

ANALYSING THE HUMAN BEHAVIOR IN A FIRE DRILL. COMPARISON BETWEEN TWO EVACUATION SOFTWARE: FDS+EVAC AND PATHFINDER

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Abstract: *The paper presents the numerical simulation of a fire drill on an educational building using two egress models implemented in different software products. The purpose of this case study is to establish if the computed travel times are comparable and to identify if the crowd movement is similar in both numerical simulations. An important issue is presenting the main concepts and methods used by the two evacuation models. Following the numerical analysis it was concluded that for the considered scenario the differences between the results are acceptable.*

Key words: *FDS+Evac, Pathfinder, fire drill numerical simulation.*

1. Introduction

Fires are the natural disasters with the greatest losses of human lives and material losses. Protecting people and goods in case of fire was a concern of society since ancient times.

Fire safety of buildings is the second essential requirement according to the European [1] and Romanian legislation [2].

The prescriptive approach to fire safety (used by many countries) do not sufficient use the full possibilities of a building for safe human evacuation in case of fire.

The engineering approach to fire safety engineering use mathematical models that describe human behaviour in fire situations with a high degree of reliability.

The behavioural response of individuals in fire incidents has been examined for approximately 50 years by researchers [3] and the mathematical modelling of human

behaviour in case of fire has been developed with the use of computers in research and building design.

Numerical simulations of human behaviour in case of fire are useful tools for ensuring the safe design of evacuation routes from buildings.

Fire protection engineers often use one model the simulate the evacuation process and this could lead to mistakes caused by its weak points or the lack of experience. A comparative analysis performed with different egress models can provide a design with a high degree of reliability.

2. Objectives

This study was motivated by the need to compare and verify the results obtained from the numerical simulation of the human evacuation process.

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The aim of this study is to present that egress models having different approaches can compute similar results by modelling the most complex “phenomena”: human behaviour.

This study may represent a starting point for engineers who want to improve the design of evacuation routes from buildings.

3. Material and Methods

In this paper it is analyzed the 1st floor of an education building (the main house of Building Services - Faculty of Civil Engineering and Building Services from

Jassy, Romania) having approximately 35.00 x 37.00 m and 3.50 m height. The building has two exits (main and secondary) located on the ground floor near the two staircases (main and secondary).

It was considered a number of 7 rooms with 219 people inside them. The floor plan is presented in Figure 1.

As input data, besides the geometry of the analyzed space (which is the same in both programs) it was considered the following properties for building occupants (adult person) [4,5]:

