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Simulating Panic Effect on Crowd Evacuation

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Summary

Panic is a condition in which an individual can arrive suddenly when in its environment different stimuli appear, meaning excitatory factors which may cause a reaction to the body, more or less controlled. This can be amplified by another person or by a group that is subject to the same stimuli, usually transforming it in a violent terror. In this case, the judgment of an individual comes to be dominated only by the primary instinct of survival forgetting about others.

In the category of stimuli that can cause panic are: fires, earthquakes, impossibility to leave a space, various transportation accidents, an outbreak infection etc.

That means that the spaces in which crowded situations appear must be designed so that emergency evacuation, when panic stimuli arise, to occur normally with no injuries or casualties. Such situations can be prevented by sufficient exits properly signposted and calibrated with respect to their maximum capacity and through education. Education is extremely important and must be repeated regularly in order to replace fear with individual judgment. Unfortunately, this is superficially considered by the authorities leaving everything to those who conceive the buildings. Moreover, there are some special buildings that are not taken into account, such as churches, which have only one exit.

Evacuation scenarios can be simulated only by specialised software in which certain parameters, such as stampede, the appearance of human or material obstacles, etc., are difficult to enter.

This paper proposes some ways of adapting the existing software sin order to meet specific requirements, leading to delays in people evacuation in case of panic stimuli.

KEYWORDS: evacuation, panic, software, stampede

1. INTRODUCTION

Mass evacuation has several definitions in the literature. All of them have some common factors like a mass of people is involved, a threat to life is perceived and there must be a reasonable chance that within a limited time to be able to escape from danger (Drury & Cocking, 2007). When analysing mass evacuation it is important to consider people psychology and how their behaviour depends on several factors, as personal matters and if the person is alone or in a group when the danger occurs. At the same time, different individual factors can certainly be expected to vary with gender and the cultural, social and geographical environment.

Gender differences are found from the earliest stages. When a person first notice that there is a possible emergency going on, men usually search for more information than women do. Later women tend to warn others then leave the building. Women use to seek for help, in contrast to men, who more often try to search for people who are trapped (Canter, et al., 1980).

How a person handles a certain situation depends on a lot on the environment as well as the surrounding individuals. The social influence refers to the effect of surrounding people and their behaviour in the evacuation process. The fear of making a fool of themselves often leads to delayed decision times. Nevertheless as someone in the group takes the first step, and for example, begins to walk to an exit door or just stands up, others are likely to follow (Nilsson & Johansson, 2009).

When a person joins a high-density group of people, e.g. religious ceremonial, the individuals will most likely change their usual attitude and mentality. The article considers psychological crowd (people attending a religious ceremonial), without analysing the behaviour of an aggregate crowd (the occupants of a supermarket) (Friberg and Hjelm, 2014).

The panic effect will be considered in the analysis and several cases will be reviewed. Keating defined panic as a concept of four elements (Fahy, et al., 2009): hope to escape through dwindling resources, contagious behaviour, aggressive concern about one's own safety and irrational, illogical responses. Meanwhile, the Oxford English Dictionary considers panic: “a sudden feeling of alarm or fear of sufficient intensity or uncontrollableness as to lead to extravagant or wildly unthinking behaviour, such as that which may spread through a crowd of people; the state of experiencing such a feeling. Also: an instance or an episode of such feeling; a scare” (Panic, 2014).

2. CROWD MODELING

A crowd is not simply a collection of individuals. The behaviour of an individual may be affected by others in the crowd, which may depend on various physiological, psychological and social factors. In order to reduce casualties in case of mass gatherings research is being conducted all around the world. There have been implemented three modelling approaches: flow-based, particle/entity-based and agent-based (Zhou, S. et. al. 2010):

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- *flow-based approach*: models a crowd as a continuous flow of fluid, neglects the features of individuals;
- *entity-based approach*: individuals are modelled as a set of homogeneous entities, some global emerging phenomena such as jamming and flocking can be generated by these models;
- *agent-based approach*: models each individual in a crowd as an intelligent and autonomous agent, which may have capabilities to behave in the simulated world ranging from reacting to certain events to adapting to the complex dynamic environment. This approach also allows for more behavioural factors to be considered.

