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Determination and Implementation of the Shortest Path for Emergency Evacuation at the Bali Dwipa University Building: A Case Study

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ABSTRACT

This study applies the Floyd Warshall Algorithm to determine the shortest emergency evacuation route in the Bali Dwipa University building. An efficient and fast evacuation route is essential to ensure the safety of all building occupants. This study was conducted at Bali Dwipa University, Denpasar, Bali, to evaluate and map the building layout to the third floor as part of the evacuation system analysis. The research methodology involves collecting primary and secondary data and direct manual measurements in the field. The research stages begin with creating a building plan, which includes collecting information on the layout and existing evacuation procedures. Furthermore, using a precision measuring instrument, mapping the relationship between objects is carried out with manual measurements of the distance between rooms to determine the evacuation route to a safe point. The results of these measurements are analyzed to build a spatial structure by selecting the nodes and edges in the graph that represent the building. Then, the Floyd-Warshall algorithm is implemented to find the shortest path from each room to the gathering point, located in the first floor's lower front yard. The study results indicate that applying the Floyd-Warshall algorithm effectively determines the shortest path from each node in the Bali Dwipa University building to the main evacuation point. By mapping the nodes from the 1st to the 3rd floor and measuring the distance between the nodes, this study produces a clearly defined optimal evacuation route. This study is expected to improve the efficiency of evacuation routes and the safety of occupants in emergencies.

Key Words: Emergency Evacuation Routes, Floyd-Warshall Algorithm, Graph Theory.

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1. INTRODUCTION

Rapid and safe evacuation from buildings is crucial in emergencies such as fires, earthquakes, or other natural disasters. Bali Dwipa University, as an educational institution with a large population, requires an effective evacuation system to ensure the safety of all its occupants. This study was initiated by direct observation to map the building layout of Bali Dwipa University, focusing on rooms actively used by many people across three floors. Distances between nodes were meticulously measured to ensure the accuracy of the Floyd-Warshall algorithm application.

The research problem addressed here is the urgent need for an efficient and rapid evacuation system that minimizes emergency risks. Graph theory and the shortest path concept play pivotal roles in this context. Graph theory represents the relationships between rooms and areas within a building, while the shortest path concept—central to the Floyd-Warshall algorithm—aims to identify routes with the minimum total distance between two nodes.

This study involves creating a building floor plan up to the third floor, mapping relationships between objects (rooms, corridors, stairs, and nodes), and analyzing spatial structures to define nodes and edges in the graph representing the building. By mapping 71 nodes representing various rooms and areas within the building and measuring distances between these nodes, this research aims to provide optimal solutions for different emergency evacuation scenarios. This approach offers the shortest evacuation routes and aids in risk planning and management within the campus environment.

Some studies on the Floyd-Warshall algorithm are as follows: Smith, J., & Lee, A. (2020) presented a parallel version of the Floyd–Warshall algorithm optimized for multi-core processors, significantly reducing computational time for large-scale graphs. In the same year[1], Nguyen, T., & Patel, R. explored modifications to the Floyd–Warshall algorithm to reduce energy consumption in embedded systems without sacrificing computational accuracy [2]. Oliveira, R., & Silva, P. (2020) applied the Floyd–Warshall algorithm to social network graphs, demonstrating its usefulness in identifying shortest paths between individuals in large social structures [3]. Ahmed, S., & Wang, H. (2020 discussed the challenges of applying the Floyd–Warshall algorithm to the big data context, proposing a scalable solution to handle large datasets effectively[4].

A year later, Garcia, M., & Thompson, D. (2021) compared the Floyd–Warshall algorithm with other shortest path algorithms in a dynamic network environment, highlighting scenarios where Floyd–Warshall remains advantageous [5]. Zhang, L., & Kumar, S. (2021) proposed an enhancement to the traditional Floyd–Warshall algorithm, which yields better performance metrics when applied to dense graph structures [6]. Brown, E., & Davis, L. (2022) examined various shortest path algorithms, with a detailed analysis of the performance of the Floyd–Warshall algorithm in various weighted directed graph scenarios [7].

