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Analysis of the computer simulation for optimizing the evacuation of people in an event hall

Analiza simulării computerizate pentru optimizarea evacuării persoanelor într-o sală de evenimente

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Abstract. *The article presents the development and analysis of an evacuation simulation for the ground floor of a building intended for conferences and events, using geometric modeling in SketchUp and occupant behavior simulation in Pathfinder. A total of 31 rooms and 41 doors (11 used as evacuation exits) were defined, along with a population of 524–526 occupants, assigned with variable profiles regarding speed, behavior, and anthropometric dimensions. Three scenarios were analyzed: normal evacuation, evacuation including persons with disabilities and one blocked exit, and a severe scenario with seven exits unavailable. The results show increases in evacuation time up to 121.8 seconds and the occurrence of congestion zones caused by uneven occupant distribution and reduced evacuation paths. The study highlights the importance of redundancy in evacuation routes, optimal furniture arrangement, and assistance for vulnerable individuals.*

Key words: *evacuation simulation, Pathfinder, SketchUp, fire safety, occupant behavior, people flow.*

Rezumat. *Articolul prezintă realizarea și analiza unei simulări de evacuare pentru nivelul parter al unei clădiri destinate conferințelor și evenimentelor, folosind modelarea geometrică în SketchUp și simularea comportamentului ocupanților în Pathfinder. Au fost definite 31 de încăperi, 41 de uși (11 de evacuare), și o populație compusă din 524–526 ocupanți, incluși cu profiluri variabile privind viteză, comportament și dimensiuni antropometrice. Au fost analizate trei scenarii: evacuare normală, evacuare cu persoane cu dizabilități și blocarea unei uși, respectiv scenariu sever cu 7 uși blocate. Rezultatele indică creșteri ale timpului de evacuare până la 121,8 s și apariția zonelor de congestie cauzate de distribuția neuniformă și restrângerea căilor de evacuare. Studiul evidențiază*

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importanța redundanței căilor de evacuare, configurării optime a mobilierului și asistenței pentru persoane vulnerabile.

Cuvinte cheie: *simulare evacuare, Pathfinder, SketchUp, securitate la incendiu comportament ocupanți, flux de persoane.*

1. Introduction

The evaluation of the performance of evacuation systems in emergency situations is a fundamental element in the analysis of the fire safety of modern buildings. The progress of computer simulation tools today allows the detailed reproduction of occupant behavior and the dynamics of evacuation flows, thus contributing to the substantiation of technical decisions and the validation of compliance with regulatory provisions. In this context, the use of specialized software, such as SketchUp to create geometry and Pathfinder to simulate the evacuation, offers the possibility of generating realistic and reproducible scenarios, which reflect both the architectural conditions of the building and the behavioral variability of the people involved.

This article presents the process of realizing a complex evacuation simulation for the ground floor level of a building with conference, event and catering functions. The modeling of the space included the faithful representation of the partitions, furniture, level differences and escape routes, and subsequently, the configuration of the population was made based on individualized profiles, differentiated according to anthropometric, behavioral characteristics and functional role. In addition, three distinct scenarios were analysed, including both the normal configuration of use and situations of constraint generated by the blocking of escape doors or the presence of people with disabilities requiring assistance.

By comparatively approaching these scenarios, the study aims to identify the determinants of evacuation times, highlight critical congestion areas and assess the capacity of the evacuation network to manage highly complex situations. The results obtained contribute to an in-depth understanding of the interactions between the architecture, the behavior of the occupants and the limitations of the evacuation infrastructure, while providing support for the optimization of fire safety measures and for the improvement of intervention strategies.

2. Methodology for conducting the simulation

Geometric modeling and plane import into the simulation environment

The realization of a credible simulation of the evacuation process requires the construction of a geometric model that faithfully reproduces the spatial configuration of the analyzed building. In this sense, the ground level of the objective, intended for conferences and events, was modeled using the SketchUp software, thanks to its ability to quickly generate three-dimensional geometries compatible with the format used by Pathfinder. The model includes partitions, furniture, escape routes, doors and access areas, all of which are necessary to obtain a realistic simulation.

Subsequently, the plan was exported to the .dae format (Collada), natively compatible with Pathfinder, and imported into the simulation mediator. At this stage, scale and positioning adjustments were made to ensure the exact correspondence between the model and the actual escape routes, avoiding geometric overlaps that could affect the behavior of the simulated agents.

