IZVORNI ZNANSTVENI RAD - Original scientific paper

Simulation of a school facility evacuation-The case of the Secondary school "Svetozar Marković" in Niš

Simulacija evakuacije školskih objekata – Slučaj gimnazije „Svetozar Marković" iz Niša

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ABSTRACT

Evacuation of any kind of facility presents a very complex and serious task which can very easily go wrong and have serious, even tragic consequences. The fact that there are a lot of people in a facility makes this task even more complicated and more difficult. Reasons for the evacuation of a facility can be varied, such as fire, overflow, earthquake, terrorism, etc. No matter what the reason for evacuation is, the most important thing is to evacuate occupants to a safe place or safe location as quickly and safely as possible. Schools present a particularly complex facility for evacuation because there are a lot of pupils-children who are difficult to organize even in normal conditions. So, in the presence of fear, stress, and evacuation reason consequences, such as, for example, flame or smoke, complete chaotic behaviour is the only expected epilogue. Furthermore, this task can be even more complicated in the case when the architectural properties of a school don't provide safe, fast, and easy evacuation. This paper was written to show potential evacuation scenarios and evacuation times in the case of the secondary school "Svetozar Marković" in Niš.

Keywords: evacuation, school, simulation, pupils

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Sažetak

Evakuacija bilo kojeg objekta predstavlja veoma kompleksan i ozbiljan zadatak koji može vrlo lako poći po zlu i imati ozbiljne, čak i tragične posljedice. Činjenica da u objektu postoji mnogo ljudi čini taj zadatak još kompleksnijim i težim. Razlozi za evakuaciju objekta mogu biti različiti, kao što su požar, poplava, zemljotres, terorizam itd. Bez obzira na to što su bili razlozi za evakuaciju, najvažnija stvar je evakuirati ugrožene osobe na sigurno mjesto ili lokaciju uz maksimalnu brzinu i sigurnost. Škole predstavljaju posebno kompleksne objekte za evakuaciju zato što imaju dosta učenika koje je veoma teško organizirati čak i u normalnom stanju i okolnostima. Tako da, u prisustvu staha, stresa i posljedica razloga za evakuaciju, kao što su, na primjer, plamen i dim, totalno kaotično ponašanje jedini je očekivani epilog. Uz takvo ponašanje, posljedice mogu biti veoma teške, čak i smrtonosne. Bez obzira na to što su evakuacijski putevi jasno označeni na svakom katu i u svakom dijelu objekta, uz prisustvo panike, straha i kaosa, to je potpuno irelevanno. To generalno važi za sve objekte u kojima se nalaze djeca, odnosno đaci. Također, ovaj zadatak može biti još kompleksniji u slučaju kada građevinske karakteristike objekta-škole ne osiguravaju sigurnu, brzu i laku evakuaciju. Građevinske karakteristike ove škole su takve da veoma lako može doći do povećanja vremena za evakuaciju jer škola posjeduje samo dva potencijalna izlaza, jedan širine od oko 200 cm (u odnosu na položaja vrata), a drugi od 90 cm, bez požarnih stepenica. Širina stepenica je također oko 250 cm, a i širina hodnika koji vode do učionica, zbornice, knjižnice i drugih ureda je oko 225 cm. Upitna je i širina vrata učionica i drugih prostorija koja je različita (uglavnom za većinu učionica iznosti 85 cm, ali postoje i prostorije gde je širina vrata manja od 85 cm, ali i veća). Ovaj rad je napisan s ciljem da prikaže potencijalne evakuacijske scenarije i evakaucijska vremena u slučaju gimnazije Svetozar Marković u Nišu koja su dobijena simulacijom u poznatom simulacionom softveru Pathfinder i na taj način potvrdi i prikaže ogromne prednosti upotrebe simulacijskog softvera.

Ključne riječi: *evakuacija, škola, simulacija, đaci*

INTRODUCTION

Uvod

Evacuation of a facility for a reason presents a very complex and serious task that demands knowledge and experience in different technical spheres. A well-known definition of evacuation is that evacuation presents the fast, safe, and secure moving of people, animals, and material properties from the dangerous location or facility to a safe location or area. The reasons for evacuation are also well known, and in most cases they can be fire, earthquake,

flood, tsunami, hurricane, terrorism threat or attack, etc. Regardless of type of facility, there are many different factors that can make evacuation very difficult, complex, and even tragic. With the presence of other difficulties, such as architectural properties of the facility, presence or absence of a determined number of exits, presence of different obstacles, presence of persons with mobility difficulties or immobile persons, presence of children and numerous other factors. A particularly difficult problem in evacuation situations is people`s behaviour in the presence of panic, stress, and fear. The main reason for that is the fact that this is something that is almost impossible to predict and that can cause unfathomable and tragic consequences. Fear, stress, and panic cause people not to be able to help themselves or others. In the presence of fear, stress, related to experience, people only take care of themselves and their human potential and emotions are significantly reduced in such situations. It is specially expressed in a situation with persons with mobility difficulties, immobile persons, or persons that need physical assistance. A very obvious example for the above-noted facts are high residential buildings with lot of people (Jevtić, 2020; 2021).

