can be combined with hand sketches to form a scene.

For AR modeling, the most highly cited paper was presented by van den Hengel et al., which described an interactive process for generating 3D texture-mapped models of real objects within an AR system using an image-based modeling approach. The described system combined a real-time camera tracking system and automated image analysis with a user interface consisting of a range of modeling interactions (Fig. A.25 & Fig. A.26).



(a) input frame captured by the camera (b) segmented images (c) detection of the paper rectangle and the marker (d) set of candidate drawings

Figure A.25: Segmentation process



(a) A scene being dramatized in a virtual place (b) the user sketching an object; and finally (c) the sketched object (sword, in this case) coming to life in the augmented reality environment

Figure A.26: User Interaction

Figure 5User Interaction. Image (a) shows a scene being dramatized in a virtual place; image (b) shows the user sketching an object; and finally, image (c) shows the sketched object (sword, in this case) coming to life in the augmented reality environment.

- **Multimodal Interaction:** Multimodal interactions are still is a niche feature in AR. hand gestures and speech commands can be combined for effective interaction in AR. This multimodal interaction technique was named Gesture-Speech and was rated significantly higher in usability for specific tasks such as uniform resizing of virtual objects than other interaction techniques compared against [43]. The below illustration a simplified architecture of G-SIAR where the inputs are the raw hand poses data from 3Gear Nimble SDK, audio and depth images captured by Creative Senz3D, and dual video streams from the AR-Rift stereo cameras. The output includes visual feedback through the AR-Rift and audio feedback through speakers or headphones [38].

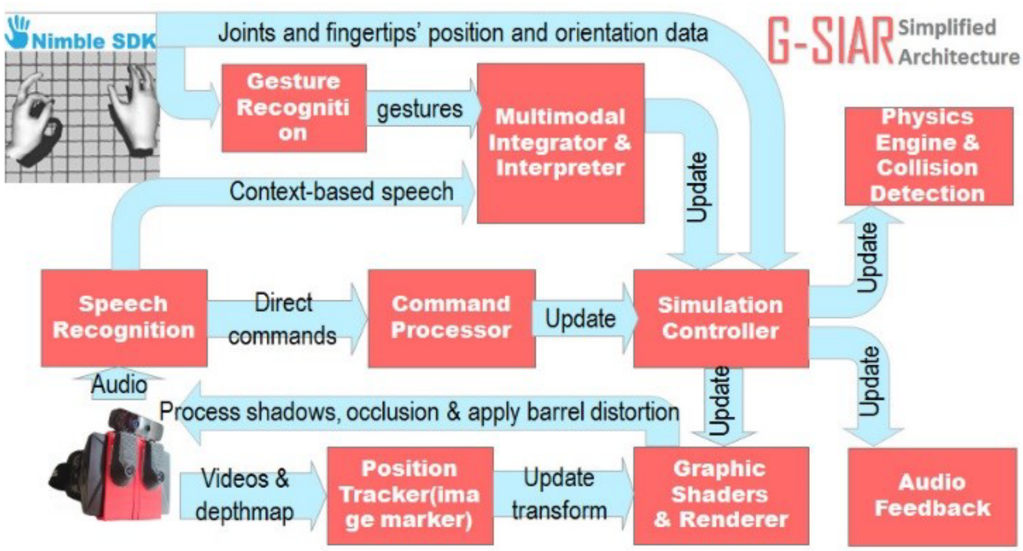


Figure A.27: G-SIAR Simplified Architecture

Figure A.28: Experimental Setup

A.6 Spatial Augmented Reality(SAR)

Spatial augmented reality (SAR) homogeneously fuses the real and virtual worlds by superimposing computer-generated graphics onto real surfaces spatially[44]. This tool for 3D visualization, could be used to improve a user's ability to view, understand, and manipulate 3D visualized data. It enhances physical objects' visual aspects, allowing users to understand the virtual content better[45].

The principle factors in Spatial Augmented Reality are:

- **Time:**

  By overlaying the images of a place taken at different times in history, the Spatial Augmented Reality could be applied to see the changes of that place over time as a historical reference.

