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EXPERIMENTAL RESEARCH SIMULATION ON EVACUATION OF MIXED FLOWS CONSISTING OF DIFFERENT MOBILITY GROUPS

Research in this area deal with identifying challenges and developing strategies to improve the protection and support of different mobility groups representatives. They can be an important tool to create a society with equal opportunities and to reduce risks during emergency situations.

The authors emphasize the importance of computer simulations for analysis and improvement of evacuation strategies. These tools allow testing different emergency scenarios, help to improve infrastructure and planning different structures for providing maximum safety.

The work is dedicated to the experimental research on evacuation simulation of mixed flows consisting of different mobility groups (M1, M3, M4) in case of fire. The aim is to compare the results of simulation with experimental results and to make conclusions about future use of obtained data in scientific exploration as well as establishing relationships between the evacuation participants' movement speed and the flow density.

Analytical and computer modelling methods were used to achieve the goal and implement the set tasks. Movement simulation results of mixed flows evacuation were analysed.

Evacuation features of people with different mobility in case of fire were studied. The results of simulation were compared with experimental results. Conducted work is important for evaluating the reliability of studies and for confirming the model suitability for father research. The work is also aimed at creating an empirical database of the movement parameters of different mobility groups' representatives during evacuation from a building in case of fire.

Modelling was carried out in two stages. The first block of models was intended for a real-life experiment preparation of different mobility groups' representatives. These modes were used for obtaining an empirical database of mixed evacuation flows movement parameters. The initial data for this calculation were used in accordance with [1]. The second block of models was based on empirical data obtained during the experiments.

The results of this work can be used in further experimental studies. They can help in determining the speed-density relationships for each flow configuration.

Keywords: *simulation, experiment, low-mobility population groups, evacuation flow, evacuation, flow density, people with disabilities.*

Formulation of the problem. One of the priority tasks of the society is respectful attitude to the rights and dignity of all people, focusing on the needs of vulnerable and sick population groups. This task includes providing assistance to all people with reduced mobility which need support in everyday life. In modern multi-threat world, the evacuation of different groups of people with all levels of mobility is critical to ensuring safety and minimizing life losses. Providing effective and safe evacuation for people with limited mobility, children, the elderly and other vulnerable population groups requires specialized strategies.

Currently, [1] is the main document on the calculation of evacuation time. It does not consider configurations of people flows with different mobility groups, while in real situations we deal with various percentages of such people in different buildings. The document does not contain the necessary recommendations for such situations. In particular, there is a lack of recommendations for medical institutions and other objects, where people with disabilities are present.

The article is a part of research which aims to solve the problem of protecting and supporting people of different mobility groups.

Nowadays emergency situations are unpredictable and risky that’s why it is important to be prepared to evacuate and ensure the safety of the population. Evacuation experiments combined with computer simulations are becoming a key tool for understanding, analyzing, and improving emergency evacuation strategies.

Computer models make it possible to reproduce various emergency scenarios, from fires and earthquakes to natural disasters, and help to understand how people react in stressful situations. This contributes to the development of effective and safe evacuation strategies, taking into account the psychological aspects, behavior and needs of people in these situations.

Conducting experiments in a virtual environment makes it possible to analyze different infrastructure options, determining the optimal location of exits, escape routes and safety zones. This helps to improve the plans of buildings, streets and other structures in order to ensure maximum safety of evacuation.

One of the main advantages of evacuation experiments is their ability to test different strategies. This allows identifying gaps in evacuation plans and developing optimal and effective emergency response methods.

Conducting experiments in a virtual environment also allows improving the training of personnel and the population. People have the opportunity to train their skills and knowledge on proper evacuation behavior, which contributes to overall safety.

The use of computer models in combination with experiments in the field of evacuation enables the development and improvement of strategies and action plans that will save lives and reduce the risks to the public in case of emergency.