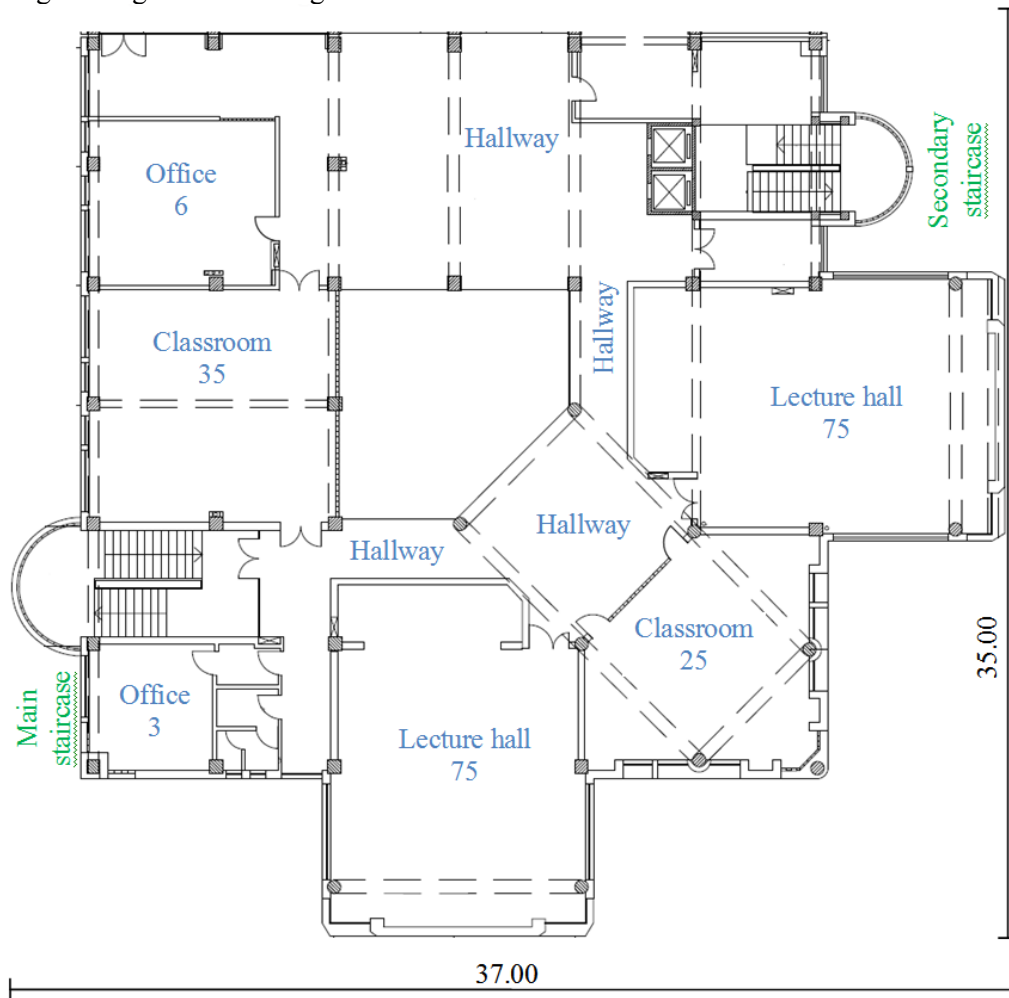


Fig. 1. The analyzed floor of the building with the number of users per each room

- speed: uniform distribution 0.95 – 1.55 m/s and an 0.80 speed factor for ramps;
- body dimension: uniform distribution $R_d=0.44-0.58$ m, $R_s=0.19$ m, $R_t=0.3$ m for FDS+Evac; $R_s=0.44-0.58$ m for Pathfinder (for more details see 3.1.2. and 3.2.2.).

3.1. FDS+Evac 2.5.0

FDS+Evac (Fire Dynamics Simulator with Evacuation) is the human evacuation module implemented in FDS. FDS (Fire Dynamics Simulator) is a Computational Fluid Dynamics (CFD) model of fire-driven fluid flow.

FDS+Evac is a research tool used for studying human evacuation in buildings. It allows simultaneous simulation of fire and evacuation process but it can also be used to simulate only fire drills [5].

This software consider the analogy between large crowd movement and fluid dynamics [5].

FDS+Evac is developed by VTT Technical Research Centre of Finland and it is available for free (no charge).

3.1.1. Mesh

FDS+Evac approximates the analyzed space geometry on a rectilinear mesh. The agents are moving only in two-dimensional horizontal planes representing the floors of the building [5]. Moving agents from one floor (mesh) to another floor (mesh) is done (“manually” by the user) using an internal door connection [5]. This method is time consuming and can easily generate errors.

Using rectilinear grid is also due to the analogy agent-fluid particle where the Finite Volume Method is used in calculation.

The rectilinear grid is suitable for buildings because their geometry is mainly rectangular. Figure 2 presents the computational mesh of the analyzed

geometry.

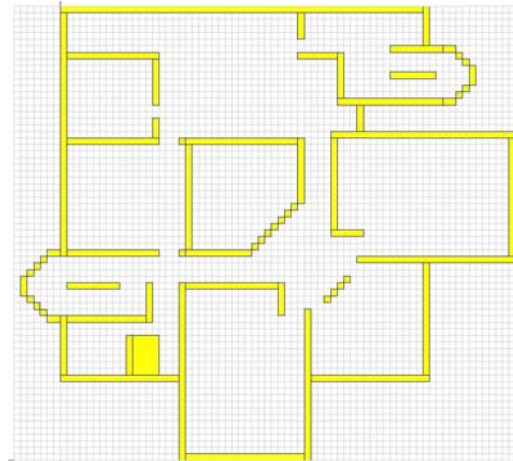


Fig. 2. FDS+Evac computational mesh

3.1.2. Agent Movement Model

FDS+Evac treats each person as an individual agent whose movement is treated by an equation of motion; each agent have its own personal properties and escape strategies [5].

Each agent is represented by three circles which approximate the elliptical shape of the human body (Figure 3).