Hanif, M. K., Zimmermann, K.-H., & Anees, A. (2022) formulate parallel versions of the Floyd–Warshall and Torgasin–Zimmermann algorithms to efficiently compute shortest paths in bipartite graphs, achieving a speedup of nearly 274 compared to the serial Floyd–Warshall algorithm for randomly generated undirected graphs [8]. Xian, S., Ma, D., Guo, H., & Feng, X. (2023) introduce a novel Pythagorean-hesitant fuzzy linguistic term set to describe complex travel route information and propose a dynamic programming model, leveraging the Floyd–Warshall algorithm to find optimal routes considering multiple factors [9]. Gómez Rivera, U. Á., Pérez Olguín, I. J. C., Pérez Domínguez, L. A., Rodríguez-Picón, L. A., & Méndez-González, L. C. (2023) present a continuous supply chain optimization tool that integrates the Floyd–Warshall algorithm with Google Maps to determine the shortest routes between all pairs of locations, aiming to optimize transportation costs and reduce delivery times [10]. Calderón, S., Rucci, E., & Chichizola, F. (2024) adapt the Floyd–Warshall algorithm developed for Xeon Phi KNL processors to run on Intel x86 processors, introducing new optimizations that improve performance by up to 23% in computing all pairs of shortest paths [11].

Relevant literature demonstrates the applicability of the Floyd-Warshall algorithm in various contexts. For instance, study by Yulia Darnita et al. at the Muhammadiyah University of Bengkulu used the same algorithm to determine the optimal location for a travel company in Bengkulu [12]. Furthermore, research by Friska Widya Ningrum and Tatyantoro Andrasto at Semarang State University utilized this algorithm to model tourism networks in Semarang City, while tsunami evacuation optimization was achieved using Dijkstra's algorithm [13].

Additional studies exploring evacuation routes in different settings provide further theoretical support. For example, Nixon S. Mantiri and his team examined evacuation routes in dormitory buildings at Manado State Polytechnic [14], while Yohanes Satyayoga Raniasta conducted a case study on integrating evacuation routes in high-rise public buildings at Duta Wacana Christian University[15]. These studies highlight the effectiveness of graph theory and shortest-path algorithms in designing safe and efficient evacuation systems.

By implementing the Floyd-Warshall algorithm, this study aims to significantly enhance safety and security at Bali Dwipa University. The research identifies the shortest evacuation routes and contributes to better risk planning and management at the university, ensuring the safety of all occupants during emergencies. It seeks to fill the gap by providing a campus-specific evacuation system tailored to the unique layout and usage of Bali Dwipa University buildings.

2. LITERATURE SURVEY

This study explores the application of the Floyd-Warshall algorithm in designing emergency evacuation routes in the Bali Dwipa University building. The following is a summary of the literature review that supports this study:

Implementation of the Floyd-Warshall Algorithm in Other Contexts:

a. Yulia Darnita et al. applied this algorithm to determine the location of travel companies in Bengkulu, which shows the flexibility of the algorithm's application in various scenarios [12].

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b. Friska Widya Ningrum and Tatyantoro Andrasto used it to model the tourism network in Semarang City, emphasizing the algorithm's ability to handle large-weight graphs [13].

Previous Studies on Emergency Evacuation:

a. Nixon S. Mantiri and team studied the evacuation route in the Manado State Polytechnic dormitory building. This study is relevant in identifying emergency evacuation needs in multi-storey public buildings [14].

b. Yohanes Satyayoga Raniasta integrated evacuation routes with a space syntax approach for school buildings, which enriched the design of a graph theory-based evacuation system [15].

This study is supported by graph theory and the shortest path algorithm. The Floyd-Warshall algorithm has been proven to optimize evacuation routes through adjacency matrix simulation and weighted graph analysis. The above approaches provide a strong foundation for implementing the Floyd-Warshall algorithm in this study. This study integrates concepts from previous studies to produce efficient and safe evacuation routes. This study also contributes by adapting the algorithm to the Bali Dwipa University building, ensuring the safety of occupants in emergency scenarios.

3. OBJECTIVE OF RESEARCH

This research was conducted at Bali Dwipa University at Jalan Raya Puputan No. 108, Panjer, South Denpasar, Denpasar City, Bali, Indonesia. This research method involves collecting primary and secondary data and direct manual measurements in the field.

a. Making a Building Plan up to the Third Floor: Collecting information related to the building layout and existing evacuation procedures.

b. Mapping the relationship between objects and Direct Measurement: Measure the distance between each room manually to determine the evacuation point to the safe point. Measurements are made using the right measuring instruments and documented in detail.

c. Analysis of spatial structure: determining the nodes and edges in the graph that represent the building.