Analysis of recent research and publications. In previous works existing programs for calculating the evacuation time in case of fire have been studied. A comparative analysis of available software complexes that perform calculations in this area has been conducted. In [2] description of the mathematical models of evacuation flows movement in case of fire has been also done. The conclusions regarding the functionality of the considered software complexes have been summarized. In study [3] the limitations in the computer simulation of people’s with disabilities behavior have been analyzed. Within that research six building evacuation scenarios have been regarded. Three different software complexes (SIMULEX, STEPS, and Pathfinder) have been used. Modeling of different variations of people with impaired mobility and comparison of the methodologies of using these programs has been carried out. The results of the study have showed significant differences in the use of these three programs, even with the same initial data. The difference in the total evacuation time reached 8%.

Scientists from China, within the mixed evacuation flows research have conducted a series of simulations performed on pedestrian routes. In particular, people in wheelchairs have passed through narrow funnel-shaped places with an angle range from 0° to 90°. The simulations have been carried out using the software "Pathfinder". The results of these simulations have been compared to previous experiments for studying the effect of angles on the evacuation process. Simulations have shown that at an angle of 45° there is greater efficiency and less congestion. However, compared to the previous experimental results, the average moving speed of the wheelchairs is has been 0.224 ± 0.028 m/s less, the evacuation time has increased, and the traffic efficiency and congestion at 0° and 45° angles have showed a difference in the simulations with large number of wheelchairs. The problems of frequent overtaking and shorter edge distances within the simulations also have been regarded. These findings indicate the possibility of improving the traffic efficiency and the pedestrian movement modeling accuracy, in particular for wheelchair users [4].

Korean scientists have conducted a study using the Fire Dynamics Simulator (FDS). Available Safe Egress Time (ASET) has been calculated for patients of hospitals for the elderly. Within the research the situation in which evacuation became impossible due to the onset of fire has been regarded. Required Safe Egress Time (RSET, the duration of time required for the safe evacuation of the building occupants after the fire alarm) was also calculated using Pathfinder software. In the article various escape routes such as stairs, elevators and ramps were considered, in conjunction with the deployment of the traffic pattern. According to the assessment of evacuation efficiency and the choice of evacuation route and traffic pattern have an impact on the number of victims among different groups of patients. Due to the research the use of escape ramps allows reducing the number of deaths in comparison to the use of stairs or elevators. Such a choice of evacuation route during a fire in a hospital for the elderly has been proved to be safer for vulnerable persons [5].

A group of Chinese scientists has carried out calculations and simulations of indoor evacuation due to 15 scenarios involving different numbers of people (20, 40 and 60). Trajectories and coordinates of agents have been obtained in real time. It has been established that with the increase in the share of pedestrians with disabilities, the individual evacuation time of the agents increases. This trend has been consistent with the results of a previous controlled experiment. The fundamental diagrams obtained by simulation have been similar to the experimental results. The presence of people with disabilities in the scenario has been found to result in higher crowd density compared to scenarios without disabilities. As the proportion of pedestrians with disabilities has increased, the danger of a stampede in the crowd has also increased. These conclusions are useful for computer simulations for preventing crowding during the evacuation in case of fire [6].

Ukrainian scientists R.I. Maiboroda, Yu.A. Otrosh, N.V. Rashkevich, R.S. Melezhik in their work have investigated the current state of the problem of low-mobility population groups evacuation from high-rise residential buildings during a fire. The possibility of safe self-evacuation of these population groups using fire elevators has been substantiated. Mathematical and graphical calculations of the evacuation time using the Pathfinder software complex with and without the use of fire elevators have been carried out and proposals dealing with the evacuation of low-mobility population groups from high-rise residential buildings have been made [7].

During the scientific explorations, O. Khlevnoi and V. Kovalyshyn have carried out an analysis of the methods of calculating the evacuation time, described in the current legislation. They made the conclusion that regulatory documents and scientific literature did not contain data on evacuation parameters of the school-age children with different levels of mobility mixed flows. In their works [8–11], the authors have focused on taking into account different mobility groups of children of different ages in the planning and organization of the evacuation process. The necessity to create an empirical database of the evacuation flows movement parameters in schools with inclusive education has been substantiated. Such parameters can be used for updating requirements for evacuation routes and exits in modern school institutions. However, these studies have not paid enough attention to modelling the evacuation of mixed flows containing people of different mobility groups (M1, M3, M4).

