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Digital Twin for Disaster Evacuation Simulation

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Abstract- — Planning safe evacuation during disasters is extremely important, yet traditional methods are oftenrigid, expensive, and difficult to update. In this paper, we present a Digital Twin–based Disaster Evacuation Simulation System that creates a virtual version of real-world environments such as buildings. The system uses agent-based simulation implemented in Python along with real-time visualization to model how people move during emergencies like fires, floods, or earthquakes. It helps in understanding how congestion forms and how evacuation routes are used under different conditions. By testing multiple scenarios in a virtual setup, the system makes it easier to identify bottlenecks and improve evacuation strategies. Overall, this approach offers a safer and more cost-effective alternative to physical drills and supports better planning for emergency situations.

Keywords – Digital Twin, Disaster Evacuation, Crowd Simulation, Pathfinding, Emergency Management.

I. INTRODUCTION

Ensuring safe evacuation during disasters is a critical challenge in emergency management. Situations such as fires, floods, and earthquakes require quick and efficient evacuation strategies to minimize loss of life. Traditional evacuation planning methods rely on static maps, manual analysis, and physical drills, which are time-consuming, costly, and sometimes risky.

These methods also lack the ability to simulate real-time conditions such as congestion, blocked routes, and dynamic crowd movement. As a result, it becomes difficult to accurately predict evacuation behaviour and improve planning strategies. With advancements in technology, Digital Twin systems have emerged as a promising solution. A digital twin is a virtual representation of a physical environment that allows simulation and analysis without real-world risks. It enables testing of different scenarios and supports better decision-making.

In this paper, a Digital Twin–based Disaster Evacuation Simulation System is proposed. The system models building environments and simulates evacuation using Python-based logic. It represents individuals as agents and uses path finding techniques to guide them toward exits while considering congestion and dynamic conditions.

II. LITERATURE SURVEY

Many researchers have explored the use of digital twin technology, simulation models, and immersive tools in disaster management. The following studies provide useful insights into existing approaches and highlight their limitations.

A. Setijadi Prihatmanto et al. (2025)
This study introduces the concept of a Digital Twin City to improve flood evacuation systems. It uses geographical and environmental data to simulate evacuation scenarios and identify risk-prone areas. While the approach is effective for large-scale planning, it requires advanced infrastructure and is not easy to implement in smaller environments

.B. Hancko et al. (2025)
This work focuses on using Virtual Reality and Augmented Reality technologies for fire and rescue training. It creates immersive environments that help users better understand emergency situations. However, the system is mainly designed for training purposes and does not focus on actual evacuation modeling or route optimization.

C. Gong et al. (2024)
This research studies the role of Augmented Reality in safety training. It shows that AR improves user engagement and helps people learn emergency procedures more effectively. However, it does not include simulation of crowd movement or real-time evacuation scenarios.

D. Korkmaz et al. (2024)
This study presents a Digital Twin–based approach for disaster management, especially for earthquakes. It integrates data from multiple sources to improve monitoring and decision-making. Although powerful, the system is complex and requires significant computational resources.

E. Cheng et al. (2023)
This paper provides a review of digital twin applications in emergency management. It highlights the benefits of using digital twins for monitoring and prediction. However, it mainly

focuses on theory and does not provide a detailed implementation for evacuation simulation.

III. SYSTEM ARCHITECTURE

The proposed system follows a structured architecture consisting of a user interface, simulation engine, digital twin model, and visualization module.

The user interface allows users to define building layouts, number of people, and disaster scenarios. These inputs are passed to the simulation engine, which performs the core processing tasks.

The simulation engine is implemented using Python and models each individual as an agent. It uses pathfinding techniques to determine the shortest path to exits and handles dynamic conditions such as congestion and obstacles.

The digital twin model represents a virtual replica of the building environment, including walls, exits, and pathways. It serves as the simulation space where evacuation scenarios are executed. The visualization module displays real-time movement of agents, congestion areas, and evacuation routes, enabling better understanding of the evacuation process.