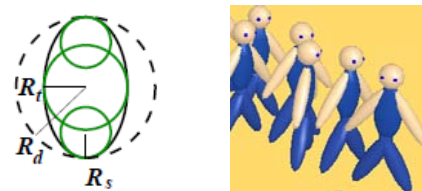


Fig. 3. The human body shape (left) and the visual representation (right) for agents used by FDS+Evac [5]

The agent movement algorithm is based on Helbing’s model modified by Langston. This model is also called the “social force model” because a force is used to keep reasonable distances to walls and other agents (Figure 4) [5].

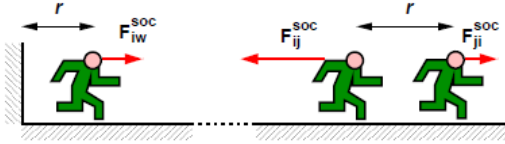


Fig. 4. The social force concept [5]

Cording to [5] (for a fire drill) the force acting on agent “i” is:

$$f_i = F_{motive} + F_{agent-agent} + F_{agent-wall}. \quad (2)$$

where:

$$F_{motive} = \frac{m_i}{\tau_i} (v_i^0 - v_i). \quad (3)$$

motive force on the agent;

$$F_{agent-agent} = \sum_{i \neq j} (f_{ij}^{soc} + f_{ij}^c + f_{ij}^{att}). \quad (4)$$

agent-agent interaction force;

$$F_{agent-wall} = \sum_w (f_{iw}^{soc} + f_{iw}^c). \quad (5)$$

agent-wall interaction force;

Parameters involved in equations (3), (4) and (5) are:

m_i - mass of agent “i”;

τ_i - relaxation time parameter (strength of the motive force);

v_i^0 - walking speed of agent “i”;

f_{ij}^{soc} - social force for agent-agent interaction;

f_{ij}^c - attraction/repulsion force for agent-agent interaction;

f_{iw}^{soc} - psychological wall-agent force for agent-wall interaction;

f_{iw}^c - physical wall-agent force for agent-wall interaction;

Due to agent-fluid particle analogy the movement of a crowd towards an exit, in FDS+Evac, is similar to the flow of a fluid caused by a fan. This method produces a

nice directional field for egress towards the chosen exit door [5] shown in Figure 5.

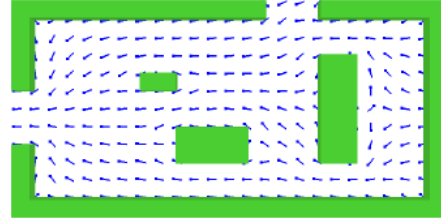


Fig. 5. Bi-dimensional flow field used to guide agents towards exit [5]

This method will guide more agents to the wider escape routes than on the narrower ones because the field is a solution to an incompressible flow. This analogy (an incompressible fluid flow) is a good starting point to find the movement directions of large crowds [5].

FDS+Evac uses a Verlet algorithm to solve translation and rotational equations of motion [5]. Verlet integration are often used in molecular dynamics simulation to calculate trajectories of particles [6].

3.1.3. Exit Selection

According to [3] real life evacuations support the fact that people will prefer familiar routes even if shorter and faster unfamiliar routes are available and clearly visible. Another observation is that many occupants tend to select the exit where the majority of the others are heading. This behaviour is called herding.

The exit selection algorithm implemented in FDS+Evac can take into account the herding behaviour and also the tendency to favour familiar routes.

According to [5] the agents observe the actions of the other and select the exit through which the travel time is estimated to be the shortest. The travel time for an agent is calculated from the distance to the exits and the congestion in front of the exit.

3.2. Pathfinder 2014.2.0806

Pathfinder is a human movement simulator used to studying human evacuation from buildings. This software can only simulate fire drills, no occupant-fire interaction can be considered [7].

Pathfinder provides two options for occupants movement: an SFPE mode and a steering mode [7]. This paper focuses only on the steering approach because it can generate more realistic results.

Pathfinder is developed by Thunderhead Engineering USA and it is not available for free (paid access).

3.2.1. Mesh

Pathfinder uses a 3D triangular mesh to approximate the movement environment [7]. The mesh consists of continuous 2D triangulated surfaces which can be horizontal or inclined. The occupants can move from a floor to another floor by using ramps belonging to the same "general" mesh.

