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Integrate Building Information Modeling (BIM) and Occupant Characteristics Simulator to Assess the Effectiveness of Emergency Requirements

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ABSTRACT

Building fires are a major hazard to residents, first responders, and the structural system. Rapid spread can impede evacuation, resulting in human fatalities. However, studying occupant characteristics in a burning building is unrealistic and unethical. Hence, the current data-gathering techniques employed in evacuation simulation models have constraints when capturing occupant attributes. To address these constraints, The study introduces a novel method of serious gaming that combines Building Information Modelling (BIM) with an occupant characteristics simulator with varying mobility capabilities depending on age, gender, and physical ability, using Unity3D, to simulate fire growth and evacuation duration for residential buildings with and without emergency requirements. The study reveals that occupant characteristics significantly affect evacuation time, and implementing emergency requirements can improve evacuation efficiency in fire-exposed residential buildings by up to 100%. Implementing emergency requirements reduced mortality rates from 50% to 0%, suggesting that simulation results can be used to improve building design and emergency needs assessment.

1. INTRODUCTION

The proliferation of urbanisation and worldwide growth has led to a significant escalation in the magnitude and intricacy of catastrophes in multi-story structures. Fires in multi-story buildings present substantial hazards to individuals within the structure and emergency personnel, leading to considerable destruction [1]. Building fires can occur for a variety of reasons, including electrical problems, pyrotechnic occurrences, incorrect storage practices involving combustible items, and purposeful acts of arson and vandalism [2]. The frequent fires in residential buildings pose a significant threat to people's lives, necessitating increased fire safety supervision, improved resident awareness, and rigorous design in line with the Code for Building Fire Protection [3]. The increase in residential building fires will increase casualties, particularly among vulnerable groups like the elderly and children who struggle to dispose of the fire and escape [3]. The high number of fire emergency casualties and injuries are largely due to the failure to evacuate occupants from the burning building promptly [4]. Building fires pose a substantial hazard to residents, first responders, and structural systems. The quick spread of fire and smoke can make escape difficult, resulting in human casualties. Reliable egress systems are critical for ensuring safe evacuation [5].

Human behaviour and the available time heavily influence the probability of a successful evacuation during a fire incident [6]. The correlation between human behaviour and building attributes serves as the initial foundation for fire prevention [6]. Ensuring a secure evacuation minimises the casualties and harm during a fire emergency. Several factors influence the safe evacuation of a building, such as the behaviour of the residents, their acquaintance with the structure's paths, life-threatening events created by fire, and the structural aspects of the building [7]. The first goal is to promptly and effectively evacuate the building to minimise loss of life. The primary means of escape is the outdoor fire escape stair, which has been proven to reduce the number of casualties in situations where fire safety measures are not functioning correctly or are insufficient [8]. Due to their open nature, these stairs are less affected by smoke and heat, reducing the effectiveness of escape routes [8]. The placement of escape signs along all normal and emergency exits, making sure they are visible from all angles [9]. External and internal escape signals are lighted [10]. The exit route doors must be devoid of any locks or alarms [11]. When moving on, doors must swing in the same direction as travel [12]. The route of escape must always be free of obstructions [13].

Additionally, other factors might potentially impact the responses and conduct of those using a space. These factors are linked to the attributes of persons, the structure's properties, and the fire's qualities. To get a deeper understanding of human behaviour in fires and improve the design and implementation of fire protection measures in buildings, it is essential to consider the interplay of these factors [14]. Understanding and predicting potential occupant behaviour can be facilitated by considering the characteristics of the occupants [14]. Studying occupant characteristics is essential as it enables us to comprehend the diverse range of evacuation behaviours exhibited by various vulnerable groups while attempting to exit a building during fire-related emergencies. Having this comprehension may assist in creating and executing fire safety measures that are tailored to the specific requirements of different susceptible groups. It can also contribute to formulating management strategies to enhance building fire safety [15]. The successful evacuation relies on fire safety measures, structural characteristics of the structure, and human-related variables. BIM and fire simulations have been utilised in fire safety management to encompass all relevant factors [16]. Over the past decade, researchers and practitioners have used information technology to assist in designing fire safety measures and managing emergencies. BIM is a technique that utilises advanced digital technology to facilitate the design, modelling, and analysis of fire prevention systems [16]. BIM is a highly efficient technique that enhances emergency evacuation planning and administration in intricate building systems. This, in turn, improves safety and effectiveness during disaster situations [17].

BIM is a highly advanced technology in the Architecture, Engineering, and Construction (AEC) industry [18]. The researchers employed an integrated BIM game engine solution to enhance visualisation and teaching within the construction sector [19, 20]. Buildings must be equipped with an evacuation system to ensure the safe removal of occupants during emergencies, such as a fire. Typically, such a rule must adhere to relevant regulatory criteria. To achieve this for uncomplicated buildings, a set of prescriptive requirements is incorporated into the design. To handle more intricate buildings, employ BIM-based simulation [21].