  For instance, Haugstvedt and Krogstie described a mobile SAR application with old photographs and interesting information about a historical street (Figure A.29).

(a) (b)

Figure A.29: Mobile AR applications with cultural heritage resources

- **Material(See-through):**

  Augmented Reality could be used to display the hidden layers of the places and spaces. For instance, in a building, there are several layers of structure, plumbing system...that are hidden from the sight; By visualizing these layers with a SAR app, whenever they are needed they'd be available for the users.

Figure A.30: See-through the materiel

- **Scale:**

Some real-world objects are too small or too big to be perceived by human eyes. for instance, the COVID-19 virus is too small, and the solar system is too big. Employing Spatial Augmented Reality, we could visualize them by scaling up the first type and scaling down the second type to the human scale, so they became perceivable for humans.

Figure A.31: Visualization the solar system in an AR Application

A.6.1 Spatial Augmented Reality in the Architectural Practice

For architectural design, effective design collaboration is vital, as it helps to promote teamwork through encouraging cooperation and sharing stakeholders' ideas and project knowledge.

Lately, the application of building information modeling (BIM) has facilitated this matter. The technical core of BIM consists of 3D imagery and information management for buildings. Since all the data is accessible in 3D, BIM could further promote visualization as a method to exchange ideas and share knowledge.

Notwithstanding the advantages of visualizing architectural concepts using 3D models, existing BIM visualization platforms are not useful for sufficient design information sharing. In particular, even though 3D models could be built by BIM software, participants would still have to image and map the models on 2D display mediums into the 3D real space, which relies on the participants' spatial awareness. To address this issue, an attempt has been taken place to promote the process of translating modeling data into a further intuitive physical experience by combining simulated models with an actual environment. In this context, SAR has been introduced as an alternative visualization platform to effectively convey 3D models into realistic insights via BIM visualization's extended assistance. SAR is generally employed to enhance real-world objects and spaces by using digital information. In SAR, data that stimulates and enhances the real world is presented and integrated into the users' observation, sharing resources between an SAR display and users. These shared resources help to recognize associated issues and inspire a innovative method of solution generation. SAR additionally serves as an extension or a supplement of BIM to immerse abstract 3D images into the users' view of the real world, which reaches a more profound level of reality [46]. In general, it may be safe to say that SAR could be the future of 3D modeling and presenting in the architectural practice in any of its areas such as renovation, interior design, architectural design, etc.

A.7 Environment sensing

Spatial Augmented Reality is a technology that permits information stored digitally to be overlaid graphically and spatially on views of the real world [47].An operational SAR requires knowledge of the user's location and the position of all other objects of interest in the environment.[48]. In the proposed project, users' locations are the pivotal aspect of the data visualization; in the methodology, I will explain further about it.

A.8 Representation of information

Presentation and representation are distinct from each other. Representation depicts how information is organized, while the presentation displays that data. There is an unlimited number of methods that information can eventually be presented in AR[45].