Another important aspect is the behavioural factors which were divided into three categories. The *physical factors* refer to those external tangible characteristics of an individual such as position, moving speed, appearance and gesture, etc. The *social factors* are also tangible factors, which considers that human behaviour is also influenced by a wide variety of social factors, such as culture, social norms, family ties and leadership etc. The computational models that incorporate these factors are usually based on social theories and observations from social studies. The *psychological factors* such as emotion play an important role in human decision making.

Several phenomena can be identified when evacuating a crowd. Some of the most common ones is reviewed below.

Counterflows is arisen when different flows meet each other. Lanes are often formed when humans are walking in the same direction (Helbing, et al., 2002).

When the natural flow of pedestrians cannot continue due to an obstacle (door, corridor) that does not allow the entire flow to get through at once, a *bottleneck* situation occurs (Drury & Cocking, 2007). If the pressure over a bottleneck gets too high, the opportunities to evacuate can be paralysed. When this actually happens, it can also be very difficult to reduce the already built up pressure, as well as to release the people who have been trapped. The people in the back do not know how the situation actually looks, the pressure often continues. This was the cause of the very tragic disaster, which occurred during the discotheque fire in Colectiv, Bucharest, 2015.

When density variation occurs, *stop and go waves* are formed. In the areas where the density in lower, the speed is higher, meanwhile, where the density increases the flow speed decreases significantly.

When the density of a crowd becomes even larger than what has been presented under stop and go waves, *turbulence* sometimes occurs. This can be compared with the aftermath of an earthquake, where various forces randomly are distributed in all the different directions (Ma, et al., 2013). With a density of about 8 persons per square meter, there is no longer any space between the persons, at this stage waves can move the individuals up to 3 meters in lateral directions. Crowd turbulence has for example been proven to be the cause of the Love Parade disaster (Helbing & Mukerji, 2012).

Stampede is another main cause of crowd disasters. It represents a collective rush of people towards either united direction or destination or in a random manner (Still, 2014).

3. CASE STUDY

3.1. General information about structures

A general classification of the structural typology of Romanian Orthodox churches based on the plan view shows three major types: rectangular, trefoil and Greek cross, Figure 1. According to the specific architectural conception, the typical spatial structure of an Orthodox church consists of a well-established sequence: narthex, nave and altar.

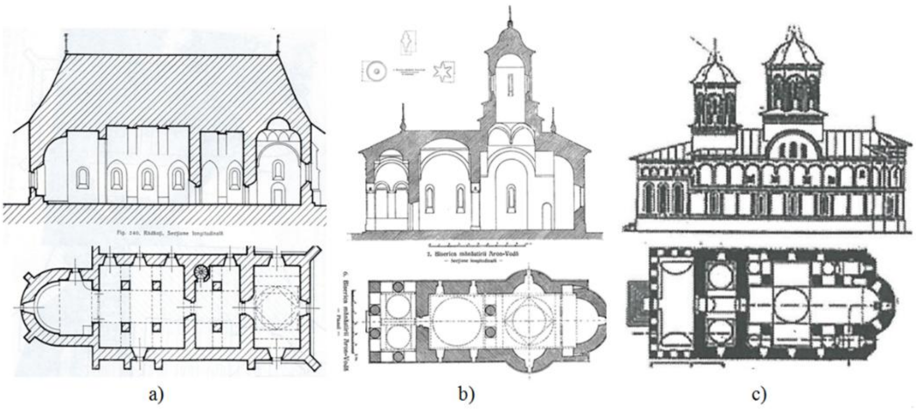

Figure 1. Structural typology of orthodox churches

The orientation of the church is symbolical, with the altar to the east. After the nave, the altar apse follows delimiting the church to the east. The altar is slightly elevated compared to the nave being separated from the latter by the iconostasis. Compared with the initial/classic orthodox structure, architectural innovations have resulted in slightly alteration of spatial configuration of the nave, in adding spaces with specific functions (crypt, exonarthex) or by the presence of a symbolic number of domes or towers.