Definition of rooms and parameterization of escape doors

After importing the geometric model, the 31 rooms used in the simulation were delimited: conference rooms, event rooms, hallways, public catering areas, changing rooms, toilets, offices and corridors. This step is essential because it allows the attribution of specific characteristics to each space, such as the maximum permissible density and the behaviour of the occupants in relation to obstacles.

Similarly, 41 doors have been defined, of which 11 constitute exhaust exits to the outside. The doors were classified by color codes: orange for the interior doors, green for the exhaust doors, respectively red for the unavailable doors. The parameters introduced – effective width, direction of circulation and direction of opening – complied with the requirements of the P118/1 [1] standard on the dimensioning of escape routes. The existing level differences in the plan also required the introduction of two stairs with 16 steps, necessary to achieve the transition between the -1.50 m and +0.00 m elevations.

Location and characterization of the simulated population

In order to reproduce the real conditions of use of the building, the population distribution was made based on the functions of the rooms and the maximum densities allowed according to the provisions of P118/1. In total, 524 occupants were introduced: 279 men, 159 women, 40 children and 46 employees. They were evenly positioned or concentrated in relevant areas (around tables, near the bar, in conference spaces) using the "Add an occupant" function in Pathfinder.

For each simulated agent, individual anthropometric characteristics (height, shoulder width, body mass) and mobility parameters (travel speed) were defined, thus ensuring a realistic heterogeneity of the population. The initial position of the occupants is a determining factor in the occurrence of congestion, temporary blockages and in the general evolution of the evacuation process.

Behavioral profiles and inclusion of persons with disabilities

To reflect real behavioral diversity, distinct profiles have been created for each category of occupants: men, women, children, employees and people with disabilities. These profiles include parameters regarding travel speed, evacuation priority, anthropometric characteristics and the associated 3D model.

A special profile was assigned to people with locomotor disabilities, represented by "polygon" models configured with wheelchair animations. These people were set as not being able to leave the building autonomously, requiring the support of evacuation teams. To this end, two additional behaviors were defined – "evacuation team" and "person in need of help" – implemented through the "Assisted evacuation teams" module. Designated employees (one for each person with disabilities) start the action with a reduced delay, reflecting specific training in evacuation procedures.

Simulation of evacuation in different scenarios

Scenario 1 – Evacuation under normal conditions

The first scenario simulates the evacuation of the 524 occupants under normal operating conditions, using all 11 available escape doors. The general behavior attributed to the agents was "go to any exit", they would go to the nearest door.

The prioritization given to the categories of occupants is as follows:

- Children
- Women
- Men
- Employees

A uniform delay of 20 s has been introduced for the perception of the alarm signal, and the capacity of the doors has been set to 1–2 persons/s, depending on the width of each door. The simulation does not involve artificial bottlenecks, except for those naturally generated by flow congestions.

Total evacuation time: 102.8 s.

Scenario 2 – Presence of people with disabilities and locking a door

Two people with disabilities were introduced in this scenario, bringing the total number of occupants to 526. At the same time, an escape door (door 41) has been deactivated, reducing the number of available exits to 10.

People with disabilities received the behavior "Wait for assistance", and the employees designated as companions – the behavior "Assist" followed by "go to any exit". The reaction time for these employees has been reduced to 10 s, and the travel speed during assistance has been set to 1 m/s.

Evacuation priorities become:

- people with disabilities
- Children
- Women
- Men
- Employees
- The rest of the parameters remain similar to the previous scenario.
- Total evacuation time: 107.3 s.

Scenario 3 – Locking the doors on the north side of the building

The third scenario involves a severely disrupted situation: 7 of the 11 escape doors (doors 24, 23, 07, 25, 10, 08 and 09) were blocked, with only 4 doors on the south side being functional. This configuration forces all occupants in the northern half of the building to travel longer routes, negatively affecting the total evacuation time.

The simulation further includes the two persons with disabilities and the related evacuation teams, with the same characteristics as in scenario 2. The remaining factors (densities, delays, priorities) are identical.

Total duration of the evacuation: 121.8 s.

3. Analysis of the results obtained

The analysis of the 3 scenarios is necessary to observe and highlight certain factors that lead to the lengthening of evacuation times, the creation of congestion areas, as well as the comparison of evacuation times between them and the degree of use of each evacuation door according to their availability.