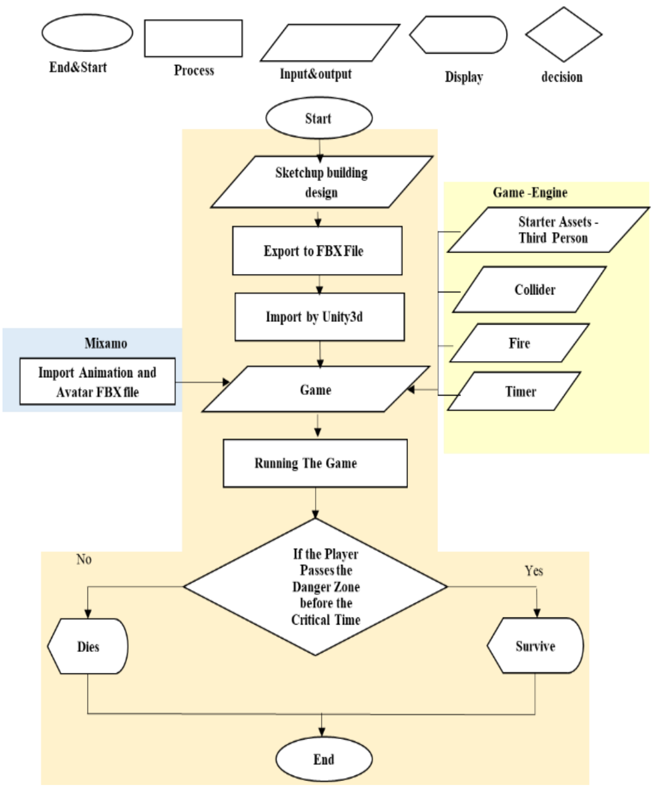


Figure 1. Flowchart of research approach used in this study

Building fires are a major hazard to residents, first responders, and the structural system. Rapid spread can impede evacuation, resulting in human fatalities. However, studying occupant characteristics in a burning building is unrealistic and unethical. Hence, there's a lack of integration of evacuation simulation and occupant characteristics, hindering their accuracy in predicting and modeling fire evacuations. To overcome these limitations, this study aims to build a suitable framework that combines evacuation simulations and an occupant's characteristics to assess the effectiveness of emergency requirements. the research presents a new serious gaming approach based on integrating BIM with the game engine Unity3D to simulate the evacuation of individuals with different characteristics, such as age, gender, and physical abilities, during a fire. This is done by applying the simulation to two case projects: A residential building with and without emergency requirements. The diagram depicted in Figure 1 illustrates how.

This study provides a literature review on BIM and fire evacuation simulation, expands on existing information, and offers practical implications for architects assessing emergency needs. It also discusses simulation implementation, findings, discussions, result validation, and future research. The introductory summary serves as a roadmap for readers, providing background information and major contributions.

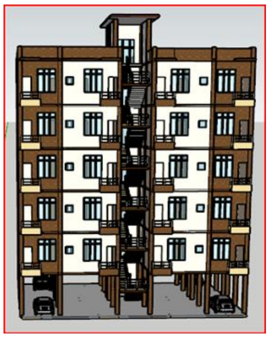
2. LITERATURE REVIEW

Integrating BIM and serious game simulation might enhance fire evacuation training by providing a virtual environment where users can undergo a fire simulation and acquire skills to manage their emotions during emergencies [22]. Studies have investigated the integration of BIM and serious games for fire evacuation training [22, 23] Ruffino et al. examined the integration of BIM and serious games for fire evacuation training. A study offered a four-level system for fire exit training that focused on various levels. Level 1 entails memorizing fire exit locations in a utopian virtual, with green arrows directing people. Level 2 seeks to reach all fire exits in 1:30 mm: ss by utilizing memory and the quickest pathways. Level 3 focuses on escaping within 30 seconds, losing if not reached within that time frame, touching the flames, or walking in the incorrect path. Level 4 prepares workers for panic situations by allowing them to identify a safe escape within 45 seconds. This training method has been evaluated by both regular employees and visitors to the building. This technique assisted workers in managing their behavior during an emergency [22]. Ribeiro et al. study utilized serious games to train evacuation behavior. A simulation scenario was created using Blender, where players must escape a fire by traversing a building with emergency signs. A simple experiment with 30 participants was conducted, with the measured time taken to evacuate the building. Results showed that users effectively learned evacuation procedures, even focusing on finding the best evacuation paths [23]. While other research looked at Agent-Based Modeling (ABM) and BIM. Huang et al. [24] utilized ABM and BIM on Unity to simulate crowd evacuation. The study explored the impact of evacuation speed and delays on creating choke points, revealing that Unity is a suitable platform for implementing ABM-BIM research on crowd evacuation. Mirzaei-Zohan et al. [25] have created a new agent-based framework for designing building emergency evacuation using BIM. The framework involved data collection, model development, and evacuation simulation using Revit-Mass Motion. The model was simulated through three scenarios with different floor numbers, and safety was evaluated for three staircase designs. The best evacuation performance was achieved when two individual stairs were designed for each floor. Conventional methods for managing evacuations are frequently inadequate due to their reliance on two-dimensional evacuation plans, their static nature, and their failure to consider the characteristics and interactions of persons within the building [26]. Beyaz et al. [26] used ABM and BIM on Unity to simulate fire evacuation, including building attributes and occupant categories. The study explored the possibility of modeling people's behavior in a three-dimensional digital environment by integrating BIM with ABM. Sun developed an interdisciplinary modeling framework that takes into account three major factors: physical building attributes, fire characteristics, and human behavior. The Fire Dynamic Simulator (FDS) program simulates fire growth, while an ABM system is employed for evacuation planning. The findings can be utilized to improve building design and evacuation plans, as 3D BIM provides a visual depiction of dangerous zones and recommended escape routes [27]