On average, the areas for visitors in Romanian Orthodox churches varies from 85 m^2 to 160 m^2 depending on their size and the presence of the closed porch.

The case study was performed on Aroneanu church which was previously analysed by the authors (Budescu et al., 2016). The structure of the church, Figure 2 respects the classic plan of churches from that era. To the west, the nave is extended by a porch. The church tower rises above the nave, resting on a star which is supported by a square base. The church has an area of 110 m^2, from which the only 93m^2 is for the visitors.

It is considered that during the main religious ceremonies like Easter, Christmas and other important celebrations, the number of Christians attending the mass increases significantly. Among these elders or people with disabilities may be present. In the case of an imminent need for evacuation this category may represent real obstacles or may only slow down the process. Another specific category is represented by the participants which are very focused on the ceremony and do not get the dangerous event happening next to them. The case studies focus on different restrains in the evacuation process. These were introduced in order to simulate to bottleneck effect, the pre-movement stage in which the announcement about the stringent evacuation due to a natural disaster (earthquake), the different behaviour of the crowd and so on.

Figure 2. Aroneanu Church – exterior view

3.2. Software characteristics and input data

Pathfinder, which is an evacuation simulating computer program, is one of the latest tools that have been developed and are used by today's engineers. Pathfinder uses Agent-Based Modelling. The purpose of the program is to facilitate the work, but also to improve the results and the validity of simulations that regards mass evacuation. The program can treat tens of thousands of spectators. It is based on

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simulations with a large number of spectators, all with their own individual characteristics. The subjects are assigned goals, characteristics and perceptions. This can be applied to larger groups as well as to each individual. The program is based on artificial intelligence, which means that the individuals also are able to adjust, based on other peoples' movement. This allows people to avoid colliding with each others. It also means that the subjects do not strictly need to follow the shortest path principles. Something that naturally gives a better flow of the pedestrians compared to other models, which are based on different calculations. Pathfinder is built from a coordinate system in 3D, the structure of the system can be created directly from the program, but can also be imported from other applications, such as CAD software. During a simulation, the user can follow the progress, pause or rewind, just like in a regular movie (Thornton, et al., 2010).

The total number of an occupant, 85, was divided unequally into three groups, justified mainly by the fact that people tend to clutter as close as possible to the altar where the religious ritual takes place. Group 1, G1, contains 10 persons with a density of 1.3pers/m^2 and it was the closest to the door. The second group, G2, has a density of 1.5pers/m^2 with a total of 25 people and is located in the middle. Group 3, G3, is located in front, in front of the altar and contains 50 people with a density of 1.8pers/m^2, Figure 3. The density represents the number of occupant per area and can be controlled by the user.

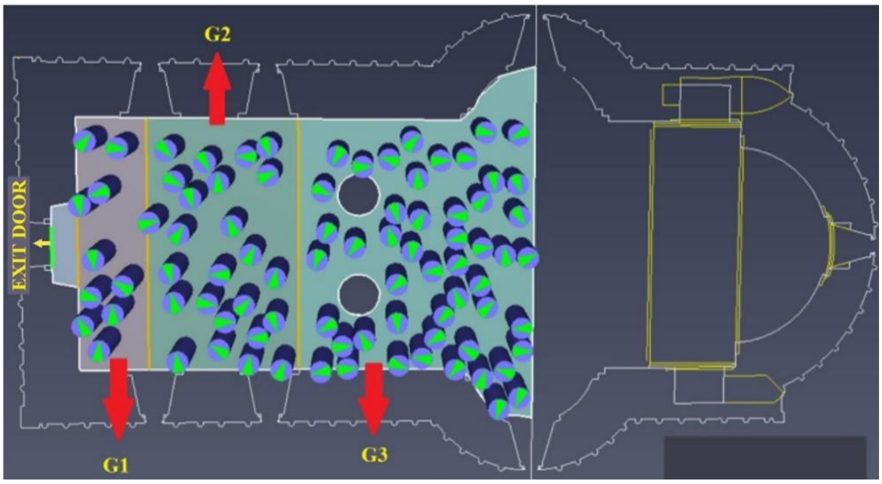

Figure 3. Crowd distribution

The following input data were considered: average walking speed - 1.19m/s, one narrow exit (0.88m) and a person shoulder width of 45.58cm. Among the considered parameters are the ones specific to the steering mode: acceleration time of 1.1s, persist time of 1s, collision response time 1.5s and comfort distance of 0.08m.