4. RESEARCH METHODOLOGY

a. Literature Review: Understand the basic concepts of graph theory, the Floyd-Warshall algorithm, and its application in emergency evacuation route planning.

b. Identification of Data Sources: Identify building maps, geospatial data, occupant information, and other data relevant to the research.

c. Data Collection: Collect data from identified sources. The data collection process involves field surveys and direct measurements on-site. The data obtained is documented in detail to ensure accuracy.

d. Graph Formation: Form an undirected graph that represents the structure of the Bali Dwipa University building using nodes and edges. Each node represents an area or room, while the edge describes the relationship between rooms.

e. Determination of Weights on Graph Sides: Determine the weights on each side of the graph based on the distance between rooms. This weight reflects the factors influencing emergency evacuation and is obtained from direct measurement results.

f. Adjacency Matrix: Determine the adjacency matrix of an undirected weighted graph using the following steps: a. Vertex Identification: Determine the number of vertices in the graph to determine the matrix dimensions. b. Matrix Initialization: Create a matrix with all elements initialized with an infinite value (INF) if the vertices are not adjacent. c. Assign Weights: For each pair of adjacent vertices, assign matrix elements with edge weights that represent the distance between the vertices [16].

g. Implementation of the Floyd-Warshall Algorithm: This algorithm is used to find the shortest path from each vertex in a building to an emergency exit or gathering point with the following steps: a. Initialization: Start with a distance matrix equal to the graph weight. If an edge exists between two vertices, fill it with an infinite

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value. b. Main Iteration: For each vertex (considered an intermediate vertex), iterate through all other vertices. c. Update Distance Matrix: In each iteration, compare the direct distance with the distance passing through the intermediate vertex. If the distance through the intermediate node is shorter, update the distance matrix [17].

h. Result Validation: Validate the evacuation route results generated by the algorithm. Validation can be done through simulation and field testing to ensure that the resulting evacuation route is effective and can be implemented in real emergencies.

This research method is expected to obtain an optimal evacuation route for Bali Dwipa University, improving the safety and security of building occupants in emergencies.

5. RESULT AND DISCUSSION

The author has formed an accurate graph model in presenting between objects, namely covering all rooms, hallways, corridors, and stairs in all buildings. An in-depth survey was conducted on each floor and building area to ensure an appropriate representation of the graph model.

a. Mapping of floor 1

The following is a floor plan of the first floor, the author analyzes the structure of the room and determines the evacuation route including the path from each room to the gathering point. The first floor has more space and partitions than other floors and makes its route more than others.

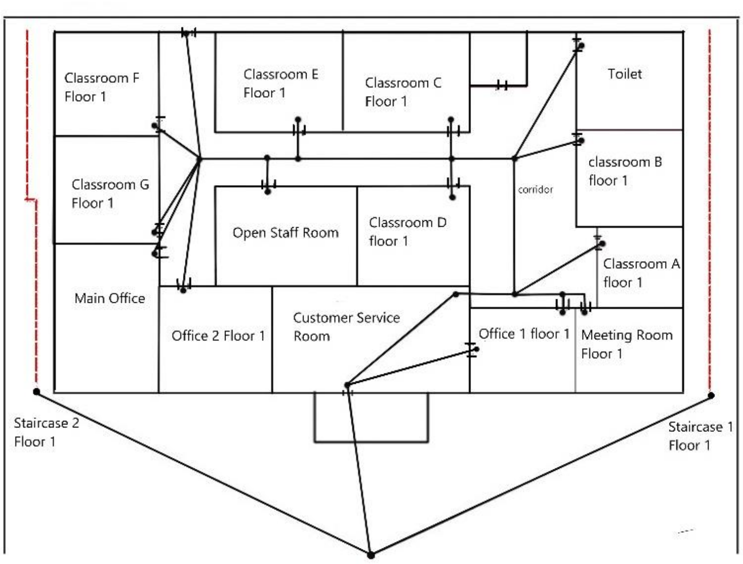

Figure 1. Floor Plan and Route of Bali Dwipa University Building, 1st Floor

b. Mapping the second floor

The second floor has fewer routes than the first floor and has easier paths and nodes; in going to the second floor, there are two stairs on the left and right of the building; here is a picture of the second floor; on the left is the plan and on the right is the designed route.