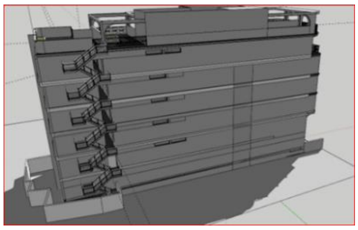
Nowadays, studies provide useful insights into BIM simulations, occupant behaviors, and fire evacuation, but there's a lack of integration between simulations and occupant characteristics, hindering their accuracy in predicting and modeling fire evacuations. Therefore, building a suitable framework that combines emergency needs and an individual's characteristics can considerably minimize casualties.

3. METHODOLOGY

The first step was exporting a BIM from Sketchup in the FBX format to begin the procedure. This study utilised a structure (BIM) of a residential structure that includes emergency requirements and a residential building without emergency requirements. Figure 2 illustrates the frontal aspect of the buildings as seen in Sketchup. Also, Table 1 presents the specifics of the residential building models used. The residential structure with emergency requirements features an escape staircase, illuminated signals, and fire-resistant finishing materials. All standard and emergency exits have escape signs that may be seen from any direction. Exit route doors have no locks or alarms, and they swing in the direction of travel. The Unity3D engine can natively interpret the model included within the FBX file. Once Unity3D has completed the import process, the model may be incorporated into the virtual world scenario. The scene will remain motionless in the absence of a player. Nevertheless, the standard components package of Unity3D includes a selection of fundamental player controllers, and for this inquiry, the third-person controller was utilised. When the player possesses its camera, specifically from a third-person perspective, it renders the default camera obsolete. The environment was fully prepared for evacuation scenarios once the player was placed within the Sketchup model.



(a) Residential building without emergency requirements



(b) Residential building with emergency requirements

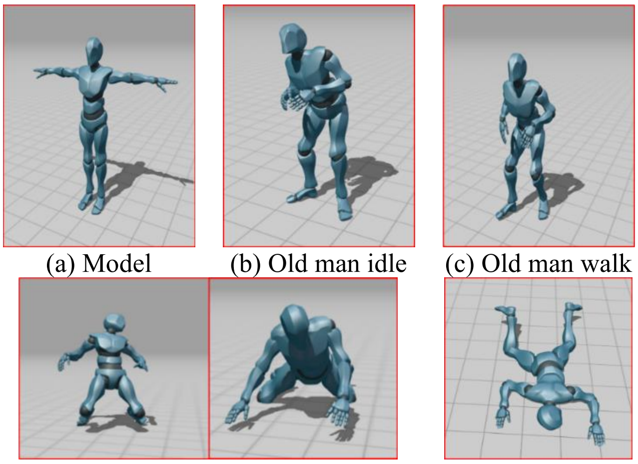
Figure 2. Case study

Colliders in games prevent objects from overlapping or passing through each other, simulating actual interaction in the game environment. Additionally, colliders trigger events like player death when colliding with fire. Clicking the "Generate Colliders" button during practice is essential, enabling the physics engine to calculate collisions with the player in the scene. The Box Collider in the Inspector window was used to add a collider to each object in the hierarchy, making sure that the size and center matched the shape and size of the object selected.

For the simulation of the evacuation of people with variable characteristics, such as the occupant movement simulation with age, gender, and physical abilities during the evacuation of the building.was obtained and imported Animations and Avatars from the Mixamo website into Unity3D in FBX format.was downloading animations of individuals with varying attributes such as age, gender, and physical ability. Figure 3 shows some of the Animations used to simulate occupant characteristics.