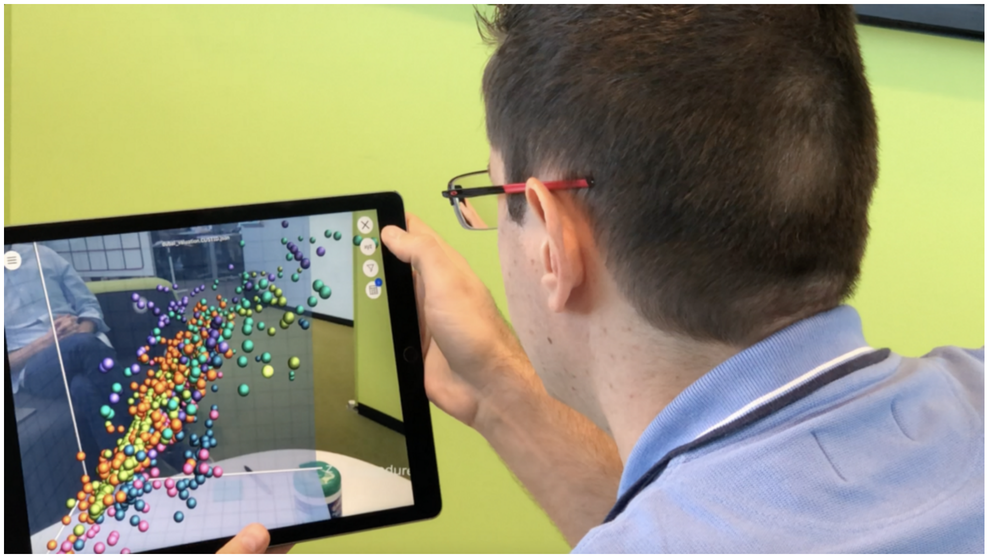


Figure A.32: Data Visualization in an AR Application

As it was mentioned in the section of different Types of Augmented Reality technology, virtual information in a 3D space, can be located in association with physical objects, locations, or events. Decomposing this presentation space - or more precisely, the principles of how data is represented in Augmented Reality - into unique and independent dimensions provides a whole spectrum of options. First, this decomposition promotes a fine-grained analysis of impacts on human perception. Second, various factors, given by varied differences between different presentation systems with respect to more than one such principle, can be determined and adequately addressed. Third, this decomposition expedites the determination of innovative fields of research by identifying not-yet-used theories[30].

Five orthogonal dimensions that address information representation for AR:

- **Temporality:** Consecutive versus discrete representation of virtual objects. The first dimension categorizes the representation of temporal assets. This dimension depends on the object's existence, independently of whether the object is within the field of view or not. Such differentiation is already known from desktop environments and human-computer interaction (HCI) in general. In the proposed project, the represented visualized data will be consecutive and present in the space all the time.

- **Dimensionality:** The number of characteristics (dimensions) that virtual and physical objects hold as well as techniques to visualize and render them. This dimension addresses the mapping and integration of virtual information into a physical environment.

  Physical reality presents plenty of characteristics of objects, such as shape, appearance, light reflection, stiffness, temperature, radiation, sound, and electrical conductivity, etc. Humans can perceive some of these physical dimensions with their senses. Visualization endeavors to reconstruct virtual information into human-perceptible representations. Rendering addresses the process of transferring the representations to physical devices such that we can truly see, hear, feel, taste, or smell them.

  In coupling physical and virtual reality, AR requires to go further by providing proper techniques for integrating both worlds into one that human users can experience as a consistent environment in which they can live and work.

- **Viewpoint reference frame:** This dimension addresses the frame of reference in which information is represented, the viewpoints of a rendering system, and those of a user. This dimension consists of three classes: ego-centric versus exo-centric and ego-motion-based control of viewpoints.

  Egocentric is a presentation from the identical viewpoint from which the users perceive the physical scenery. Egomotion is the viewpoint is different from the viewpoint of the user and/or the viewpoint of the virtual camera but is related to the user. And Exocentric is the viewpoint is different and independent of the

Definitions. An egocentric representation uses the viewpoint from which the user perceives the physical scenery. It thus places the virtual camera for object rendering equally to the user's viewing frame of reference so that the object is seen in the user's frame of reference. Such a display usually increases situational awareness and local guidance.The viewpoint reference frame in the proposed project is of this type. In contrast, an object shown from another perspective, such as a mini-map, uses an exocentric frame of reference.In my previous project in the studio lab class, I used this viewpoint reference frame in designing a mini-map for the navigation assistance for the users.In this viewpoint, The user's viewpoint is different and independent of the perspective of the virtual camera. The user's location is often (but not always) displayed as part of the world. If the camera has a particular relationship to the user, e.g., a mini-map showing the environment in a so-called face-up manner rather than a north-up manner, the term egomotion is used. The relation to the user can range from a single to several degrees of freedom.

- **Mounting/registration:** Spatial relationships between objects. This dimension locates the information concerning other objects. Two aspects are mixed together here. First is the actual mounting, which is defined by the concept of the application. Second is the technical tracking-related registration of objects relative to locations in the physical world. The properties of mounting define this dimension, and registration issues add supportive aspects with respect to technical difficulties.