Scenario 1 Analysis

In scenario 1, a scenario in which the evacuation occurs normally, without unforeseen events, the evacuation time is 102.8 seconds. The arrangement of the occupants in the first second of the simulation is shown in Figure no. 1. A filter has been applied to be able to visualize the density of people per m2, thus making it possible to identify the busiest areas in the building and the most used doors and escape routes.

Fig.1. Arrangement of the occupants in the first second of the simulation for scenario 1

According to the specifications made at the presentation of the first scenario, the evacuation starts at the 20th second.

There are 4 large areas with a high density of users and an arrangement very close to each other. As can be seen in Figure no. 2, this resulted in the creation of large queues towards the exhaust outlets starting at 23 seconds, just 3 seconds after the start of the exhaust and thus lengthening the exhaust time. The busiest doors at the beginning of the evacuation are door 25 which connects to the outside and interior doors 26, 12 and 42 which connect the rooms and corridors leading to the exits to the outside.

Fig. 2. 23 seconds, 3 seconds after the start of the evacuation for scenario 1

Starting with the 28th second, the maximum value of the density of persons/m^2 supported by the program is reached, which is highlighted in the dark red color shown in Figure no. 3. This demonstrates that in order to accommodate in a room that will have a high density of users, it is advisable to use access doors in that room as wide as possible to allow people to leave the room quickly and avoid possible blockages until they enter the escape routes.

Fig. 3.Areas with very high density of people for scenario 1

A notable aspect is found at 68.8 seconds where a congestion area is observed near door no. 13. Here it can be seen that it is the last door at which a waiting line made up of the last 68 occupants is formed.

The situation in question presents a major deficiency in the distribution of doors intended for external evacuation because for the last 68 users another 34 seconds are allocated to leave the building compared to the rest of the users who up to 68.8 seconds managed to evacuate in a very short time, which is due to the correct sizing of the width of the interior doors and the correct placement of the escape doors.

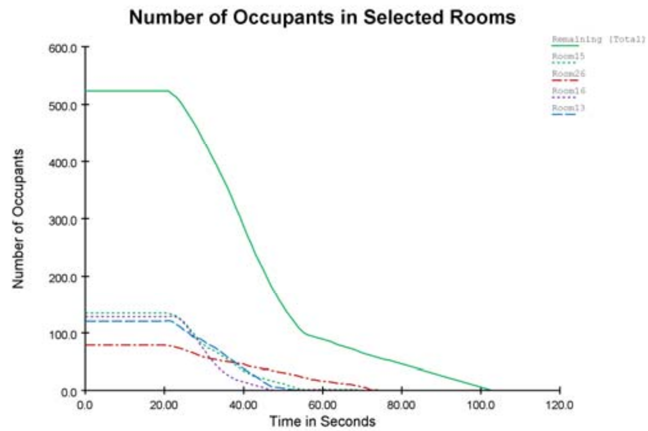

Fig. 4. Graph of users remaining in the rooms after moving to the escape doors in unit time for scenario 1

The graph in Figure no. 4 presents the number of users left in the 4 crowded rooms following their departure in time and states the situation presented in the previous paragraph, room no. 26 having a very long time for the evacuation of all occupants. This aspect can also be correlated with the Graph in Figure no. 5 which shows no. of occupants evacuated in time.

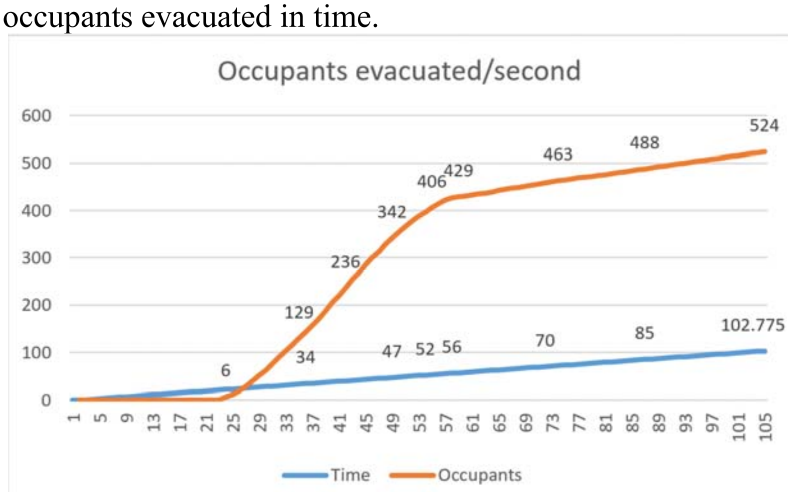

Fig. 5.Graph with users evacuated in time for scenario 1

The most used exhaust door for this scenario was door no. 13 with 157 evacuated users, and the least used door was door no. 9 with only 7 occupants evacuated.