Schools present facilities with the presence of a lot of pupils-children inside. The number of pupils-children can be very high, depending on the school. This facility can also consist of other rooms, such as a physical education hall, dining room, kitchen, rooms for extended stay, etc. In most cases, these objects have several entrances/exits and evacuation from them should not be a problem even in the presence of noted disturbing factors. But a school can be built as a high-rise with only a few entrance/exits, which could be a problem for evacuation. Experience showed that schools can be a very complex facility for evacuation, because of many reasons, and that evacuation can, unfortunately, be late (Glas Amerike, 2017, Beta, 2021, Republika, 2023). A particularly tragic event in schools occurred in the school "Vladislav Ribnikar" in Belgrade, Serbia, when a fourteen-year-old pupil killed nine persons (eight pupils and one adult) with a firearm (Marković, 2023).

Because of all the noted tasks, schools can be very difficult facilities for evacuation, especially with a lack of exits and other architectural solutions. The secondary school "Svetozar Marković" in Niš was founded in 1954. Initially, it was a mixed-programme secondary school, but later, it was switched to a natural science and mathematics programme secondary school. A very bright moment in its history was in 1983, when a delegation from Japan visited the school because they were preparing a national reform

of education in Japan. Also, in 2020, this school was entered in the world register of international schools that enable attending the IB Diploma Programme course, known as one of the most demanding and most qualitative courses in the world. The school is located in "Branka Radičevića" street in Niš. The building had a ground-level floorand three floors above in the past, but in the last years, another floor was built. The front and back side of the school are presented in figure 1 (a, b), while the interior of the school is presented in figure 2 (a, b). Figure 2.b shows one of several corridors. The average width of the corridors was about 225 cm.

The school has two possible exits. The first one is the main

a) *b)*

Figure 1. The exterior of the school- front view (a) and back view (b)

Slika 1. Vanjski prikaz škole-prednji izgled (a) i izgled sa zadnje strane (b)

a) *b)*

Figure 2. The interior of the school- the stairs between second and third floor (a) and hall with classrooms, assembly hall and offices at the first floor

Slika 2. Unutrašnjost škole-stepenice između drugog i trećeg kata (a) i hodnik s učionicama, zbornicom i uredima na prvom katu

exit and generally this is the only exit, while the potential second exit is located at the ground floor and it is closed most of the time. The width of the first exit (door) was about 200 cm, while the width of the second exit (door) was about 90 cm. The dimensions of the rest of the doors were different; in most cases, the width of the doors was 85 cm and the height of the doors was about 200 cm, and they were mostly the doors to classrooms. For some other rooms, such as the principal`s office, or the pedagogue and psychologist's office, or library, these dimensions were smaller – the width of these doors were about 60 cm, while the height of the doors was the same. Also, the only connection between the ground floor and other floors are stairs. These stairs, presented in figure 2.a, are of limited dimensions (about 250 cm) and flow rate, and they present the most likely location where collisions, jams, and other evacuation problems can occur, along with exit doors, of course. Evacuation must be conducted according to the pre-prepared evacuation plan that must be visibly displayed in the facility. The evacuation plans for the basement and fourth floor are presented in Figures 3 and 4. Beside the evacuation route, these plans consist other important information, such as the location of fire extinguishers, distribution cabinets, hydrants, location of meeting places etc. It is important to note that evacuation plans for the first, the second, the third, and the fourth floor are almost identical (except the hall on the fourth floor). The hall on the fourth floor presents the farthest location for evacuation.