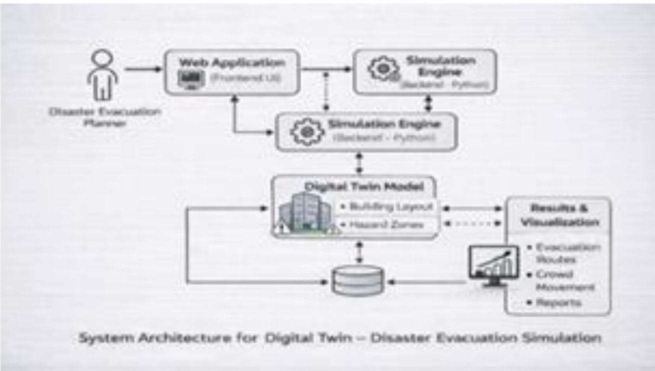

Fig 1: System Architecture for Digital Twin – Disaster Evacuation Simulation

IV. PROPOSED METHODOLOGY

The proposed methodology involves multiple stages for simulating disaster evacuation scenarios.

First, a virtual model of the building is created using a grid-based layout, defining rooms, walls, pathways, and exits. This forms the digital twin environment.

Next, simulation inputs such as number of people, their initial positions, and hazard conditions are generated. These inputs represent real-world scenarios.

Each individual is treated as an agent and is guided toward the nearest exit using pathfinding algorithms. The system continuously monitors congestion and adjusts movement when necessary to ensure efficient evacuation.

Finally, the system provides real-time visualization of the evacuation process, showing crowd movement, congestion areas, and exit usage. This helps in analyzing and improving evacuation strategies.

V. EVACUATION ALGORITHM

- Initialize the building environment.
- Input the number of people and their positions.
- Represent each person as an agent.
- Identify the nearest exit for each agent.
- Calculate the shortest path using pathfinding algorithms.
- Move agents step-by-step toward exits.
- Detect congestion or obstacles.
- Redirect agents if alternative paths are required.
- Update positions continuously.
- Monitor evacuation time and crowd density.
- Display real-time simulation.
- End the simulation when all agents reach exits.

VI . RESULTS AND DISCUSSION

The proposed Digital Twin-based evacuation system was tested under various simulated disaster scenarios such as fire and blocked exits. The system effectively modeled crowd movement and dynamically adjusted evacuation paths based on congestion and obstacles.

The results show that agents successfully identified optimal paths to exits. In high-density conditions, congestion was observed near exit points; however, the system efficiently redirected agents through alternative routes, reducing bottlenecks.

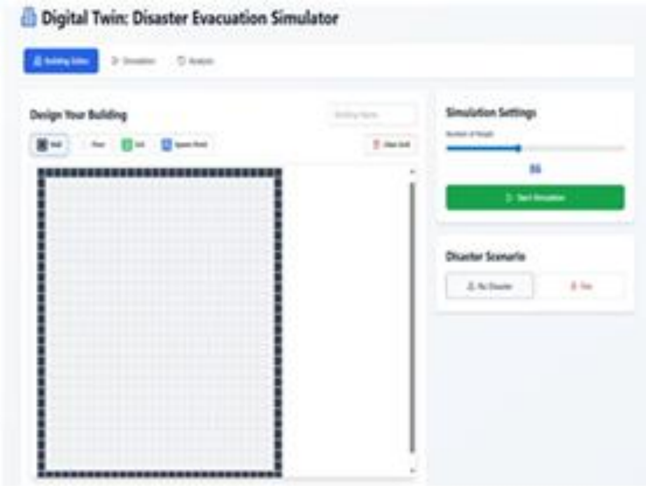

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Fig 2: Initial Empty Building Layout for Simulation Setup

Compared to traditional static evacuation methods, the proposed system improved evacuation efficiency and reduced evacuation time. The real-time visualization provided clear insights into movement patterns, congestion zones, and exit utilization. These results demonstrate the effectiveness of the Digital Twin approach in enhancing evacuation planning and safety.

Fig 3: Building Structure with Walls Defined

VII. CONCLUSION

This paper presented a Digital Twin-based Disaster Evacuation Simulation System for improving emergency planning. The system enables safe and efficient simulation of evacuation scenarios without real-world risks.

The proposed approach effectively models crowd behavior, detects congestion, and optimizes evacuation routes using dynamic pathfinding techniques. The results demonstrate improved evacuation efficiency compared to traditional methods.

The system also provides real-time visualization, which helps in better understanding and decision-making. Future work can focus on integrating real-time data and advanced AI techniques to enhance system accuracy and scalability.

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