The simulation of evacuation from multistorey building using NetLogo

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Abstract. The occupants of a multistorey building are very vulnerable when disaster happens (e.g. fire, earthquake, etc.). In the worst case, the only way to escape is through the emergency stairways, in which they scramble with the occupants coming from the higher floors. This situation often creates bottlenecks along the way, which in turn extends the evacuation time. In addition, the panic situation increases the risks of accidents, causing injuries or even death. In this research, we use NetLogo to simulate the evacuation process from a simplified multistorey building based on some parameters, which are the placement of the emergency stairways, the number of occupants in each floor, the number of stories, and the height of the floor. We set simulation scenarios to analyze the relation between the number of stories with evacuation time in each configuration. In our experiment context, we conclude that when the time-limit applies, the total evacuation through stairways is not effective for buildings having more than three storeys.

1. Introduction

The construction of high-rise buildings has increased exponentially in the cities due to scarcity of space for population growth [1]. Critical attention for high-rise buildings management and the government is to provide a safer building evacuation strategy and improve the safety aspects that affect the decision-making of people, staff and rescue operators [2]. In Jakarta for instance, there are about 160 buildings with height more than 100 meters. Several earthquakes there in recent years realize the importance of the very short-time total evacuation strategies and building designs.

In general, the occupants of high-rise buildings are always vulnerable to disasters. In case of fire or earthquake, they only have very limited time to escape in a very limited (and probably the only) way: the stairways. Several evacuation strategies were proposed, some are using mathematical analysis (for instance [3, 4]), and others using simulation (for instance [5, 6, 7]).

In this paper, we approach the problem from the building configurations. We run agent-based simulations to get initial insights about how the stairway placements affect the evacuation time, based on our pre-defined building configuration and initial conditions. We apply behaviors on the agents that cause three phenomenons: arching, clogging, and follow-the-crowd. Our scenarios are to make a total evacuation from the buildings and compare the results between those configurations. We choose NetLogo to simulate our scenarios, considering it is very adaptable to various configurations and more convenience in programming the agent behaviors.
2. The model
The parameters of our models are the number of storeys, the number of agents (occupants), and the floor height. We apply our model on two building classes, one is with a single stairway and the other with double stairways. Each of these classes consists of two different stairways placement: at the center of one side or at one corner of the building. We call these configurations after the building class followed by the placement of the stairway: single-center (S1), single-corner (S2), double-center (D1), and double-corner (D2).

Each floor consists of a single square room with no obstacles (no furniture, no partition, good visibility, etc). Each floor is divided into $(n + 1) \times (n + 1)$ grids, where $n$ is even so that the stairway position can align with the middle grids. Each grid on the floor represents an area of 0.5 × 0.5 square meters. Initially, all agents are distributed uniformly on all floors, and every grid can only contain at most one agent. See Figure 1 for an instance of the floor.

The wide of the stairways is enough for only one agent (we consider wider stairways give faster evacuation time). We assume that it needs six steps to go down 1 meter (each step is about 16.6667 cm of height). A 1-meter-tall stairway is represented by vertical 2 rows × 3 columns grids. If the agent moves to the next grid, it means he goes down one step. Descending 1 meter is simulated by an agent entering the first grid on the first row, then move horizontally to the two next grids, then go down perpendicularly to the grids on the second row and move in the opposite direction until the last grid. See Figure 2 for illustration.

For experiments purpose, we set all the storeys in the building to 4 meters in height. Figure 3 shows all configurations of 3-storeys building containing agents distributed uniformly on the floors, where each floor consists of 19 × 19 grids.
Figure 2. Descending 1 meter through the stairway steps (left) and its representation in the model (right).

Figure 3. The configurations of simplified 3-storeys building: (a) single-center (S1); (b) single-corner (S2); (c) double-center (D1); (d) double-corner (D2).

Every agent can move to one of eight adjacent grids, as long as it is empty. Once the emergency situation is declared, all agents move towards their pre-chosen exit door on their respective floors. To
reach the exit, they move to the adjacent grid that falls in their direction. However, if this grid is occupied, then they choose randomly an available grid in the range from 9 o’clock to 3 o’clock relative to their current direction (see Figure 4). In case there is no available grid to move to, the agent stays freeze. This behavior implies the arching phenomenon. To simulate a follow-the-crowd phenomenon, we set that if an agent is surrounded with 4 or more agents going to the other exit door, then this agent switches his direction.