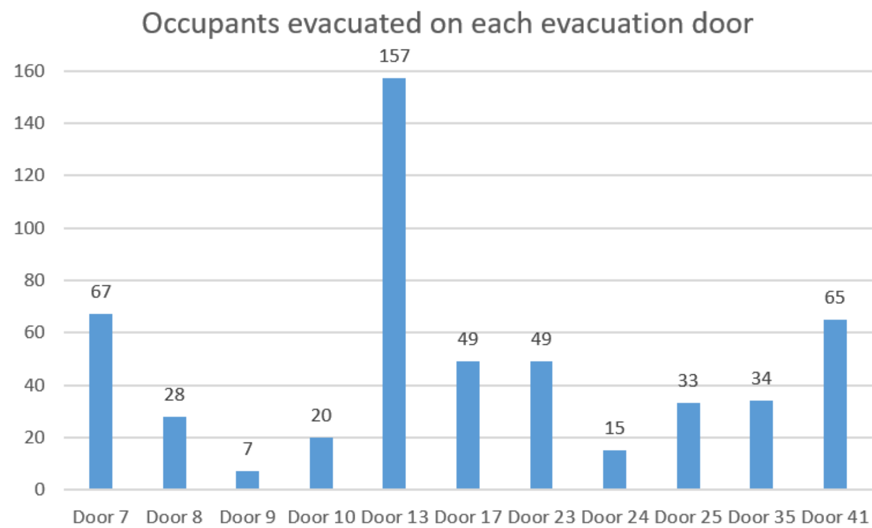

Fig. 6.Graph with the total number of users evacuated on each door for scenario 1

Scenario 2 Analysis

In scenario 2, a scenario in which the evacuation does not occur under normal conditions, the evacuation time is 107.3 seconds, a time 4.38% longer compared to that in scenario 1. This increase is due to door lock no. 41 as well as the addition of persons who cannot evacuate themselves. The arrangement of the occupants in the first second of the simulation is shown in Figure no. 7. A filter has been applied to putea visualize the density of people per m^2 thus making it possible to identify the busiest areas in the building and the most used doors and escape routes.

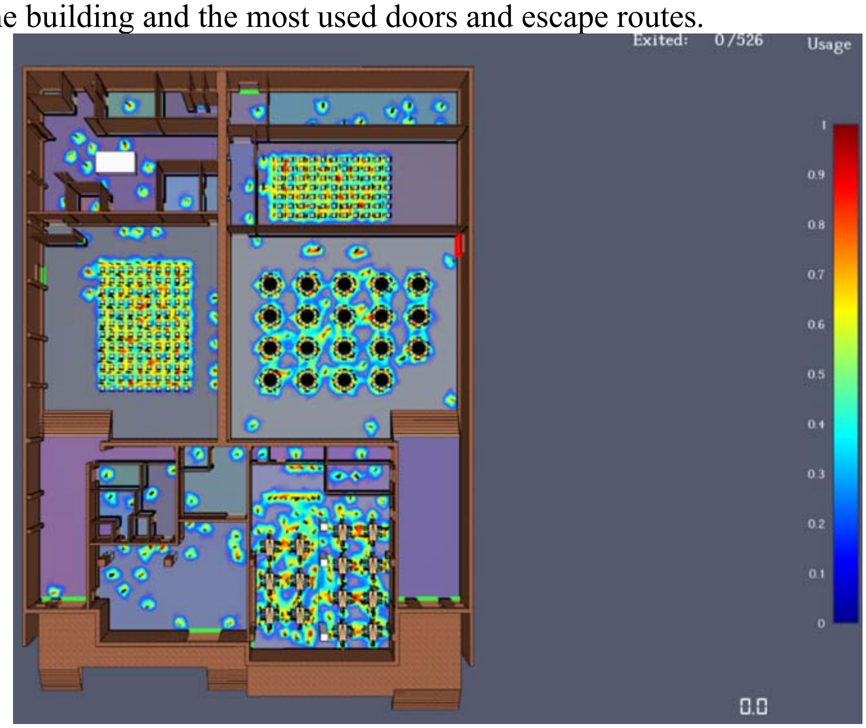

Fig. 7. Occupant arrangement in the first second of the simulation for scenario 2

The new situations imposed by the locking of a door and the introduction of two occupants who cannot evacuate themselves are, on the one hand, the increase of the evacuation time by 4.5 seconds compared to the previous scenario and on the other hand, the formation of new congestion zones (found in Figure no. 8), as well as the change in the number of people evacuated over time and the number of people evacuated on each escape door.