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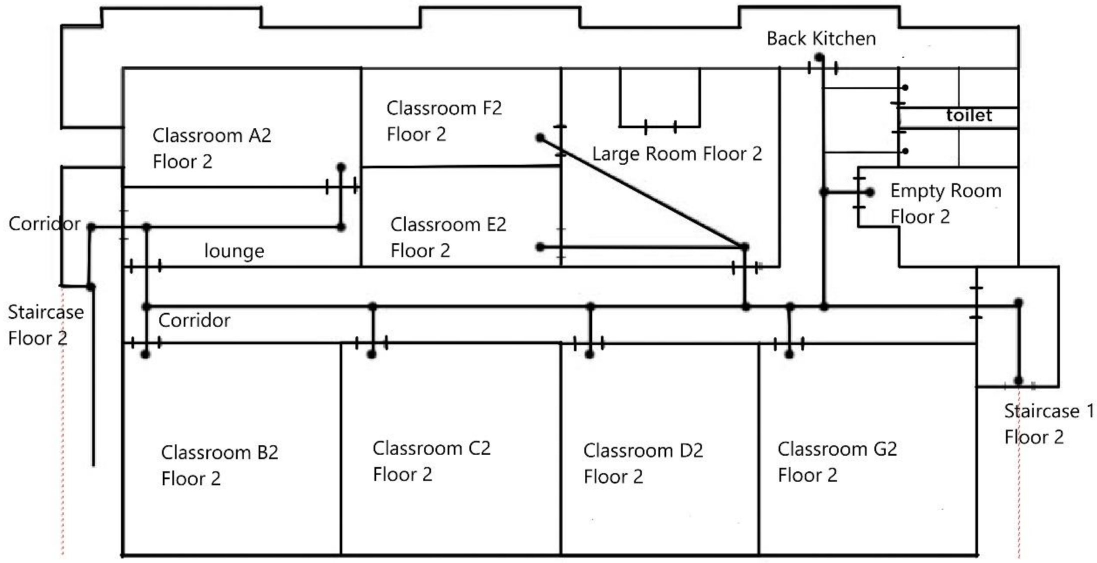

Figure 2. Floor Plan and Route of Bali Dwipa University Building, 2nd Floor

c. Mapping the third floor

The third floor has the character of a wider room and less space, and the measurement of the room is in the door area. To get to or out of the third floor there are two main stairs on the left and right of the building. The following is a picture of the floor plan and route of the 3rd floor (on the left is the plan, and on the right is the route).

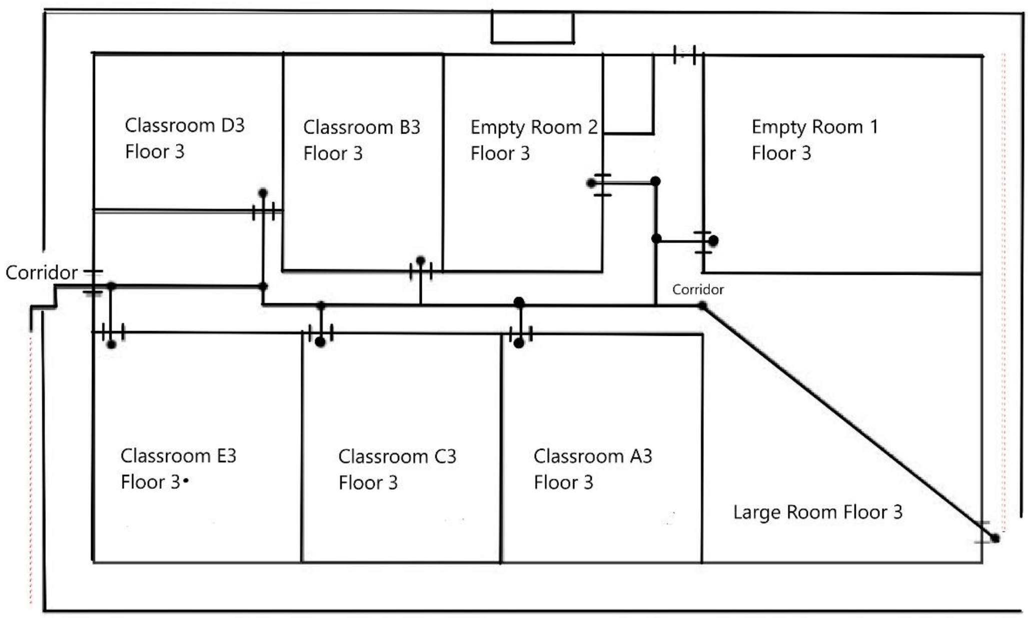

Figure 3. Floor Plan and Route of Bali Dwipa University Building, 3rd Floor

Room data and gathering points (v1) are obtained based on images 1, 2, and 3 and then adjusted to the node name. The list of rooms from the 1st and 2nd floor buildings of Bali Dwipa University can be seen in Table 2.