Setting the problem and solving it. The purpose of this article is to study and reveal the aspects of evacuation flows consisting of representatives of different mobility groups (M1, M3, M4) in case of fire. The main goal is comparative analysis of the simulation results and the results of real experiments to confirm the adequacy of modelling results and their suitability for further use in scientific work. The research consists in creating a basis of empirical data describing the movement parameters of different groups of people during evacuation from buildings in case of fire and obtaining this data for establishing dependencies between the evacuation speed and the density of the flow. These dependencies will be used to calculate the duration of evacuation from different types of buildings and structures, to create heat maps reflecting the density of human flow on different sections of evacuation routes. In addition, they will help to determine the duration of delays and accumulations at the doors and local obstacles, as well as the average speed of movement of the evacuation participants.

Methods. The simulation is performed with the software that implements an individual flow model of the movement during evacuation. The program has a graphical interface for specifying the output data, as well as tools for 2D and 3D visualization of the results.

The environment of people's movement is presented as a three-dimensional grid that coincides with the real dimensions of the building model. The grid is automatically generated according to the imported FDS geometry data and due to the drawings of the building sections where the experiment is conducted.

Walls and other impassable areas are shown as gaps in the navigation grid. Such objects are not modelled directly in the program. They are expressed implicitly, since people cannot move where there is no navigation grid.

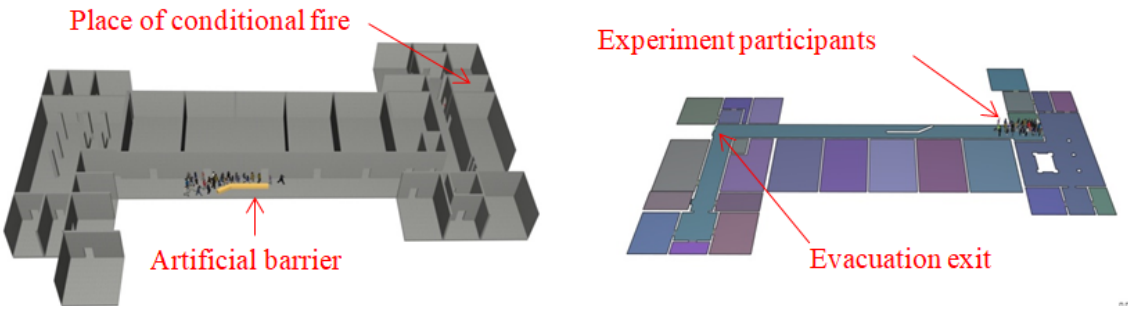
Doors are presented as special boundaries of the navigation grid. In all calculations, they provide a mechanism for connecting spaces and tracking human flow. Doors are also used to explicitly control human flows.

Stairs are also presented as special boundaries of the navigation grid and triangles. The movement speed of people decreases by a factor that depends on the slope of the stairs. Each stair has two doors that work just like any other door in the model, but are editable in the stair properties.

Each agent (the human in the model) has a location, a profile (specified size, speed, etc.) and a behaviour (the agent's goal) that allow creating scenarios. The agent is modelled as a vertical cylinder moving on the grid using inverse controlled motion. The movement of each agent is calculated independently.

Results and Discussion. In this work modelling was carried out in accordance with [12]. In order to obtain more data for comparison and assessment of the calculated models adequacy, the simulation of experimental studies consists of two blocks. In the first block the initial data are taken according to [1]. The second block is built on the basis of empirical data obtained during a real-life experiment investigating the evacuation of a mixed flow of people with the presence of persons of different mobility groups.

Within each series of simulation experiments, all participants were combined into one flow, the total number of which was 30 agents. The percentage ratio of M3 and M4 agents in groups varied from 3.33% to 10% of the total number of participants in the group. The ratios were chosen according to the conducted experiment scenarios and [12] (Fig. 1 a).



a) b)