Therefore, in some specific and demanded situations,

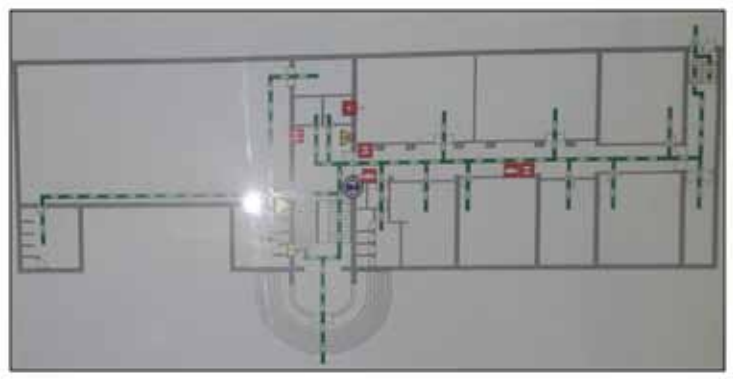


Figure 3. Evacuation plan for the basement

Slika 3. Evakuacijski plan za prizemlje

Figure 4. Evacuation plan for the fourth floor

Slika 4. Evakuacijski plan za IV. kat

the evacuation of such a facility could be problematic. The presence of fear, stress, and panic is almost a inescapable consequence of any crisis situation, especially in the case when the occupants are older or younger children. Children's behaviour in stressful or panic-filled situations is impossible to predict – they are hard to organise even in the normal conditions, which makes evacuation extremely difficult and complex, with a significant extension of time needed to leave the facility and significant increased possibilities for tragic epilogue.

This paper was written to show all the potential evacuation scenarios and to calculate evacuation times for determined speeds of occupants-pupils, professors, and school staff with the use of simulation software Pathfinder in the case of the secondary school "Svetozar Marković" in Niš.

SIMULATION SOFTWARE PATHFINDER-
Simulacijski softver pathfinder

Simulation software presents an unchangeable resource in the area of prediction, safety, and costs. One of the most famous and used pieces of software for simulation of evacuation scenarios and calculation of evacuation times is Pathfinder. This software has presented a great scientific advantage from the moment of its appearance. This software has a unified calculation and visualisation part of the simulation. Results can be presented as graphics, numbers, and film-like simulations. The software has a special graphic interface for design simulation models and simulation scenarios. An example of the graphic interface is presented in figure 5.

The software uses two different work modes, Steering

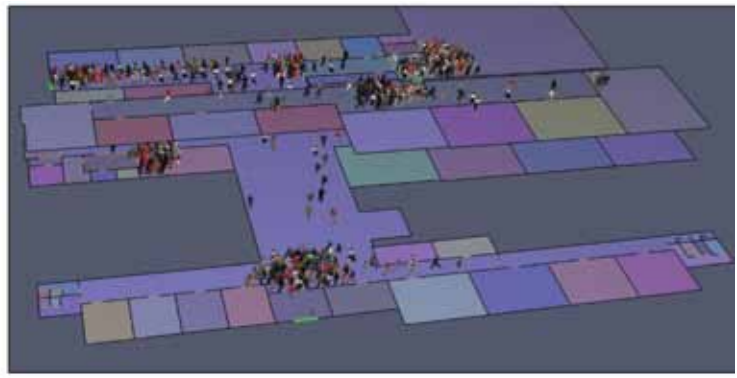


Figure 5. An example of Pathfinder graphic interface- the simulation model in Pathfinder of the elementary school "Car Konstantin" in Niš

Slika 5. Primjer grafičkog sučelja Pathfindera-simulacijski model osnovne škole Car Konstantin u Nišu u Pathfinderu

mode and SFPE mode. A simulation can be realised in both modes. The behaviour of occupants can be defined in the sense of waiting, finding the closest exit, moving with determined speed, use of the elevator, waiting at determined points and similar. A very important characteristic of the software is the potential of importing of the simulation of the facility from some other graphic software, such as for example AutoCAD. This can significantly reduce the time needed for drawing and designing the facility and easily add other objects such as of doors, exits, obstacles etc.

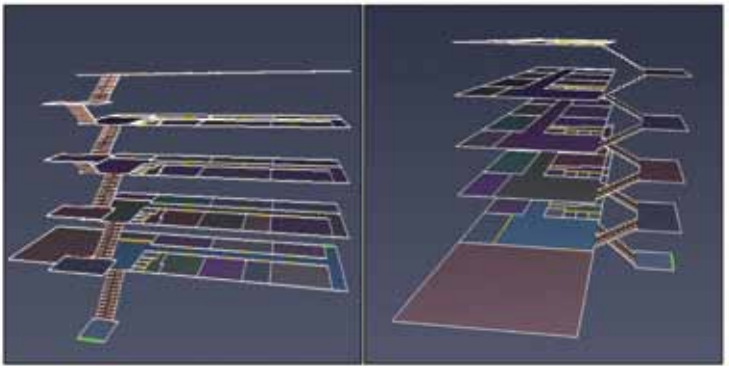
Also, this type of software demands a strong hardware configuration for comfortable work. According to the manual, the minimum software requirements are a 64-bit Windows 8 Pro with an Intel Core i7 2.60 GHz processor, 8 GB of RAM, and an NVIDIA NVS 5200M graphics card, but real use with complex models showed that a much stronger configuration was needed. The version of software used for this paper was Pathfinder 2023.2 (Thunderhead, 2020).