Table 1. Specifics of the residential building models used

Case Study Information	Residential Building without Emergency Requirements	Residential Building with Emergency Requirements
Number of floors	The building has 6 floors, including the basement floor and 5 residential floors.	The building has 6 floors, including the reception floor and 5 residential floors.
Number of units per floor	Twelve residential units	Ten residential units
The area per floor	281.6 m^2	1,144 m^2
Construction Materials	The building structure employs reinforced concrete, resulting in a strong and fire-resistant framework, and fire-resistant finishing materials.	The building structure employs reinforced concrete, resulting in a strong and fire-resistant framework, and fire-resistant finishing materials.
Layout per floor	The floor layout has a central area with an elevator and stairs, surrounded by four residential apartments. The layout included a combination of two bedrooms, a kitchen, a bathroom, and living room flats.	The floor layout consisted of 10 bedrooms, 10 bathrooms, and an escape stair.



(a) Model (b) Old man idle (c) Old man walk

(d) Old man dying (e) Old man died

Figure 3. Some of the Animations used to occupant characteristics simulate

In the Inspector of Avatar or Animation from (Rig), the pressing was done on (Humanoid). Then was added death animation or changed occupant characteristics such as age, gender, and physical abilities (by changing animation) from the "Window" menu > Animation > Animator > ThirdPerson Controller > Blend Tree. To produce realistic and accurate analytical findings within the scope of the study, different speeds were chosen based on the categories of passengers, as shown in Table 2.

Table 2. Occupants movement speeds in building

Occupants Characteristics	Move Speed m/s
Woman	1.7
Woman 2	1.8
Woman Less Fitness	1.5
Man Less Fitness	1.5
Old Man	1
Old Woman	1
Sick, Injured	1
Young Man	2.5
Young Man 2	2
Young lady	2
Boy	2
Boy 2	1.8
Girl	2
Girl2	1.8

A new Particle System game object was built, with properties such as emission rate, start lifespan, color, rotation, and size adjusted to imitate fire based on the information in Table 3. A C# script is added to the object to generate a fire-like effect that spreads over time, as seen in Figure 4.

Table 3. Particle system (fire) parameters

Parameter	Number
Start Speed	1
Start Rotation	60
Color	Orange
Emission / Rate Over Time	20
Shape / Angle	0
Shape / Radius	0.1
Rotation Over Life Time	60

Using the occupant characteristic simulation is a precious and efficient approach for predicting evacuation timeframes. So, a primary timer has been incorporated to determine the entire evacuation duration in a simulation. was created as a UI text element to display the timer. It was attached to the script in C#, as shown in Figure 5 in the game object.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class FireSpreadController : MonoBehaviour
{
    public ParticleSystem fireParticleSystem;
    public float spreadSpeed = 1f;
    public float maxSpreadDistance = 4f;
    public float maxEmissionRate = 100f;
    public float duration = 50f;

    private float initialSpreadDistance;
    private float targetSpreadDistance;
    private float initialEmissionRate;
    private float targetEmissionRate;
    private float timer;

    private ParticleSystem.ShapeModule shapeModule;
    private ParticleSystem.EmissionModule emissionModule;

    private void Start()
    {
        shapeModule = fireParticleSystem.shape;
        emissionModule = fireParticleSystem.emission;

        initialSpreadDistance = shapeModule.radius;
        targetSpreadDistance = initialSpreadDistance + maxSpreadDistance;

        initialEmissionRate = emissionModule.rateOverTime.constant;
        targetEmissionRate = maxEmissionRate;

        timer = 0f;
    }

    private void Update()
    {
        timer += Time.deltaTime;

        float t = Mathf.Clamp01(timer / duration);
        float currentSpreadDistance = Mathf.Lerp(initialSpreadDistance,
targetSpreadDistance, t);
        float currentEmissionRate = Mathf.Lerp(initialEmissionRate, targetEmissionRate,
t);

        shapeModule.radius = currentSpreadDistance;
        emissionModule.rateOverTime = currentEmissionRate;
    }
}
```

Figure 4. C# Script of fire spread

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;

public class Timer : MonoBehaviour
{
    public Text timerText;
    private float elapsedTime;
    private bool isTimerRunning;

    void Start()
    {
        elapsedTime = 0f;
        isTimerRunning = true;
    }

    void Update()
    {
        if (isTimerRunning)
        {
            elapsedTime += Time.deltaTime;
            UpdateTimerText();
        }
    }

    void UpdateTimerText()
    {
        int minutes = Mathf.FloorToInt(elapsedTime / 60f);
        int seconds = Mathf.FloorToInt(elapsedTime % 60f);

        string minutesText = minutes.ToString("00");
        string secondsText = seconds.ToString("00");

        timerText.text = string.Format("{0}:{1}", minutesText, secondsText);
    }

    public void PauseTimer()
    {
        isTimerRunning = false;
    }

    public void ResumeTimer()
    {
        isTimerRunning = true;
    }

    public void ResetTimer()
    {
        elapsedTime = 0f;
        UpdateTimerText();
    }
}
```

Figure 5. C# Script of timer

28 simulations were conducted to assess the effectiveness of emergency requirements. This was done by applying the simulation to two case projects: a residential building with and

without emergency requirements. The total evacuation time for each occupant was recorded to assess the efficiency of emergency protocols. The primary metric to compute the evacuation duration is the total time required for the player to escape the structure. Given its common usage in analysing evacuation simulations, we naturally chose this statistic as a suitable alternative for our study. Additionally, we have uncovered another captivating metric concerning the timing of the player's demise.