  Mounting represents what a virtual object or unit of information is attached to. Information representation as spatial schemes is being placed around the users, placed in the virtual environment, or distributed throughout the physical environment. Going further along this train of thought, virtual information can have an infinite number of mounting-points in the physical world. For instance, objects can be hand-mounted, head-mounted, or connected to a physical object, or they can exist at a fixed position in the global world[30].In the proposed project, the visualized data will be fixed in the global world. However, the visualization will be updated continuously.

A.9 Work Flow

Although every system has its distinctive architecture, real-time performance can be achieved using the cloud. This data and workflow flowchart is illustrated in Figure **??**, shown specifically for AR mobile systems [26].

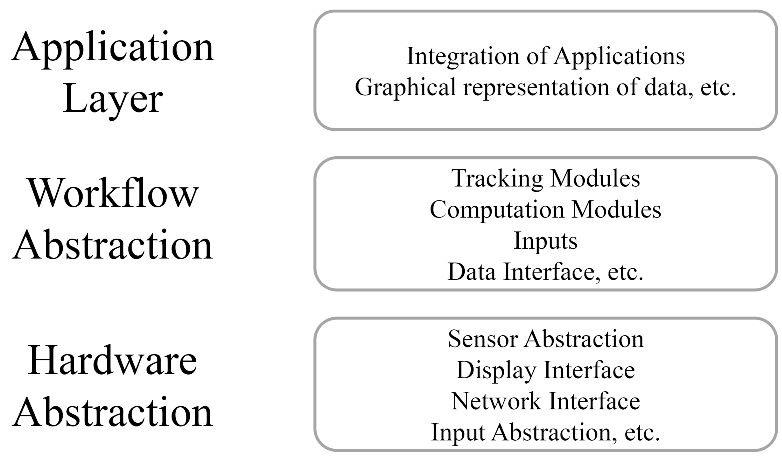


Figure A.33: Mobile AR Application Workflow

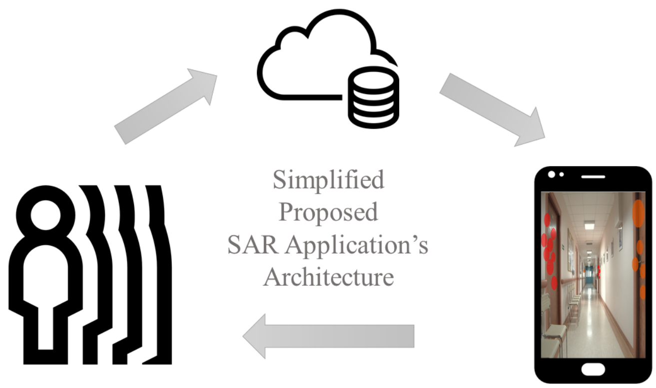


Figure A.34: Application Architecture

A.9.1 Smartphone Orientation Sensors

Smartphones have various built-in sensors, such as an accelerometer and a magnetometer for orientation determination and supplying the navigation process and positioning by PDR (Pedestrian Dead Reckoning). In PDR, for calculating the horizontal coordinates of the usersâ position, the heading and traveled distance are used, and for the height, a barometer can be used. Furthermore, a gyroscope also can be used to determine the orientation rate of a smartphone. Three angles, the Euler angles pitch θ, roll ϕ, and yaw ψ can be used to describe the orientation of mobile devices. clockwise rotation is a positive rotation for all angles(Figure. A.35) . Calculating positions in a specified coordinate system is the primary purpose of PDR. In the global system, the NED system (North(X-axis), East (Y-axis), Down(Z-axis)), is often is used in navigation tasks. for transforming the sensor measurements from the sensor coordinate system into the specified global system, the Euler angles are applied [49].

Figure A.35: The coordinate system of smartphones and corresponding orientation angles

A.10 Augmented Reality Frameworks

Augmented Reality Frameworks, are the tools employed for the development of AR applications, provide a coding environment where users can generate the functionalities that will compose software applications with the capacities and resources of augmented reality. These augmented reality SDKs promote many components within the AR application, for instance: *AR recognition*, *AR tracking*, and *AR content rendering*. In virtue of this area being in rise and continuously present in current researches, there are several AR frameworks available in the market [30]. These AR frameworks facilitate many components within the AR application.