The acceleration time specifies the amount of time it takes for the occupant to reach maximum speed from rest or to reach rest from maximum speed. The resulting forward acceleration of each occupant is max_speed/accel_time. The occupant uses a separate reverse acceleration of 2*forward_acceleration and a separate lateral acceleration of 1.5*forward_acceleration (Pathfinder, user manual)). The persist time refers to the amount of time an occupant will maintain an elevated priority when trying to resolve movement conflicts. The collision response time controls the distance at which an occupant will start recording a cost for colliding with other occupants when steering. The comfort distance specifies the desired distance one occupant will try to maintain with others in a queue. This may be entered explicitly as a distance, an occupant area, or an occupant density.

Seven cases were analysed. The first one, C1, represents also the initial condition, performs the analysis without any supplementary adjustment.

In case 2, C2, the authors considered a delay of the 30s for G2 in order to simulate the specific pre-movement actions of the people in the considered group (supplementary questions, the search of relatives or close friends, waiting for others to start moving and so on). It was considered that in the case of a dangerous event, for example, earthquake, the first to evacuate will be G1 and G3, which being close to the altar will hear and react faster to the priest directions.

In C3 two obstacles with the dimension of 0.88m were introduced as doors between G1 and G2, G2 and G3 respectively, Figure 4. The same delay was considered for G2.

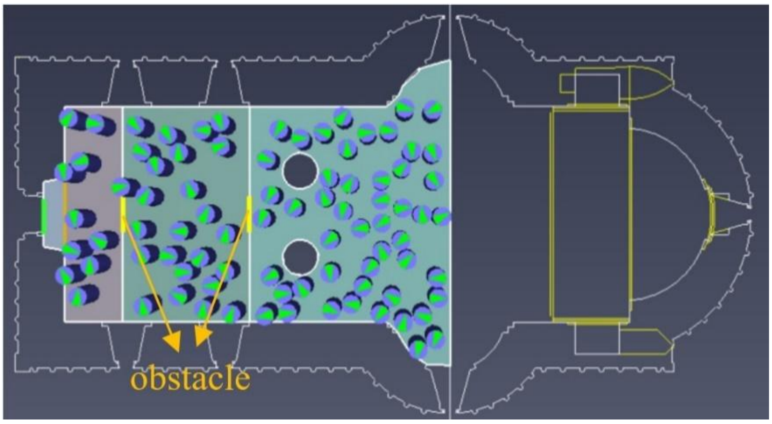

Figure 4. Obstacle distribution

For cases 4, 5, 6 and 7 a smaller speed was considered for G2, 0.5m/s^2. C4 does not use obstacle nor delay, meanwhile, C5 considers also the delay, but it ignores the obstacles. C6 and C7 focus on the effect of the obstacles, C6 ignoring the delay and C7 considering it.

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3.3. Results and discussions

A synthesis of the total required time to evacuate the entire crowd for each case is presented in Figure 5. It can be noticed, that C1, when no restrictions were applied leads to the minimum necessary time. Even though this maximum evacuation time is not realistic. It can be concluded that in order to fully evacuate the church in case of a disaster more than two minutes would be necessary for the most unfavorable case, C7. If we consider this information it can be stated that is possible that some of the Christians attending the ceremony might not be able to evacuate safely.