4. IMPLEMENTATION

The simulation depicts the spread of flames, which is comparable to real-world fire dynamics. The fire starts as the game begins and spreads based on airflow patterns and building structural design in an empty room on the fifth floor, spreading to the top and stairwell.

The player begins the game in a predetermined apartment on the sixth story. Right now, the timer begins. The gamer must navigate through the hazardous area to reach the exterior with the utmost expediency. The study's danger zone indicates when a fifth-floor stairway becomes deadly during a fire, greatly restricting a person's ability to move through. The player must exit the hazardous zone within 0.25 seconds before spreading the fire on the fifth-floor stairwell in a residential building without emergency requirements as shown in Table 4. Since the fire cannot be overcome, this might ultimately pose a threat, resulting in the player's demise before they can pass the hazardous zone. A player's score is determined exclusively by when it takes them to pass the danger zone. This means that a lower score indicates more excellent performance.

Table 4. Danger zone in a residential building without emergency requirements

Danger Zone	Danger Time	Safe Time
Fifth Floor	0.25 sec and above	less than 0.25 sec

While the player must exit the hazardous zone within 0.59 seconds before spreading the fire on the fifth-floor stairwell in a residential building with emergency requirements as shown in Table 5.

Table 5. Danger zone in a residential building with emergency requirements

Danger Zone	Danger Time	Safe Time
Fifth Floor	0.59 sec and above	less than 0.59 sec

The first scenario is while the player is inside a residential building that does not have any emergency needs. A primary timer has been incorporated to determine the entire evacuation duration in a simulation. This timer starts counting from the beginning until the player either reaches an exit or succumbs to the passage of time because of the player's inability to consistently pass the danger zone 0.25 seconds ago, as seen in Table 4. Figures 6-10 show case several simulation situations from the first application.

Mixamo's animations provided a realistic representation of various occupants, including woman, woman2, woman less fitness, man less fitness, old man, old woman, injured person, young man,young man 2, young lady, boy, boy2,girl,and girl 2, enabling simulation of potential evacuation variations based on diverse characteristics. The animation representation used in the study aligns with the aim of investigating various occupant characteristics during evacuation simulations.

Figure 6. An old man died in a building without an emergency requirement

Figure 6 depicts an animation of the elderly man moving at 1 m/s and succumbing to time owing to his failure to cross the danger zone 0.25 seconds earlier.

Figure 7 presents a representative animation of the man with a less fit body type moving at 1.5 m/s and succumbing to time owing to his failure to cross the danger zone 0.25 seconds earlier.

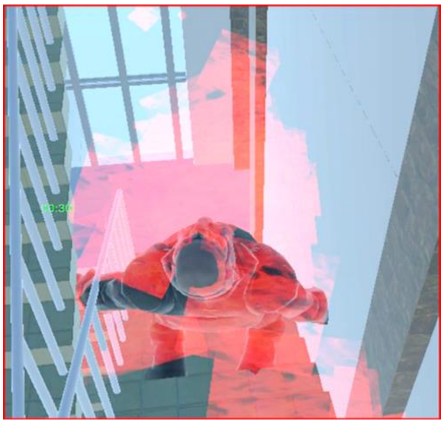


Figure 7. A man less fitness dying in a building without an emergency requirement

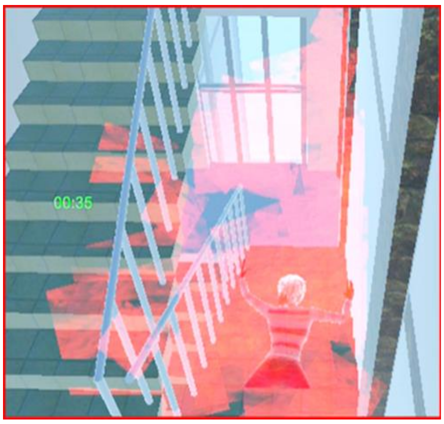


Figure 8. A woman died in a building without an emergency requirement

Figure 8 presents an animation of a woman moving at 1.7 m/s and succumbing to time owing to his failure to cross the danger zone 0.25 seconds earlier.