Figure 1. Estimated model of the experimental section of the evacuation route

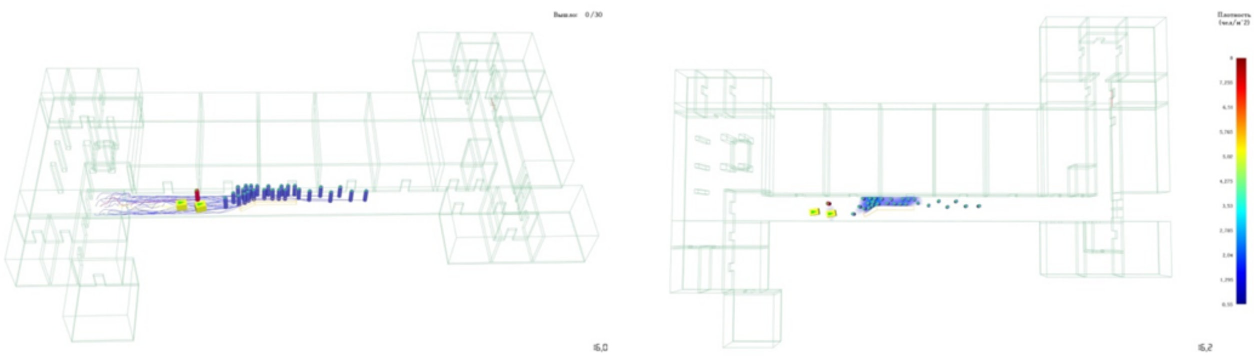
It is assumed that the conditional fire is located on the floor area, where the fire can be detected simultaneously by all agents according to [1] and [12], and the value of the evacuation start time is taken to be zero.

The length of the simulated experimental area is 49.91 m, the width is 3.07 m.

The flow of participants moves to a relatively safe zone, which is considered safe from the moment a person passes through the evacuation exit (Fig. 1 b). An artificial barrier is located on the traffic path. It limits the width of the corridor to 1.2 meters on a certain section of the 5-meter-long evacuation route.

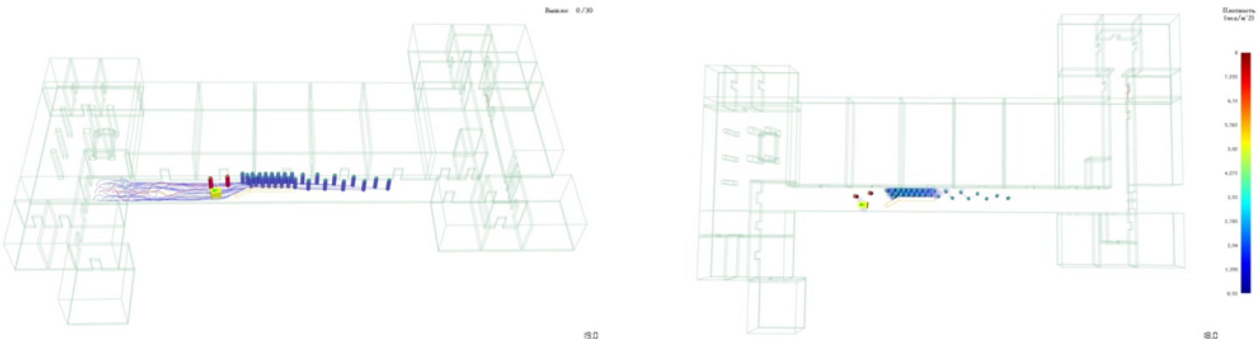
Visualization of the evacuation simulation process makes it possible to observe the agents' movement in time and to record the flow density value at each section of the route (Fig. 2-5).

The data obtained during the experiments in real conditions were used as the initial parameters for the simulations as well as the values given in legislative documents [1].



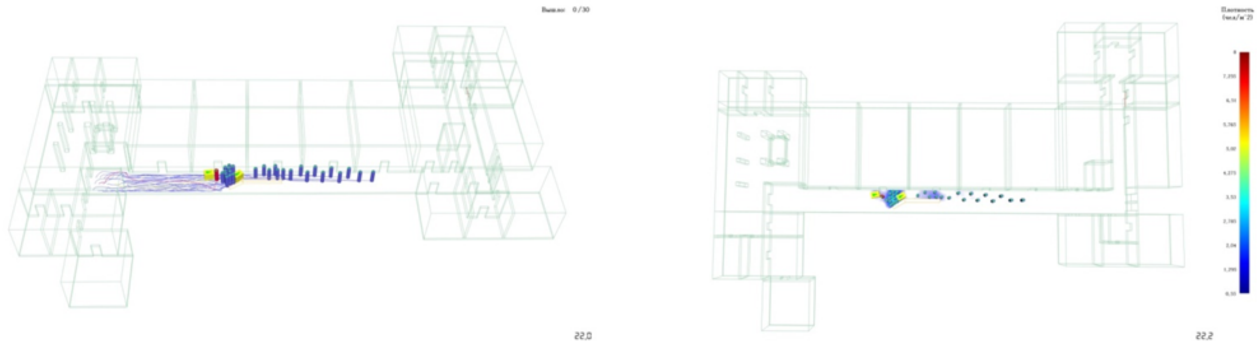
a) b)