Figure 4. The alternative grids to move to if the agent cannot move forward (shown by the dark grids).

The agent in front of the exit door, let say agent $a$, has to struggle against those in his left and right (if any) to pass the door. These two agents push agents away from the exit door. On the other hand, the agent behind (if any) pushes the agent towards the exit door. If the cumulating power of the left and right agents exceeds that of $a$ and of his behind, then $a$ cannot move. The struggle is simulated by increasing the power of $a$ randomly in the next timestamp until it can move forward. This behavior implies a clogging phenomenon in the simulation.

3. Implementation and analysis
We set the simulation interface as shown in Figure 5. There we can set the parameters of the model: the number of occupants, the number of storeys, the height of the floor, and the stairway placement (center or corner). If the “Setup” button is clicked, then the initial situation is set and displayed. The agents are distributed uniformly on all floors and their pre-chosen exit-door (uniform-randomly assigned by the program) is shown by the color of the agents (in this case, blue for agents preferring the left door and yellow for those preferring the right door). Clicking the “Go” button declares the emergency situation and all agents, controlled by their behavior, move towards their respective exit doors.

During the evacuation process, the simulation shows arching and clogging (Figure 6) and follow-the-crowd phenomenons (Figure 7). The clogging is indicated by the agent with black color. This agent cannot move forward since his forward power is not enough to overcome the pressure from his left and right.

An example of evacuation simulation is illustrated in Figure 8. The simulation is set for 3 storeys building holding 300 occupants with $42 \times 42$ grids floor of height 4 meters and double-corner building configuration. In the earlier ticks (the time stamp in NetLogo), chaotic moments happen when occupants block each other due to their movement to opposite directions. After 20 ticks the moment's end, the occupants begin to assemble in arch formation in front of exit doors. Agents in red indicate that they stay freeze. Finally, the building is clear after 293 ticks.
We apply some experiments on our model to get some insights about the relation between the parameters with the time required to clear the building. The experiment scenarios are to simulate
evacuation from 2, 3, 4, and 5 storeys building holding 200, 300, 400, and 500 occupants, respectively, which uniformly distributed over $36 \times 36$ grids in all floors. Intuitively, double stairways configuration always gives faster evacuation time than the single one (and our experiments show this tendency). Therefore, we compare the evacuation time (the number of ticks needed) between stairways placement in the same building class. The results show that the relation between the number of storeys and evacuation time tends to be linear in each configuration. The double configurations (D1 and D2) give about two times faster than the single one (S1 and S2). On average the evacuation time is not significantly different for the higher number of storeys ($\geq 3$ for single and $\geq 4$ for double stairways). See Table 1 and Figure 9 for the results obtained.

![Simulation of evacuation](image)

**Figure 8.** The simulation of evacuation from 3 storeys building containing 300 occupants: (a) initial; (b) after 20 ticks; (c) after 50 ticks; (d) after 100 ticks.

**Table 1.** The evacuation time (in ticks) according to the number of storeys in each configuration.

|       | Single-Center (S1) | Single-Corner (S2) | Double-Center (D1) | Double-Corner (D2) |
|-------|-------------------|--------------------|--------------------|--------------------|
| 2     | 493               | 393                | 252                | 204                |
| 3     | 622               | 586                | 328                | 302                |
| 4     | 823               | 788                | 408                | 403                |
| 5     | 1019              | 989                | 507                | 503                |

We observe as well that in the single-center and double-center experiments, the bottlenecks develop slowly on the stairway due to the flow resistance caused by the clogging phenomenon in each floor. However, the more the storeys, the more likely bottlenecks to happen. In the single-corner, the clogging
phenomenon is less frequent, since the pressure received by the agent in front of the exit comes only from one side. This less-restricted flow develops bottlenecks more often on the stairway.

Figure 9. The graph of evacuation time to the number of storeys for each model: (a) single stairway; (b) double stairways.

4. Conclusion and future works
Based on the experiment results, we conclude that our simulation scenarios give significant difference evacuation time for the building having maximum of three storeys. In addition, if the time limit is enabled, then potentially many occupants do not survive when the time is up. The evacuation from a high-rise building is only effective up to the third storey, even when there are no obstacles. We suggest doing the real-world experiments to validate the model. For further developments, we suggest adding more behavior and various configurations to the model.

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