Figure 9 depicts a sample animation of a young man 2 moving at 2 m/s to cross a building without an emergency requirement. And Figure 10 depicts an animation of a girl moving at 2 m/s to cross a building without an emergency requirement.

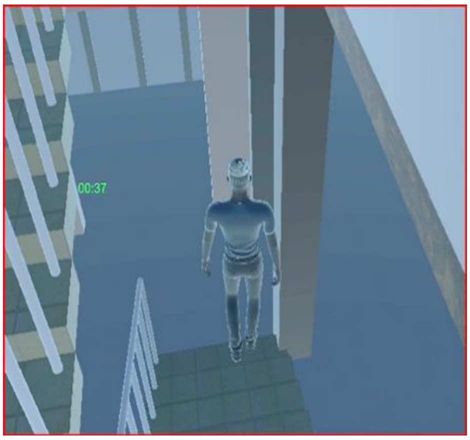


Figure 9. A young man 2 crossing a building without an emergency requirement

Figure 10. A girl crossing a building without an emergency requirement

The second scenario occurs when the player is inside a residential building with urgent emergency needs. A primary timer has been incorporated to determine the entire evacuation duration in a simulation. This timer starts counting from the beginning until the player reaches an exit. Based on the data in Table 5, the player successfully passed the danger zone 0.59 seconds ago. Figures 11-15 showcase several simulation situations from the second application.

Figure 11 presents a representative animation of an old man type at a speed of 1 m/s to cross a building with an emergency requirement.

Figure 12 depicts a typical animation of a man with a less fit body type traversing a building at 1.5 m/s during an emergency.

Figure 13 presents an animation of a woman moving at 1.7 m/s to cross a building with an emergency requirement.

Figure 14 depicts a sample animation of a young man 2 moving at 2 m/s to cross a building with an emergency requirement.

Figure 11. An old man crossing a building with an emergency requirement

Figure 12. A man less fitness Crossing a building with an emergency requirement

Figure 13. A woman crossing a building with an emergency requirement

Figure 14. A young man 2 crossing a building with an emergency requirement

Figure 15. A girl crossing a building with an emergency requirement

Figure 15 depicts an animation of a girl moving at 2 m/s to cross a building with an emergency requirement.

5. RESULT AND DISCUSSION

As presented in Tables 6 and 7, older adults and those with limited mobility face difficulties in quick evacuation navigation. Physical fitness also impacts efficient navigation, with physically fit individuals moving more swiftly, impacting the pace of evacuation. additionally, women walk more slowly than men. Determining the duration of evacuation is a complex task. Anticipating every possible occurrence during an evacuation might be challenging at times. Using occupant's characteristic simulation is a precious and efficient approach for predicting evacuation timeframes. This cost-effective technique ensures the safety of human lives and material assets. Therefore, it has great value and motivation in preserving lives and property.

Table 6. Simulation data for a residential building without emergency requirements

Number	Occupants Characteristics	Evacuation Time (mm:ss)	Deaths Times (mm:ss)
1	Woman	0	0.35
2	Woman 2	0	0.27
3	Woman Less Fitness	0	0.35
4	Man Less Fitness	0	0.3
5	Old Man	0	0.4
6	Old Woman	0	0.4
7	Sick, Injured	0	0.51
8	Young Man	0.35	0
9	Young Man 2	0.37	0
10	Young Lady	1.12	0
11	Boy	0.55	0
12	Boy 2	0.57	0
13	Girl	0.53	0
14	Girl 2	0.58	0

Table 7. Simulation data for a residential building with emergency requirements

Number	Occupants Characteristics	Evacuation Time (mm:ss)	Deaths Times (mm:ss)
1	Woman	1.55	0
2	Woman 2	1.53	0
3	Woman Less Fitness	2.06	0
4	Man Less Fitness	2.04	0
5	Old Man	3.12	0
6	Old Woman	3.18	0
7	Sick, Injured	3.33	0
8	Young Man	0.35	0
9	Young Man 2	0.37	0
10	Young Lady	1.12	0
11	Boy	0.55	0
12	Boy 2	0.57	0
13	Girl	0.53	0
14	Girl 2	0.58	0

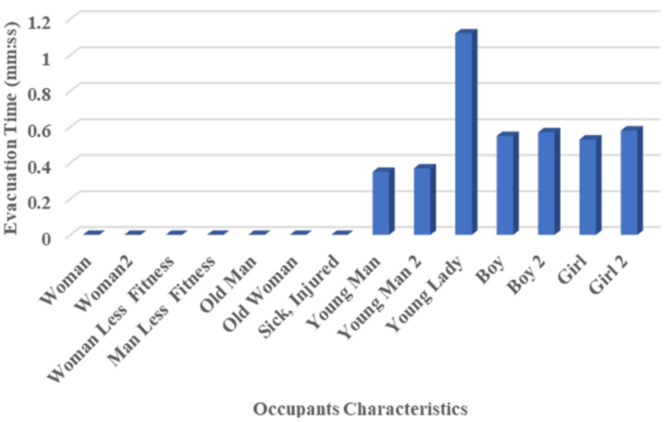


Figure 16. Evacuation time of occupants for a residential building without emergency requirements (mm:ss)

The simulation findings for the residential building without emergency requirements (Figure 16) demonstrate that the non-utilization of emergency requirements diminishes the ability of all inhabitants to evacuate safely. The young male achieved the shortest evacuation time, whereas the young lady had the longest.