Figure 2. Visualization of the movement simulation process for the evacuation flow including mobility groups M1 (90%), M3 (3.33%) and M4 (6.67%) in accordance with [1]: a) movement trajectories at the time mark 16 s, b) density of agents at the time mark 16.2 s.



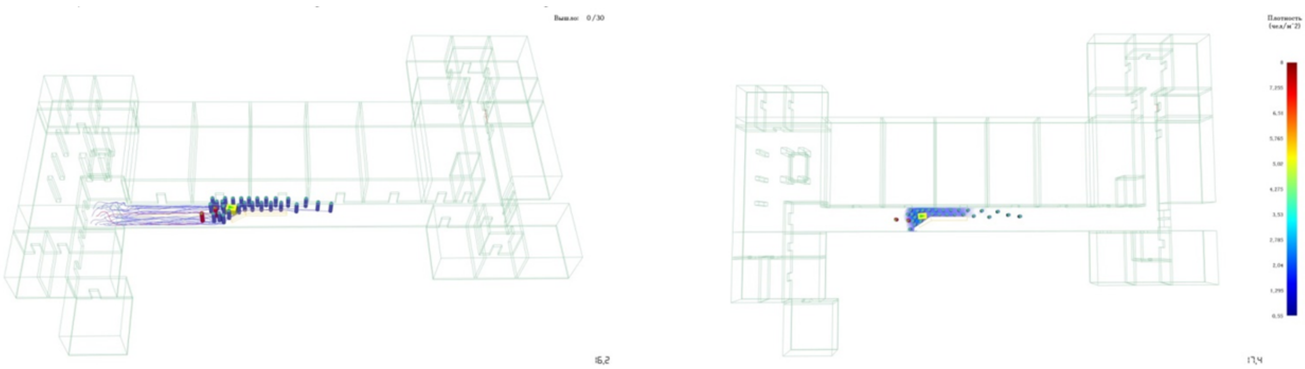
a) b)

Figure 3. Visualization of the movement simulation process for the evacuation flow including mobility groups M1 (90%), M3 (6.67%) and M4 (3.33%) in accordance with [1]: a) movement trajectories at the time mark 19 s, b) density of agents at the time mark 18 s.



a) b)

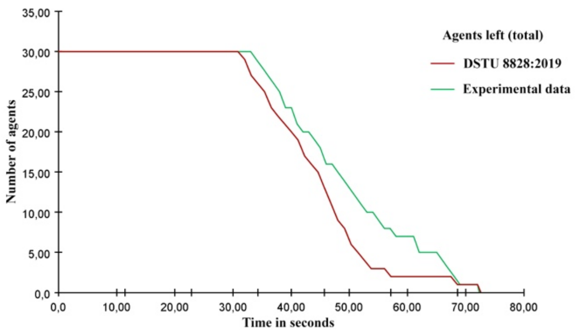
Figure 4. Visualization of the movement simulation process for the evacuation flow including mobility groups M1 (90%), M3 (3.3%) and M4 (6.67%) in accordance with experimental data: a) movement trajectories at the time mark 22 s, b) density of agents at the time mark 22.2 s.