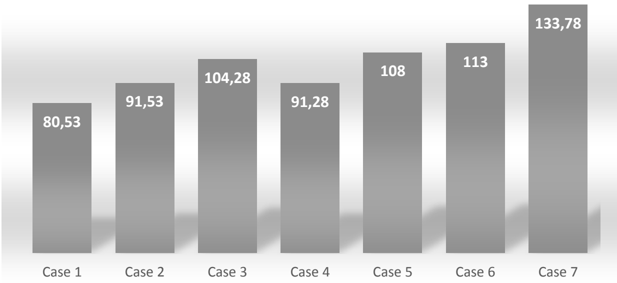

Figure 5. Total evacuation time synthesis in seconds

From Figure 6 in can be concluded that the most dangerous situation would be for C7, where only 21 people will be evacuated in the 30s and 33people will be evacuated in 60s. It is also noticed, that if the number of exited persons would be considered, for the 30s, C5 gets closer to C1. This is because G1 evacuates first (10 people) and in this time people from the G3 approach the door and the flow evacuation is constant until a bottleneck effect is produced.

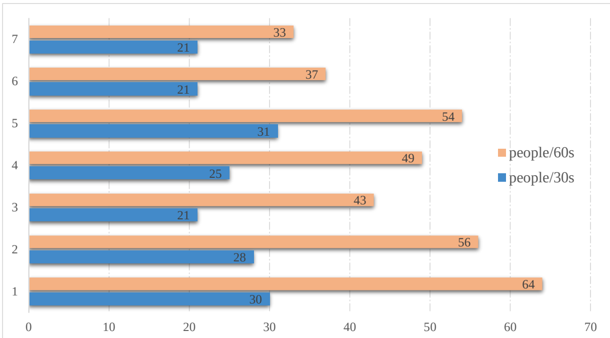

Figure 6. Number of people evacuated in the 30s and 60s

Other important comparisons which can give relevant information regarding the evacuation process refer to the flow rate through the main exit door and the

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intermediate doors/obstacles placed between the considered groups. Figure 6 presents the flow rates for the analysed cases.

Figure 7. Flow rate for: (a) C1; (b) C2; (c) C3; (d) C4; (e) C5; (f) C6; (g) C7

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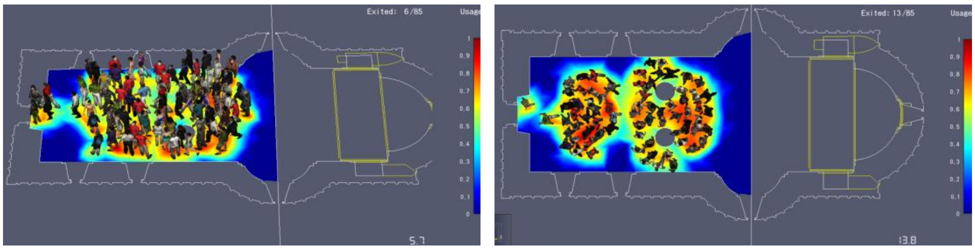

(a) (b)

Figure 8. Instantaneous usage for: (a) C3 and (b) C6

Figure 7 presents some print screens taken from the evacuation process with the instantaneous usage of the surface. Only two cases are presented due to lack of space. These photos show how the crowd is going to the exit and how they are distributed in the considered area. The effect of the bottleneck caused by the introduced obstacles is obvious in Figure 7(b).

4. CONCLUSIONS

Pathfinder software is among the most used software for simulating evacuation situations. The software allows the introduction of several parameters: number of people, speed, direction, delays and so on. With all this, there are some particularities that are not yet implemented in the software - stampede or bottleneck effect, or panic.

Based on the heterogeneity of people attending the mass gathering in general, religious ceremonial in particular several situations may occur that might slow the evacuation process. In order to simulate these obstacles were introduced. More detailed analysis is taken into consideration in order to modify parameters of each person, and not for an entire group.

Also, the human behaviour in cases of panic or disaster can lead to jams in the evacuation process. The changes in the human behaviour in case of a limit situation - the desire to survive, the fear for own life, should be also considered in further studies.

The current study shows that the characteristics of this type of structure – one narrow exit, might lead to severe human losses in case of a disaster due to difficulties to evacuate.

More complex studies should be done on structures with the same functionality in order to obtain some common lines. Based on the building vulnerability, estimates on the evacuation time required are targeted by the authors. Justified limitations should be imposed regarding the number of people who can enter a building at once in order to allow a constant evacuation flow with reducing to a minimum the number of causalities.

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