Next, the researcher conducted a direct observation of the building and identified every important node in the building, such as doors, stairs, and main paths, with a total of 71 nodes observed and recorded, in addition to including critical factors such as direction, corridor width, stair capacity, and exit location. The distance data was then entered into an adjacency matrix, which presents the relationship between each vertex node in the form of a graph.

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Table 2. List of Rooms at Bali Dwipa University

No	Node	Room	No	Node	Room
1	V2	Staircase 1 Floor 1	25	V32	Corridor
2	V3	Staircase 2 Floor 1	26	V33	Classroom B2 Floor 2
3	V4	Customer Service Room	27	V34	Classroom A2 Floor 2
4	V5	Office 1 Floor 1	28	V37	Classroom C2 Floor 2
5	V9	Office 1 Floor 1 Second Door	39	V38	Classroom E2 Floor 2
6	V10	Meeting Room Floor 1	30	V39	Classroom F2 Floor 2
7	V11	Classroom A Floor 1	31	V41	Classroom D2 Floor 2
8	V12	Corridor	32	V42	Large Room Floor 2
9	V13	Classroom B Floor 1	33	V45	Classroom G2 Floor 2
10	V14	Toilet	34	V47	Back Kitchen Floor 2
11	V15	Classroom C Floor 1	35	V51	Toilet 1
12	V16	Classroom D Floor 1	36	V52	Toilet 2
13	V18	Classroom E Floor 1	37	V53	Empty Room Floor 2
14	V21	Open Staff Room	38	V54	Staircase 1 Floor 2
15	V22	Back Room Floor 1	49	V55	Large Room Floor 3
16	V23	Classroom F Floor 1	40	V56	Corridor
17	V24	Classroom G Floor 1	41	V58	Empty Room 1 Floor 3
18	V25	Corridor Floor 1	42	V59	Empty Room 2 Floor 3
19	V26	Main Office	43	V61	Classroom A3 Floor 3
20	V27	Office 2 Floor 1	44	V63	Classroom B3 Floor 3
21	V28	Corridor Floor 2	45	V66	Classroom C3 Floor 3
22	V29	Staircase Floor 2	46	V67	Classroom D3 Floor 3
23	V30	Corridor	47	V69	Classroom E3 Floor 3
24	V31	Lounge	48	V71	Corridor Floor 3

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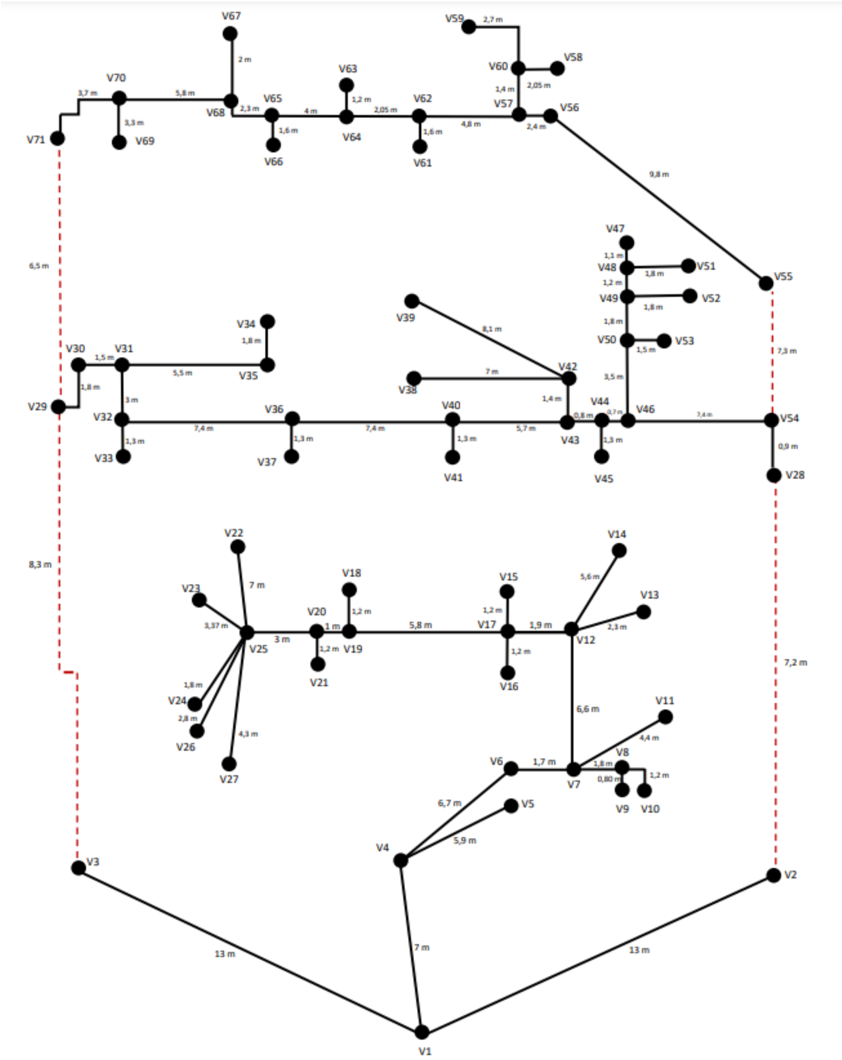