SIMULATION MODEL OF THE SCHOOL SVETOZAR MARKOVIĆ-
Simulacijski model škole Svetozar Marković

The simulation model of the secondary school "Svetozar Marković" in Niš, with complete real dimensions, is presented in figure 6, front view (a) and side view (b). In the front view, the two possible exits can be seen. Because of better visibility and perspicuity, the function HIDE was

used to hide some elements – desks, wardrobes, chairs and similar obstacles, even some smaller rooms (dressing rooms in the sports hall).

The evacuation of secondary school "Svetozar Marko-



a) *b)*

Figure 6. Simulation model of secondary school "Svetozar Marković" in Niš, front view (a) and side view (b)

Slika 6. Simulacijski model gimnazije Svetozar Marković u Nišu, prednji pogled (a) i pogled sa strane (b)

vić" in Niš was realized in two different scenarios. In the first scenario, occupants (pupils, professors, and school staff) were randomly arranged in the building, while in the second scenario occupants (pupils, professors, and school staff) were precisely arranged; pupils were in classrooms or the physical education hall, professors were in cabinets or in the assembly hall and the school staff were in their offices or in the hall. The first scenario presented a situation that would be akin to paused time, while the second scenario presented a situation that would be akin to a classroom in progress.

The capacities of classrooms were 25 and 20 pupils in the classroom, the maximum capacity of the assembly hall was 115 professors, the maximum capacity of the physical education hall was 52 occupants (two professors and 50 pupils). According to the latest information, the school has 910 pupils in two shifts; 95 full-time professors and 35 part-time professors. With regards to the other school staff, there were 25 of them. So, both scenarios have 610 occupants (455 pupils, 130 professors and 25 school staff).

For every scenario, there were three different cases. The first case had only the first exit open, the second case had only the second exit open, while the third case had both exits open. The speeds of occupants in simulations were

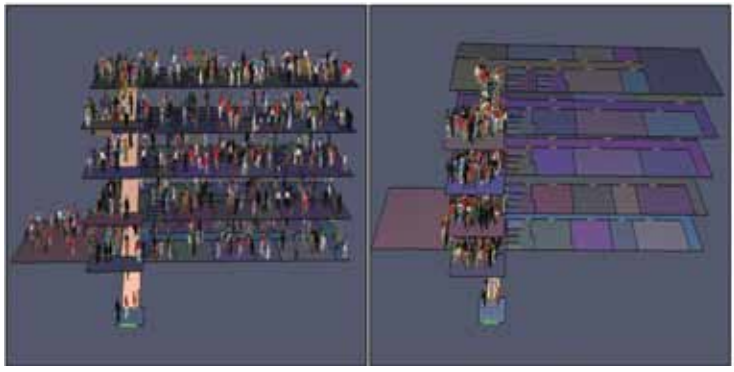
1.2 m/s, 1.6 m/s, 2.2 m/s, 2.8 m/s, 3.4 m/s and 4.0 m/s. It means that the complete number of realized simulations included in both scenarios was 36.

SIMULATION RESULTS

Rezultati simulacija

Some simulation moments are presented in Figure 7 to Figure 9 (a and b), while the complete simulation results for the fastest and for the slowest case are presented in Figures 8 and 9.

It is also important to note that all simulations in this



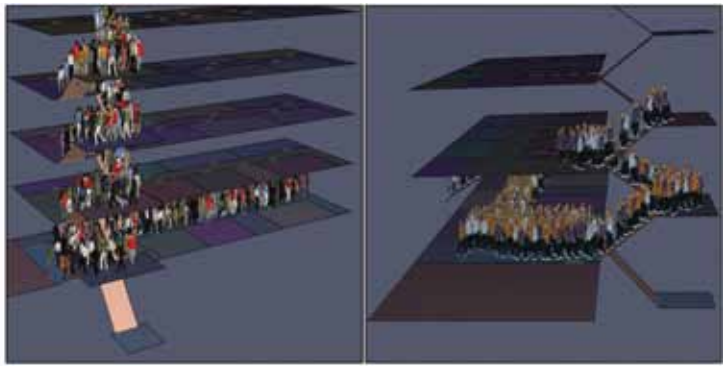
a) *b)*

Figure 7. Simulation moment of the first scenario, third case for speed of occupant of 1.2 m/s (a) and simulation moment of the second scenario, the first case for speed of occupant of 1.6 m/s (b)