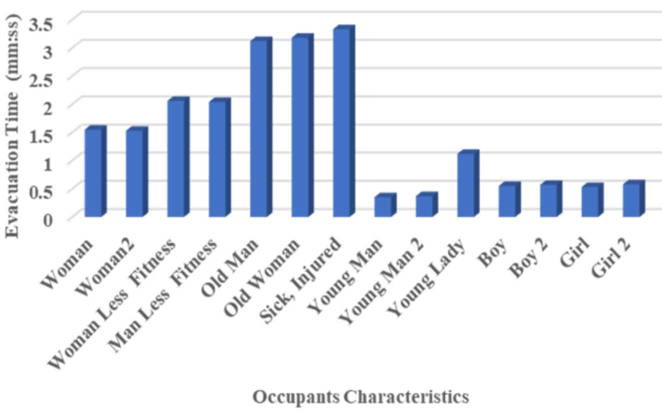


Figure 17. Evacuation time of occupants for a residential building with emergency requirements (mm:ss)

The simulation results for the residential building with emergency needs (Figure 17) demonstrate that using emergency requirements enhances the safe evacuation of all residents. The youthful guy had the shortest evacuation time, whereas the sick and injured individual had the longest.

Occupants' personal qualities significantly impact the time it takes to evacuate. The simulations demonstrated that the duration of evacuations increased in correlation with the characteristics of the occupants. The observed results are consistent with the findings of Kady and Davis [28]

This paper notes that the simulations differ from those used in earlier studies. As a result, direct comparisons of evacuation times are critical, although reveal variances. Previous research did not include occupant characteristics while determining evacuation time. As a result, the evacuation times in this study varied from those reported in earlier investigations. Nevertheless, the study found that girl 2 had an average evacuation time of 58 seconds, which is consistent with the average evacuation time of Ribeiro individuals who are frequent game players and lack prior building knowledge [23]. This study revealed that young man had an evacuation time of 35 seconds, consistent with Agent-based modeling for evacuation simulation in four classes, with D103 classes having the longest evacuation time of 35 seconds [26]. The results indicate that the model can predict the duration of the evacuation.

There are certain limitations in this study. For example, the sample size is tiny. Additionally, the model does not mimic crowd evacuation.

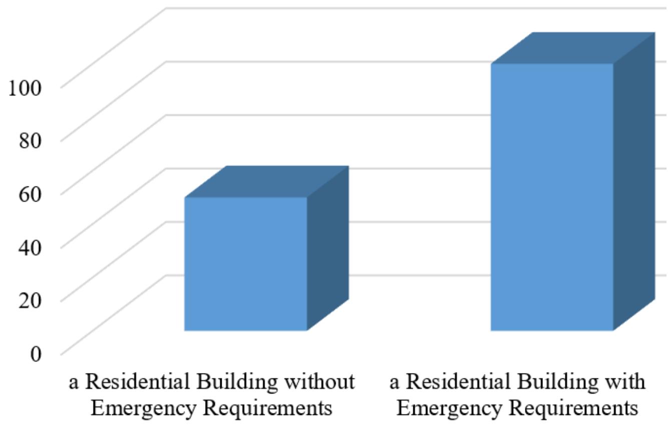


Figure 18. Effect of emergency requirements on evacuation rates %

The study revealed a high safe evacuation rate in residential buildings with adequate emergency measures, covering 100% of the total residents (Figure 18).

The modelling of a residential building without emergency provisions has demonstrated that a secure evacuation from a burning structure is not universally feasible. According to Figure 19, the death rate in a non-emergency residential facility is significantly higher, reaching over 50%.

Figure 20 demonstrates the significance of implementing emergency provisions in residential structures to safeguard human life .Figure 20 shows a gradual increase in deaths over time due to the absence of emergency requirements during a fire event. Peaks in the fire correspond to critical points where evacuation difficulties occur. In contrast, the scenario with emergency requirements shows a starkly different pattern, with the number of deaths consistently low at zero at each time point. Implementing emergency requirements successfully prevents the negative effects found in the scenario without emergency requirements.