Figure 4. Weighted Graph

From the graph obtained, the next step is to form an adjacency matrix as explained in the theoretical basis, then implement it in the Floyd-Warshall algorithm in the C++ programming language.

```
void floydWarshall(vector<vector<double>>& graph, int V, int target) {
    vector<vector<double>> dist = graph;
    vector<vector<int>> next(V, vector<int>(V, -1));

    for (int i = 0; i < V; i++) {
        for (int j = 0; j < V; j++) {
            if (graph[i][j] != INF) {
                next[i][j] = j;
            }
        }
    }

    for (int k = 0; k < V; k++) {
        for (int i = 0; i < V; i++) {
            for (int j = 0; j < V; j++) {
                if (dist[i][k] != INF && dist[k][j] != INF && dist[i][k] +
                    dist[k][j] < dist[i][j]) {
                    dist[i][j] = dist[i][k] + dist[k][j];
                    next[i][j] = next[i][k];
                }
            }
        }
    }

    printResults(dist, next, V, target);
}
```

Figure 5. Floyd Warshall's C++ Syntax

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Discussion

The results of the C++ calculations to determine the shortest path from each room to the gathering point will be presented in the table below.

Table 3. The shortest route from Bali Dwipa University Room

No	Room	Node	Evacuation Route	Distance (m)
1	Staircase 1 Floor 1	V2	v2 -> v1	13
2	Staircase 2 Floor 1	V3	v3 -> v1	13
3	Customer Service Room	V4	v4 -> v1	7
4	Office 1 Main Door	V5	v5 -> v4 -> v1	12.9
5	Office 1 Second Door	V9	v9 -> v8 -> v7 -> v6 -> v4 -> v1	18
6	Meeting Room Floor 1	V10	v10 -> v8 -> v7 -> v6 -> v4 -> v1	18.4
7	Classroom A Floor 1	V11	v11 -> v7 -> v6 -> v4 -> v1	19.8
8	Corridor	V12	v12 -> v7 -> v6 -> v4 -> v1	22
9	Classroom B Floor 1	V13	v13 -> v12 -> v7 -> v6 -> v4 -> v1	24.3
10	Toilet	V14	v14 -> v12 -> v7 -> v6 -> v4 -> v1	27.6
11	Classroom C Floor 1	V15	v15 -> v17 -> v12 -> v7 -> v6 -> v4 -> v1	25.1
12	Classroom D Floor 1	V16	v16 -> v17 -> v12 -> v7 -> v6 -> v4 -> v1	25.1
13	Classroom E Floor 1	V18	v18 -> v19 -> v17 -> v12 -> v7 -> v6 -> v4 -> v1	30.9
14	Open Staff Room	V21	v21 -> v20 -> v19 -> v17 -> v12 -> v7 -> v6 -> v4 -> v1	31.9
15	Back Room Floor 1	V22	v22 -> v25 -> v20 -> v19 -> v17 -> v12 -> v7 -> v6 -> v4 -> v1	40.7
16	Classroom F Floor 1	V23	v23 -> v25 -> v20 -> v19 -> v17 -> v12 -> v7 -> v6 -> v4 -> v1	37.07
17	Classroom G Floor 1	V24	v24 -> v25 -> v20 -> v19 -> v17 -> v12 -> v7 -> v6 -> v4 -> v1	35.5
18	Corridor Floor 1	V25	v25 -> v20 -> v19 -> v17 -> v12 -> v7 -> v6 -> v4 -> v1	33.7
19	Main Office	V26	v26 -> v25 -> v20 -> v19 -> v17 -> v12 -> v7 -> v6 -> v4 -> v1	36.5
20	Office 2 Floor 1	V27	v27 -> v25 -> v20 -> v19 -> v17 -> v12 -> v7 -> v6 -> v4 -> v1	38
21	Corridor Floor 2	V28	v28 -> v2 -> v1	20.2
22	Staircase Floor 2	V29	v29 -> v3 -> v1	21.3
23	Corridor	V30	v30 -> v29 -> v3 -> v1	23.1
24	Lounge	V31	v31 -> v30 -> v29 -> v3 -> v1	28.9
25	Corridor	V32	v32 -> v31 -> v30 -> v29 -> v3 -> v1	27.6
26	Classroom B2 Floor 2	V33	v33 -> v32 -> v31 -> v30 -> v29 -> v3 -> v1	28.9
27	Classroom A2 Floor 2	V34	v34 -> v35 -> v31 -> v30 -> v29 -> v3 -> v1	31.9
28	Classroom C2 Floor 2	V37	v37 -> v36 -> v32 -> v31 -> v30 -> v29 -> v3 -> v1	36.3
29	Classroom E2 Floor 2	V38	v38 -> v42 -> v43 -> v44 -> v46 -> v54 -> v28 -> v2 -> v1	37.8