The first people to be evacuated were the people who cannot evacuate themselves due to the staff who consider themselves trained in this regard and act 10 seconds before the other users.

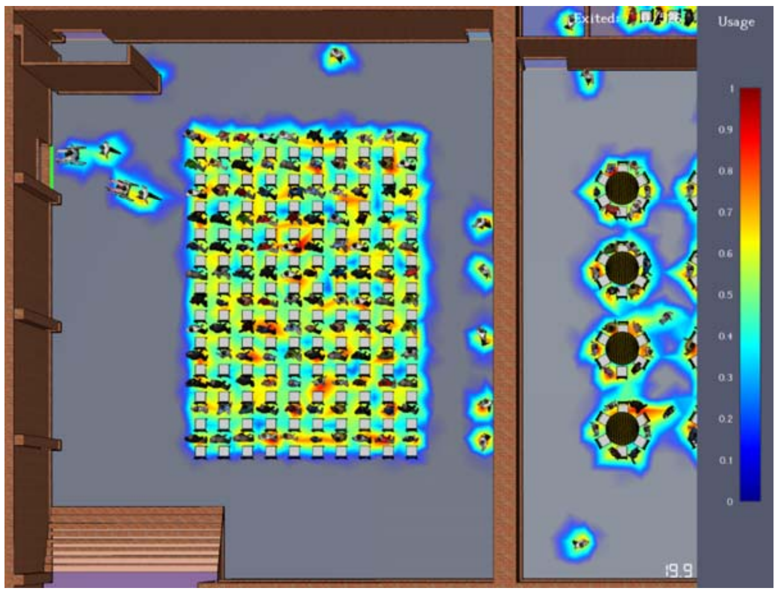

Fig. 8. 20 seconds, rapid evacuation of people who cannot evacuate themselves for scenario 2

Fig. 9. New area with increased density of people for scenario 2

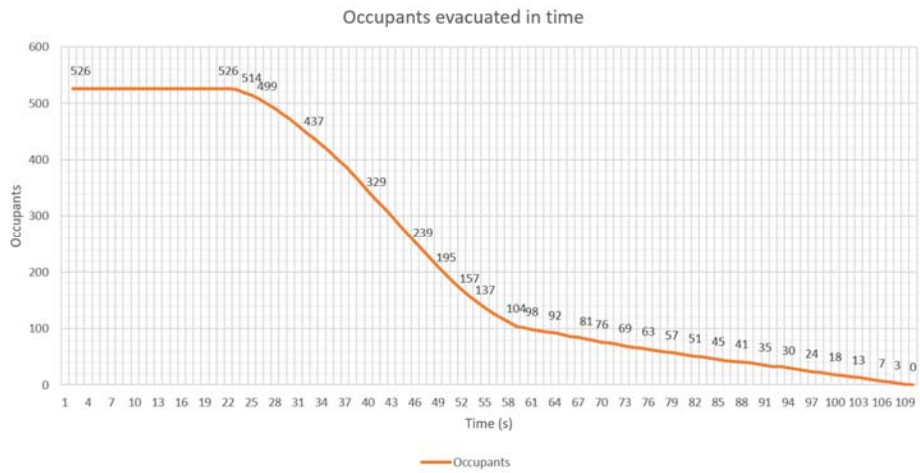

Fig. 10. Graph of users evacuated in time for scenario 2

Compared to scenario 1, there is a significant increase in users evacuated through door no. 9 (from 7 users to 25), but also an increase of 6 users for door no. 13 which was already very crowded.