Figure 6 presents the computational mesh of the analyzed geometry.

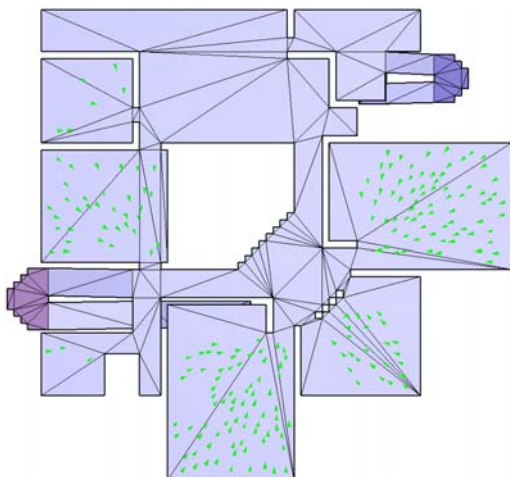


Fig. 6. Pathfinder computational mesh

The 3D triangular mesh is very suitable for buildings with complex geometries

because it can easily approximate rounded surfaces and ramps/stairs. The obstacles (like walls) are represented as gaps in the mesh [7].

3.2.2. Agent Movement Model

In Pathfinder a behaviour is assigned to each occupant; this behaviour dictates the goals that must be achieved in the simulation by each occupant [7]. This goal, for example, can be reaching an exit.

Each occupant is represented by a circle which approximates the shape of the human body (Figure 7) [8].



Fig. 7. The human body shape (left) and the visual representation (right) for agents used by Pathfinder

To reach a destination a person must follow a path taking into account collision avoidance with other persons.

Pathfinder assumed that an occupant has a global knowledge of the building (distance to the doors) and calculate the "cost" of a specific door; a path is then generated to the targeted door and the occupant moves towards [7]. The resulting path is as a series of points on edges of the triangular mesh. To smooth out the path a special algorithm is used by the software [7].

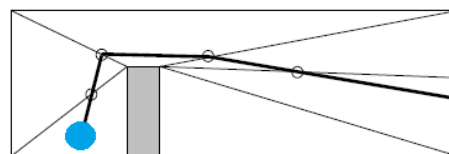


Fig. 8. An occupant's planned path [7]

An occupant will evaluate a set of discrete movement direction and choose the direction that minimizes a cost function. The cost function is evaluated by combining several types of steering behaviour to produce a cost. The implemented steering behaviour are [7]:

- seek behaviour that steers the occupant to travel along a seek curve;
- separation behaviour that steers occupants to maintain a desired distance away from other occupants;
- avoid wall behaviour that detects walls and steers the occupant to avoid collisions with walls;
- avoid occupants behaviour that steers an occupant to avoid collision with other occupants.

3.2.3. Exit Selection

The occupants are selecting an exit by calculating the lowest cost for the targeted exit [7]. The criteria used to calculate the cost are [7]:

- current room travel time (the time necessary for an occupant to reach the door at maximum speed ignoring all other occupants);
- current room queue time (the time estimated for an occupant will have to wait in a room)
- global travel time (the time necessary for an occupant to travel at maximum speed from the target to the current seek goal ignoring all other occupants);
- distance travelled in room (the distance the occupant has travelled since entering the current room).

4. Results and Discussions

At the start of both simulations the occupants begin to travel towards the main staircase, reach the ground floor of buildings and leave the computational model when they reach the main exit.

The occupants are moving towards the exit of the building that can minimize the travel time according the movement algorithm:

- FDS+Evac: the social force model and the fluid flow - large crowd movement analogy;
- Pathfinder – the steering behaviour and minimising the cost of an exit.

Both movement algorithms identify that the evacuation through the main staircase and the main exit can provide the minimum travel time.

Results of the numerical simulations are presented in Table 1: the time needed for the first occupant to leave the building (t_{1st}), the time needed for all occupants to leave the building (t_{trav}) and the simulation running time (t_{run}).

Results Table 1

Time	FDS+Evac	Pathfinder
t_{1st} [s]	24	22
t_{trav} [s]	178	159
t_{run} [s]	562	20

Figure 11 presents the number of occupants in the computational domain in both simulations.