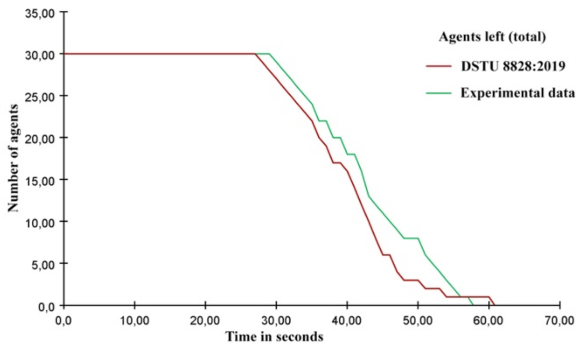
a) b)

Figure 5. Visualization of the movement simulation process for the evacuation flow including mobility groups M1 (90%), M3 (6.67%) and M4 (3.33%) in accordance with experimental data: a) movement trajectories at the time mark 16.7 s, b) density of agents at the time mark 17.4 s.

The dynamics of the mixed flows movement through the evacuation exit are shown in the fig. 6. Results obtained in accordance with [1] (red colour) and in accordance with experimental data are compared.



a)



b)

Figure 6. Dynamics of agents evacuation to the safe zone: a) M1 (90%), M3 (3.33%) and M4 (6.67%), b) M1 (90%), M3 (6 .67%) and M4 (3.33%).

Table 1 shows average speed values of different mobility groups (M1, M3, M4), which were obtained during the simulation according to [1] and similar speed values obtained during the experiment. Table 2 shows the exit time of different mobility groups obtained during the simulation according to [1] and similar exit time obtained during the experiment.

Table 1. Speeds of mobility groups used during the simulation of the experiment

#	Percentage ratio of agents in the experiment	Simulation according to [1]			Simulation according to experimental data		
		$V_{avg\ (M1)}$ (m/s)	$V_{avg\ (M3)}$ (m/s)	$V_{avg\ (M4)}$ (m/s)	$V_{avg\ (M1)}$ (m/s)	$V_{avg\ (M3)}$ (m/s)	$V_{avg\ (M4)}$ (m/s)
1.	M1 (30) 100%	1,67	-	-	1,85	-	-
2.	M1 (29) 96,67 %+ M3 (1) 3,33 %	1,67	1,17	-	1,6	1,51	-
3.	M1 (28) 93,33 % + M3 (2) 6,67 %	1,67	1,17	-	1,43	1,33	-
4.	M1 (27) 90 % + M3 (3) 10 %	1,67	1,17	-	1,37	1,39	-
5.	M1 (29) 96,67 % + M4 (1) 3,33 %	1,67	-	1	1,21	-	1,12
6.	M1 (28) 93,33 % + M4 (2) 6,67 %	1,67	-	1	1,43	-	1,33
7.	M1 (27) 90 % + M4 (3) 10 %	1,67	-	1	1,47	-	1,4
8.	M1 (27) 90 % + M3 (1) 3,33% + M4 (2) 6,67 %	1,67	1,17	1	1,35	1,29	1,63
9.	M1 (27) 90 % + M3 (2) 6,67 % + M4 (1) 3,33 %	1,67	1,17	1	1,56	1,31	1,65
10.	M1 (28) 93,33 % + M3 (1) 3,335 % + M4 (1) 3,335 %	1,67	1,17	1	1,42	1,17	1,5

Table 2. Agents’ time of evacuation to safe zone

#	Percentage ratio of agents in the experiment	Evacuation to the safe zone time (seconds)			Difference between simulation and experiment results (%)		Difference between simulation according to experimental results and experiment results (%)
		Simulation according to [1]	Simulation according to experimental data	Results of experiment	Simulation according to [1]	Simulation according to experimental data	
1.	M1 (30) 100%	49,7	44	36,75	26,05	16,48	11,47
2.	M1 (29) 96,67 %+ M3 (1) 3,33 %	51,3	50,6	49,72	3,08	1,74	1,36
3.	M1 (28) 93,33 % + M3 (2) 6,67 %	54,3	57	50,36	7,26	11,64	4,74
4.	M1 (27) 90 % + M3 (3) 10 %	55,3	59,8	55,12	0,33	7,81	7,52
5.	M1 (29) 96,67 % + M4 (1) 3,33 %	57,9	68,5	51,61	10,86	24,65	15,47
6.	M1 (28) 93,33 % + M4 (2) 6,67 %	62,3	65,2	59,03	5,25	9,47	4,45
7.	M1 (27) 90 % + M4 (3) 10 %	69,1	65,1	62,58	9,44	3,87	5,79
8.	M1 (27) 90 % + M3 (1) 3,33% + M4 (2) 6,67 %	63,3	72,1	55,21	12,78	23,43	12,19
9.	M1 (27) 90 % + M3 (2) 6,67 % + M4 (1) 3,33 %	60,7	57,5	51,62	14,95	10,23	5,28
10.	M1 (28) 93,33 % + M3 (1) 3,335 % + M4 (1) 3,335 %	59,8	61,9	56,94	4,78	8,01	3,4