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30	Classroom F2 Floor 2	V39	v39 -> v42 -> v43 -> v44 -> v46 -> v54 -> v28 -> v2 -> v1	38.9
31	Classroom D2 Floor 2	V41	v41 -> v40 -> v43 -> v44 -> v46 -> v54 -> v28 -> v2 -> v1	37
32	Large Room Floor 2	V42	v42 -> v43 -> v44 -> v46 -> v54 -> v28 -> v2 -> v1	30.8
33	Classroom G2 Floor 2	V45	v45 -> v44 -> v46 -> v54 -> v28 -> v2 -> v1	30.5
34	Back Kitchen Floor 2	V47	v47 -> v48 -> v49 -> v50 -> v46 -> v54 -> v28 -> v2 -> v1	36.1
35	Toilet 1	V51	v51 -> v48 -> v49 -> v50 -> v46 -> v54 -> v28 -> v2 -> v1	36.8
36	Toilet 2	V52	v52 -> v49 -> v50 -> v46 -> v54 -> v28 -> v2 -> v1	35.3
37	Empty Room Floor 2	V53	v53 -> v50 -> v46 -> v54 -> v28 -> v2 -> v1	33.5
38	Staircase 1 Floor 2	V54	v54 -> v28 -> v2 -> v1	21.1
39	Large Room Floor 3	V55	v55 -> v54 -> v28 -> v2 -> v1	28.4
40	Corridor	V56	v56 -> v55 -> v54 -> v28 -> v2 -> v1	38.2
41	Empty Room 1 Floor 3	V58	v58 -> v60 -> v57 -> v56 -> v55 -> v54 -> v28 -> v2 -> v1	44.05
42	Empty Room 2 Floor 3	V59	v59 -> v60 -> v57 -> v56 -> v55 -> v54 -> v28 -> v2 -> v1	44.07
43	Classroom A3 Floor 3	V61	v61 -> v62 -> v57 -> v56 -> v55 -> v54 -> v28 -> v2 -> v1	47
44	Classroom B3 Floor 3	V63	v63 -> v64 -> v65 -> v68 -> v70 -> v71 -> v29 -> v3 -> v1	44.8
45	Classroom C3 Floor 3	V66	v66 -> v65 -> v68 -> v70 -> v71 -> v29 -> v3 -> v1	41.2
46	Classroom D3 Floor 3	V67	v67 -> v68 -> v70 -> v71 -> v29 -> v3 -> v1	39.3
47	Classroom E3 Floor 3	V69	v69 -> v70 -> v71 -> v29 -> v3 -> v1	34.8
48	Corridor Floor 3	V71	v71 -> v29 -> v3 -> v1	27.8

The research results show that applying the Floyd-Warshall algorithm can determine the shortest path from each node in the Bali Dwipa University building to the main evacuation point, namely the gathering point initialized as vertex 1 (V1). By mapping 71 connected nodes in the building layout, measuring the weight of the distance between nodes, and producing optimal evacuation routes for various scenarios, the result is that each room has a clearly defined evacuation route.