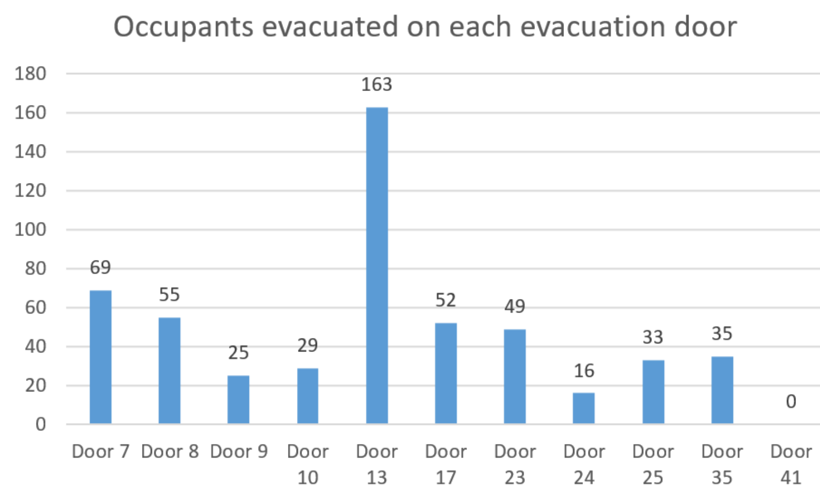

Fig. 11. Graph with the total users evacuated to each door for scenario 2

Scenario 3 Analysis

In scenario 3, a scenario in which the evacuation does not occur under normal conditions, the evacuation time is 121.8 seconds, a time 18.48% longer compared to that in scenario 1. The arrangement of the occupants in the first second of the simulation is shown in Figure no. 11. A filter has been applied to be able to visualize the density of people per m2, thus making it possible to identify the busiest areas in the building and the most used doors and escape routes.

Fig. 12. Occupant arrangement in the first second of the simulation for scenario 3

The blocking of 7 doors led to a significant increase in evacuation time (19 seconds more than scenario 1) and also an increase in the number of people evacuated on the few remaining doors that had around 50 users evacuated on each door (doors 17, 41, 13 and 35). Another effect is the creation of new congestion areas, as well as the much higher use of stairs leading to the south side of the building.

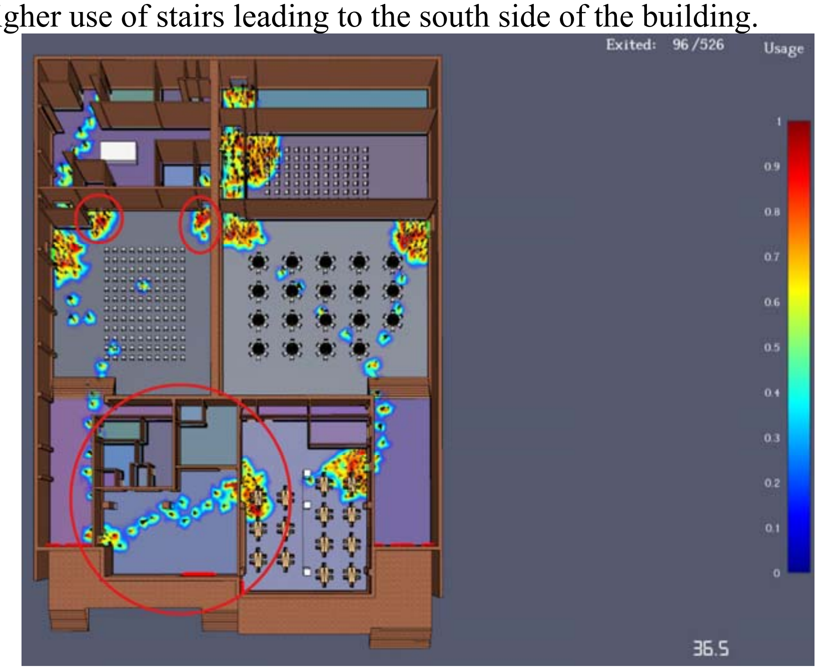

Fig. 13. New areas with high density of people for scenario 3

The first people to be evacuated were the people who cannot evacuate themselves due to the staff who consider themselves trained in this regard and act 10 seconds before the other users.