Some AR SDKs that can be applied to develop applications for smartphones, tablets, and smart-glasses.

ARKit

IOS 11 introduced ARKit, which empowers developers to efficiently generate unparalleled augmented reality experiences for iPhones and iPads. By combining a virtual object with the real environment. ARKit uses Visual Inertial Odometry (VIO) to precisely track the world around it. ARKit can recognize horizontal planes (tables, floors, etc.), track and locate objects on smaller feature points. The ARKit working can be further improved utilizing SceneKit, Metal, or outsider programming, for example, Unreal Engine and Unity. ARKit Offers:

- Fast, stable motion tracking
- Plane estimation with primary frames
- Ambient lighting estimation
- Scale Estimations.
- SLAM tracking and sensor fusion

ARCore

As phones are compact and move through the world, ARCore utilizes a procedure called simultaneous odometry and mapping, or COM, to comprehend where the device is concerning its general surroundings. ARCore recognizes outwardly particular highlights in the caught camera picture called feature points and utilizes these focuses to register its adjustment in area. The visual data is joined with inertial estimations from the device IMU to assess the camera's posture (position and orientation) relative to the world over time.

By adjusting the virtual camera pose that renders 3D content with the posture of the device's camera given by ARCore, designers can render virtual substance from the right perspective. The rendered virtual picture or 3D object can be overlaid over the picture acquired from the device's camera, influencing it to show up as though the virtual substance a piece of this present reality.

Vuforia

Vuforia is a standout amongst the most popular platforms to enable users to work with augmented reality development, which recognizes the 2D planar image as well as various types of visual objects (plane, box, cylinder), text and environments recognition, VuMark (a combination of pictures and QR-code). Vuforia introduced ground plane detection, Next Generation Object Recognition, and Support for Apple's ARKit and Google's ARCore. Employing the Vuforia Object Scanner, users can scan and generate object targets (small, toy size objects). The recognition process can be implemented using a database. Unity plugin is simple to integrate and very convincing.

Vuforia Model Targets empower users to recognize and track real objects using a digital 3D model of the object. This process is supported by the shape of the object.

AR SDK type		ARCore	ARKit	Vuforia
Platform	IOS	No	Yes	No
	Android	Yes	No	Yes
	Windows	Yes	No	Yes

Figure A.36: Target platform comparison

AR SDK Programing languages	ARCore	ARKit	Vuforia
Java	Yes	No	Yes
Objectif C	No	Yes	Yes
Unity	Yes	Exists in experimental version as a plugin in Unity Asset store	Yes
Unreal	Yes	No	No
C/C++	No	No	Yes
JavaScript	No	No	No
Other	No	Xcode	No

Figure A.37: Development platform comparison

Technique / SDKs	Image Target	Motion Tracking	Ground & plan detection
ARCore ARKit	Not stable, unexpected high drifts	Stable most of the times	Stable, but drifts due to anchoring issues when the ARKit screen is changing orientation
Vuforia	Very stable	Not stable, disparity in orientation occurs	Looks like it detects based on orientation and not with feature points

Figure A.38: comparison based on tracking feature

SDK	Recognition			SLAM	Multiple target	Extended tracking
	2D	3D	Cloud			
ARCore	No	No	No	Yes	No (not applicable)	No
ARKit	Yes	Yes	No	Yes	Yes	No
Vuforia	Yes	Yes	Yes	Yes	Yes	Yes

Figure A.39: Comparison based on functionalities

In the light of these comparisons, from the variety of SKD libraries and depending on planned features, the Vuforia SDK has been chosen for our task. Vuforia offered the best feature pack with generous support from the developer community, including integration into Unity. Notwithstanding complex and not suitable license options, which could later result in the incapability to make a free deployment of the application on Google Play or other platforms, Vuforia was evaluated as the best.