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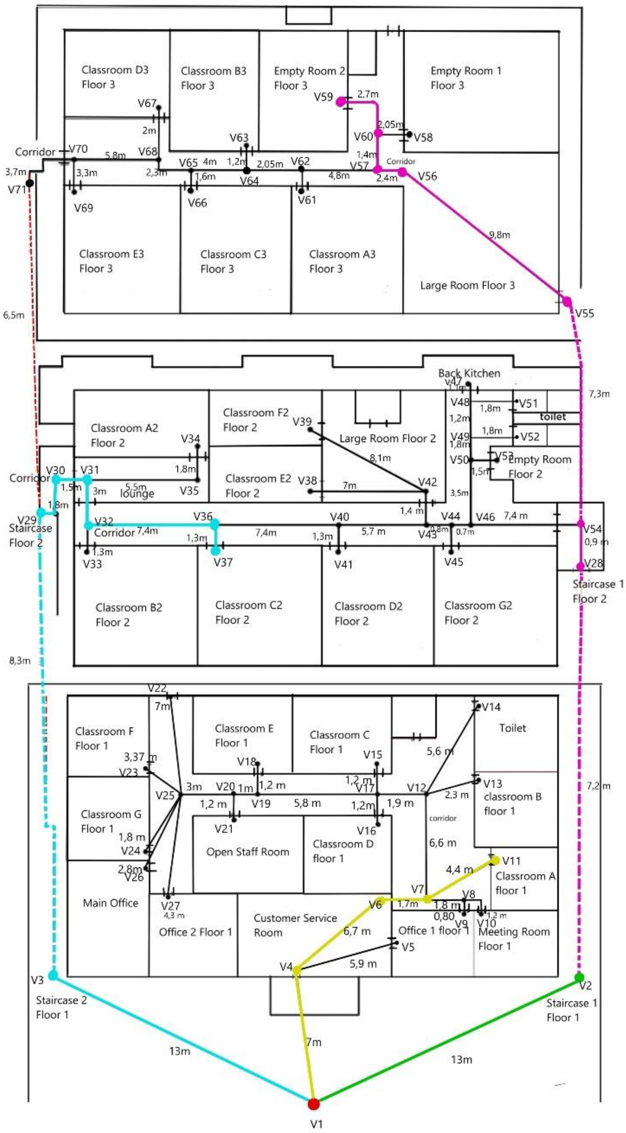

Figure 6. Partial Marking of Route Calculation Results

Here are some of the trajectories that can be found. Researchers take the example of the shortest route for stairs one floor 1 (V2), Class A floor 1 (V11), Class C2 floor 2 (V37), empty room 2 floor 3 (V59) to the gathering point, and will be marked with a different color from the root node and leading to the gathering point as a route marker as shown in Figure 6. The colored node points are a depiction of part of the route from all evacuation routes that have been produced from Floyd Warshall's theory; namely, the colored image is the shortest and most efficient route in the evacuation, which is to the results obtained.

It can be seen from node V2 (stairs one floor 1), colored green, that the shortest route is direct to V1 (gathering point) because there is only direct access to the destination. V2 -> V1 = 13 meters. For node V11 (Classroom A floor 1), which is colored yellow, according to the results of the Floyd-Warshall theory calculation, V11 -> V7 -> V6 -> V4 -> V1. Next, for V37 (Classroom C2 floor 2), which is colored blue, the route taken according to the calculation results that have been made is v37 -> v36 -> v32 -> v31 -> v30 -> v29 -> v3 -> v1. The furthest part on the third floor, namely node V59 (empty room 2 floor 3), which is colored purple and meets the node marked green, is still considered related because the destination is the same, namely to V1 (gathering point)

6. CONCLUSION

The study results show that applying the Floyd-Warshall algorithm effectively determines the shortest path from each node in the Bali Dwipa University building to the main exit point (V1). This study produces a clearly defined optimal exit route by mapping nodes from the 1st to 3rd floors and measuring the distance between nodes. Each room has an optimal and efficient evacuation route, ensuring building occupants' safety in emergencies. This study proves that the Floyd-Warshall algorithm can produce efficient and safe solutions. Further research could consider factors other than

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distance, such as travel time, ease of access for people with disabilities, or comfort levels in the evacuation process to produce more inclusive evacuation routes.

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