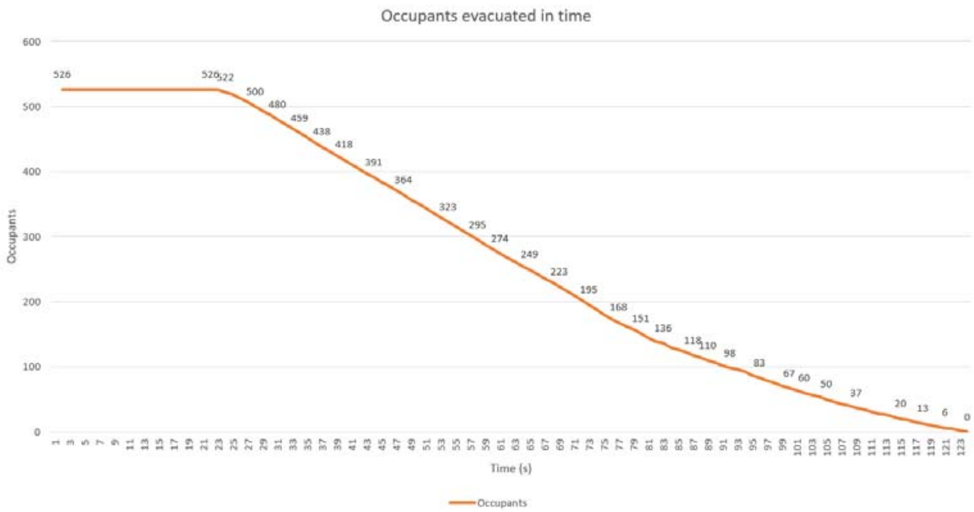

Fig. 14. Graph of users evacuated in time for scenario 3

Compared to scenario 2, the curve is no longer so steep as users from the northern part of the building have to cross the building to the southern part of it, making it impossible to use the doors closest to the main entrance.

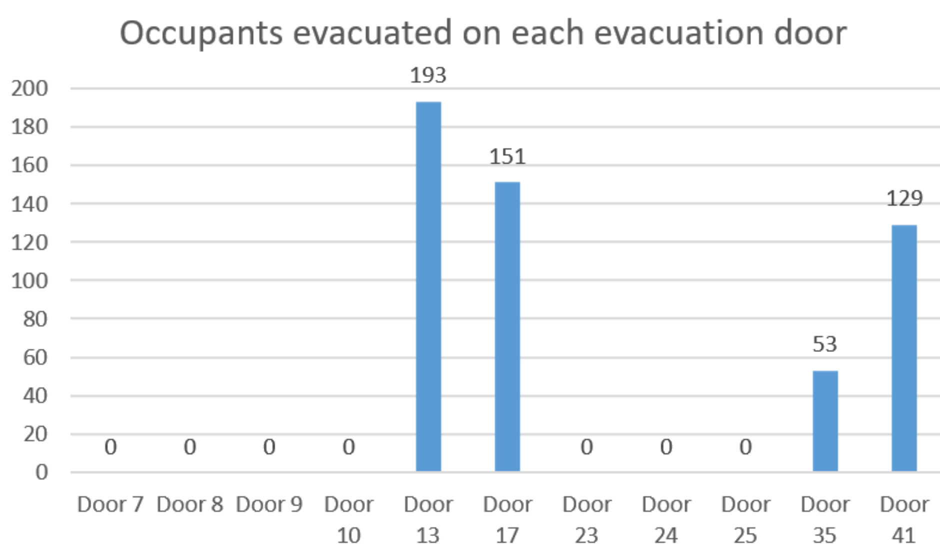

Fig. 1. Graph with the total users evacuated to each door for scenario 2

Compared to scenarios 1 and 2, only 4 escape doors are used, and the number of evacuated users on each door is considerably higher, in the case of the door no. 17 being about triple.

The scenario considered is a totally fictitious one, in practice it is impossible to decommission 7 escape doors. A special mention is that it is impossible to pregătit o building for such a scenario with such exaggerated elements. For this case, the time obtained is a very good one, being an evacuation executed in ideal time.

Solutions to make the evacuation more efficient

The analysis of the three simulated scenarios showed a significant increase in the evacuation time when one of the escape doors was blocked (scenario 2) and, in particular, when the doors at the main entrance became inaccessible (scenario 3). The evacuation time increased from 103.8 seconds (scenario 1) to 122.8 seconds (scenario 3), which represents an increase of more than 18%, indicating a vulnerability of the system in the absence of redundancy.

Based on these results, the following technical and organizational measures are proposed:

1. Reconfiguring the furniture in event rooms and hallways

In the simulations carried out, accumulations of people were observed in the vicinity of tables and chairs, especially in the areas between furniture and escape routes. It is recommended to reposition or group furniture more airy, so as not to reduce the width of the escape aisles and to allow a more fluid flow of people.