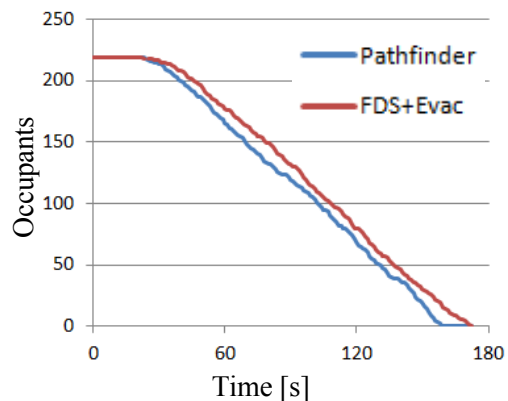


Fig. 9. Number of occupants in the computational domain

Figures 10 and 11 presents the human

evacuation process in both simulations.

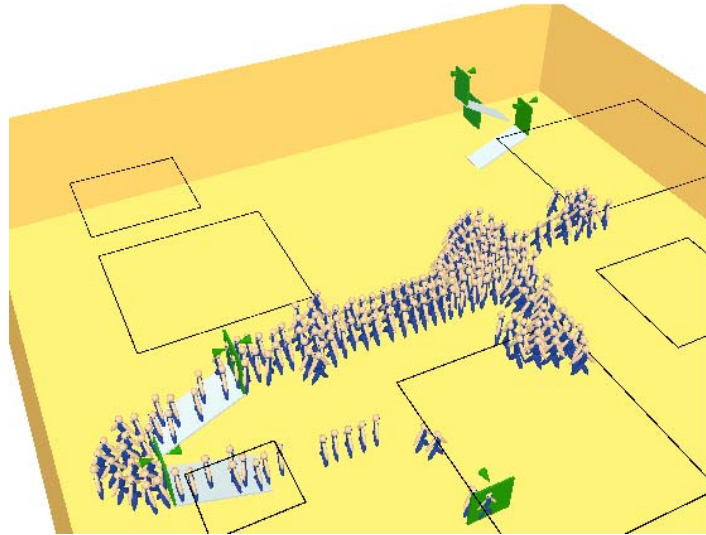


Fig. 10. *FDS+Evac evacuation*

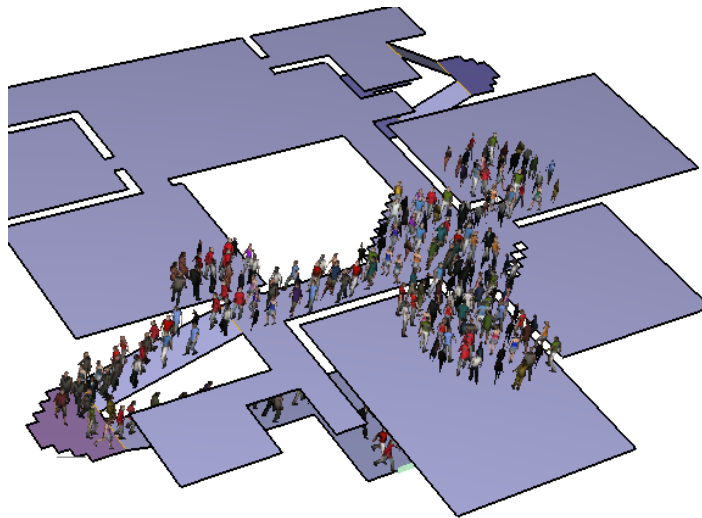


Fig. 11. *Pathfinder evacuation*

Following the performed numerical simulation it can be observed:

- all occupants are using the same evacuation route;
- the time for the first occupant to leave the building, t_{1st} , is approximately the same;
- the travel time, t_{trav} , is approximately the same;

- the different density of people on escape routes (Figure 10 and 11) can be explained due to the different approximations used for the human body shape;

- the simulation time for FDS+Evac is much higher than Pathfinder because a Computational Fluid Dynamics software will use more hardware resources.

5. Conclusions

The paper presented the numerical simulations of a fire drill on an educational building. The simulations were done using two software products that have different approaches on modeling the human evacuation: FDS+Evac use the social force model and the analogy fluid flow - large crowd movement compared to Pathfinder that use steering behavior and minimizing the cost of an exit.

The paper concludes that the travel times are comparable and the occupants are moving in similar ways in both of simulations.

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