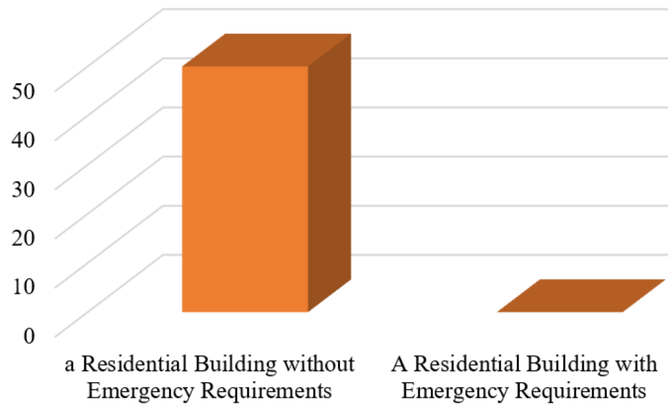


Figure 19. Effect of emergency requirements on mortality rates%

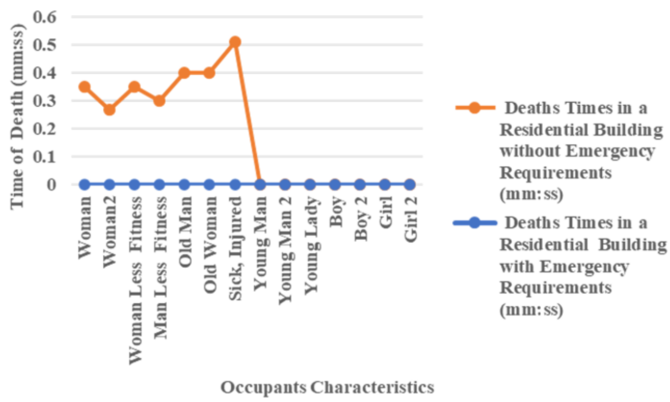


Figure 20. Effect of emergency requirements on death

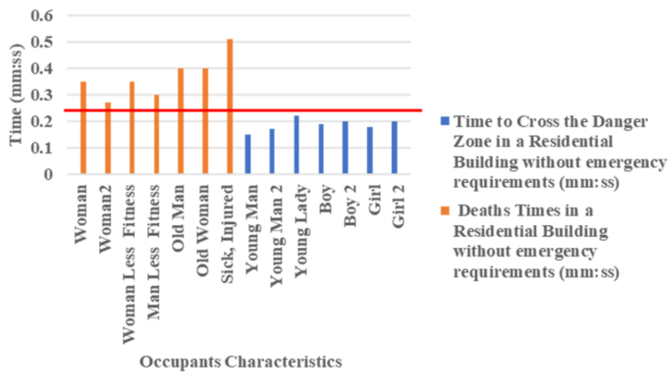


Figure 21. Danger time for a residential building without emergency requirements

Based on the data depicted in Figure 21, the player must navigate through the hazardous area (before 0.25 seconds) to exit securely and expediently before disseminating the fire on the fifth story.

5.1 Validation of the proposed framework

The Kolmogorov-Smirnova and Saphiro-Wilk statistics of the two building scenarios are all below 0.05. The results indicate that all variables are randomly distributed; therefore, the use of the Wilcoxon Signed Ranks Test is appropriate to measure the significance of differences between the two building scenarios.

(Z=-2.366) and (sig=0.018) indicate a statistically significant difference in evacuation times between the two building scenarios.

The Wilcoxon Signed-Rank Test results suggest that the evacuation times in the first scenario are significantly less than the evacuation times in the second scenario.

6. CONCLUSIONS

In this research, BIM, fire simulation, and occupant characteristics are integrated to create a framework capable of assessing the effectiveness of emergency requirements. The results of this study indicate that utilising emergency protocols facilitates the secure evacuation of all inhabitants.

The integration of emergency requirements into residential structures resulted in more effective evacuation procedures.

The approach was developed to assist engineers in evaluating the use of emergency standards in residential structures.

The integration of BIM, fire simulation, and occupant characteristics led to a novel framework for predicting evacuation timeframes. This cost-effective technique ensures the safety of human lives and material assets. Therefore, it has great value and motivation for preserving lives and property.

Previous research did not include occupant characteristics while determining evacuation time. As a result, the evacuation times in this study varied from those reported in earlier investigations. Nevertheless, the results indicated that the model can predict the duration of the evacuation.

The study primarily focuses on occupant characteristics simulation, but it is critical to investigate its interaction with crowds for the best outcomes. There are several areas for further investigation. One interesting strategy is to evaluate more building designs, taking into account environmental elements and different fire scenarios. In addition, explore the impact of integrating occupant characteristics into crowd simulation.

The proposed system can be applied to educational institutions and healthcare facilities, enabling evacuation simulation based on student populations and age-specific factors and ensuring safe evacuation of patients, staff, and visitors in emergency scenarios.

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