2. Resizing or supplementing secondary escape doors

The blocking of a single door led to an overload of the other exits. It is recommended to consider the possibility of extending the width of secondary doors or introducing a new direct exit to the outside from areas with high occupancy density (e.g. breakfast room or conference room).

3. Installation of additional directional exhaust signs

In scenarios with blocked exits, occupants initially continued to orient themselves towards inaccessible exits, wasting time. The implementation of dynamic signaling panels, capable of indicating in real time the fastest available outputs (voice alarm or sequential LEDs), can route flows adaptively and reduce local bottlenecks.

4. Provision of assistance for persons with reduced mobility

In scenario 2, the introduction of occupants who cannot evacuate themselves generated delays in areas where they crossed paths with groups of mobile evacuees. It is proposed to allocate dedicated routes for these trained occupants and/or companions, as well as to clearly mark these routes in the evacuation plan.

5. Implementation of an evacuation plan differentiated by areas

The simulation showed that the uneven distribution of the population leads to the overloading of some outputs and the underutilization of others. It is recommended to draw up an evacuation plan by sectors, with the advance assignment of pre-established routes for each functional area (e.g. restaurant area → side door; bar area → secondary main exit).

The proposed measures aim not only at geometric compliance with evacuation requirements, but also at optimizing the collective behavior of occupants under stress, ensuring a high level of safety even in situations with partial restriction of exits or in the presence of people with special needs. The implementation of these solutions directly contributes to shortening evacuation time and reducing the risk of congestion at critical points.

4.Conclusions

The computer simulation of the evacuation using the Pathfinder program was a key step in assessing the performance of the evacuation routes of the analyzed building, providing a dynamic perspective on how users react and move in emergency situations. Building the 3D model in SketchUp and importing it into Pathfinder allowed the faithful rendering of the architectural, functional and furniture configuration, factors that directly influence the trajectories and speed of movement of people.

The configuration steps – delimiting the spaces, defining the escape doors, setting the exit points and assigning the various occupant profiles – ensured the generation of extremely realistic evacuation scenarios. The differentiated distribution of occupants and the introduction of individualized characteristics (speed, reaction time, behavior) allowed the precise identification of areas with a high risk of congestion and vulnerable sections of the exhaust network.

The three scenarios tested demonstrated that relatively small changes in initial conditions – the appearance of people with reduced mobility or the blocking of doors – can have a major influence on overall evacuation times. The blocking of the main access generated a forced redistribution of flows to secondary exits, causing dangerous accumulations in constriction zones and confirming the need for effective redundancy of escape routes, as well as the importance of maintaining the permanent functionality of the doors.

The analysis of the results allowed the identification of key vulnerabilities, such as areas with dense furniture, insufficiently sized routes and high dependence on certain exits. The proposals formulated – resizing or supplementing the doors, reorganizing the furniture, installing additional directional signs and training the staff – directly contribute to increasing the level of safety.

Main conclusions of the study:

- evacuation times can increase by more than 18% in the absence of redundancy of escape routes;
- the uneven distribution of occupants is one of the main factors in the occurrence of congestion;
- people with disabilities significantly influence the dynamics of flows if the routes are not adapted;
- the width of the doors and the arrangement of the furniture are decisive elements for the efficiency of the evacuation;
- Trained staff can reduce times for vulnerable occupants.

Applicability to other types of buildings:

The principles and conclusions obtained are also valid for other buildings with large flows of people – conference centers, restaurants, hotels, shopping centers, clădiri administrative sau educaționale. Comportamentul mulțimii, influența furniture, the importance of redundancy and correct door sizing remain constant regardless of the type of construction, which confirms the generalizable nature of the methodology used.

Recommendations for occupants in case of evacuation:

- follow the signage and instructions of the staff without stopping or turning;
- Use the closest functional output, not just the input originally used.
- keep calm, walk orderly and avoid running;
- not to block doors and aisles;
- parents to keep their children close;
- people who can help vulnerable occupants to do so without exposing themselves to risks.

Strictly forbidden actions during the evacuation:

- the use of elevators;
- returning for personal belongings;
- pushing or forming compact masses that can generate panic;
- blocking of escape doors or corridors;
- ignoring signage or moving to locked doors.

In conclusion, the use of Pathfinder has proven to be a valuable tool for validating, optimizing and generalizing technical evacuation solutions. The results obtained support both architectural adaptations and operational improvements regarding occupant response and emergency management, contributing to increasing the overall level of fire safety.

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