Conclusions and directions for further research. In the article modelling has been carried out in two blocks. The first block of models has been developed in order to prepare for conducting a real-life experiment aimed to research the evacuation of mixed flows consisting of different mobility groups (M1, M3, M4). The main goal of such experiment is to obtain the empirical databases of mixed evacuation flows movement parameters. The initial data for the simulation have been accepted in accordance with [1]. The second block of models has been developed on the basis of empirical data obtained during the experiment.

The difference in the results of the simulation and the natural experiment has not exceed the significant values of the difference in time, which indicates the adequacy of the constructed models. This, in turn, have made it possible to assess the correctness of the conducted experiment and expand the limits of experimental research on the reproduction of mixed human flows evacuation processes without involving additional material and human resources.

The information obtained will be used in future experiments aimed at studying the evacuation of representatives of different mobility groups. This data will help to determine the relationship between movement speed and density for each flow configuration. In addition, in the future, the adaptation coefficient of the human flow to the change in density during movement with different percentage ratios between the participants of mobility groups M1, M3 and M4 will be calculated.

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МОДЕЛЮВАННЯ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ ЕВАКУАЦІЇ ЗМІШАНИХ ПОТОКІВ ЛЮДЕЙ РІЗНИХ ГРУП МОБІЛЬНОСТІ

Дослідження в цій області допоможуть виявити проблеми та розробити стратегії для покращення захисту й підтримки людей різних груп мобільності. Ці розвідки стануть важливим інструментом для створення суспільства з рівними можливостями та сприятимуть зменшенню ризиків під час надзвичайних ситуацій.

Автори наголошують на важливості експериментів у віртуальному середовищі та комп'ютерного моделювання для аналізу та покращення стратегій евакуації. Ці інструменти дають змогу тестувати різні сценарії надзвичайних ситуацій, що сприяють покращенню інфраструктури та плануванню споруд з метою забезпечення максимальної безпеки.

Робота присвячена дослідженню процесу евакуації осіб різних груп мобільності (М1, М3, М4) під час пожежі. Основною метою є порівняння результатів моделювання та реальних експериментів для визначення надійності та їх використання надалі у наукових розвідках. Отримані дані надають змогу встановити взаємозв'язки між швидкістю руху учасників евакуації та щільністю потоку.

Для досягнення мети та реалізації поставлених задач застосовано аналітичний та метод комп'ютерного моделювання. Проаналізовано результати моделювання руху змішаних потоків людей різних груп мобільності М1, М3 та М4.

Досліджено аспекти евакуації людей з різним рівнем мобільності під час пожежі. Порівняно результати моделювання та реальних експериментів. Це допоможе переконатися у надійності досліджень та прогнозів, отриманих за допомогою моделі, і підтвердити їхню придатність для подальшого використання в наукових дослідженнях. Наукова розвідка спрямована на створення бази емпіричних даних, що описує параметри руху людей різних груп мобільності під час евакуації з будівлі під час пожежі.

Моделювання проведено в два етапи. Перший блок моделей призначений для підготовки до натурного експерименту щодо евакуації осіб різної мобільності з метою створення бази емпіричних даних щодо параметрів руху у змішаних потоках евакуації. Вихідні дані для цього розрахунку використовувались відповідно до [1]. Другий блок моделей базувався на емпіричних даних, отриманих за результатами натурного експерименту.

Отримані дані будуть застосовані надалі в експериментах, спрямованих на вивчення евакуації осіб різних груп мобільності. Зазначене допоможе у визначенні залежностей між швидкістю руху та щільністю для кожної конфігурації потоку.

Ключові слова: *моделювання, експеримент, маломобільні групи населення, евакуаційний потік, евакуація, щільність потоку, люди з інвалідністю.*