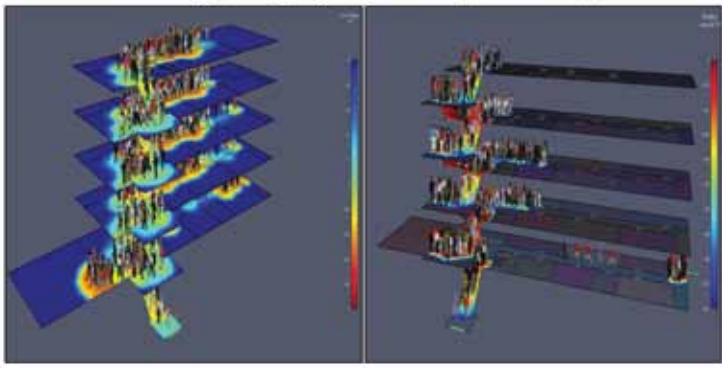
Slika 7. Simulacijski trenutak prvog scenarija, trećeg slučaja za brzinu okupanata od 1.2 m/s (a) i simulacijski trenutak drugog scenarija, prvog slučaja za brzinu okupanata od 1.6 m/s (b).

Figure 8. Simulation moment of the first scenario, second case for speed of occupant of 2.2 m/s (a) and simulation moment of the second scenario, the second case for speed of occupant of 4.0 m/s (b)

Slika 8. Simulacijski trenutak prvog scenarija, trećeg slučaja za brzinu okupanata od 1.2 m/s (a) i simulacijski trenutak drugog scenarija, prvog slučaja za brzinu okupanata od 1.6 m/s (b)



a) *b)*



a) *b)*

Figure 9. Simulation moment of the first scenario, the first case with presentation of social distance (a) and simulation moment of the second scenario, the firtt case with presentation of density of occupants per m^2 (b)

Slika 9. Simulacijski trenutak prvog scenarija, prvog slučaja s prezentacijom socijalne distance (a) i simulacijski trenutak drugog scenarija, prvog slučaja s prezentacijom gustine okupanata po m^2 (b)

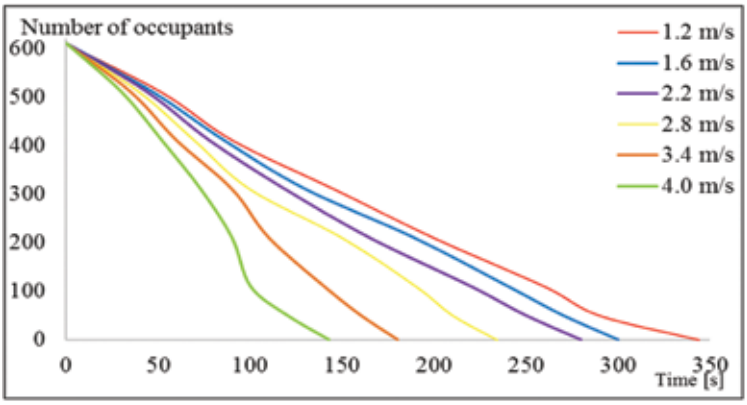


Figure 10. Complete simulation results for the fastest case (the second scenario, first case)

Slika 10. Kompletni simulacijski rezultati za najbrži slučaj (drugi scenarij, prvi slučaj)

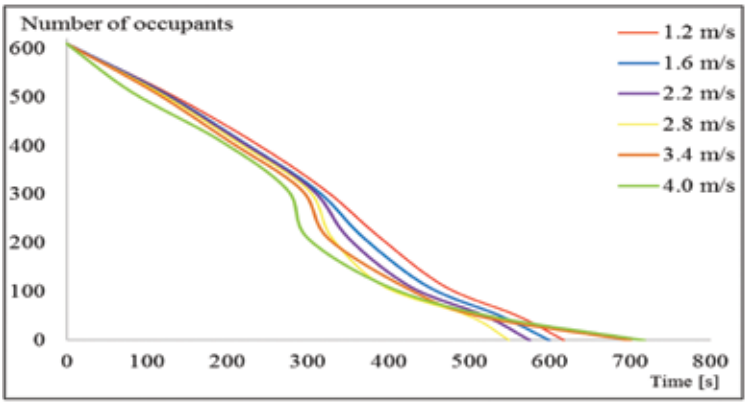


Figure 11. Complete simulation results for the slowest case (the first scenario, third case)

Slika 11. Kompletni simulacijski rezultati za najsporiji slučaj (prvi scenarij, treći slučaj)

paper were conducted with a laptop Dell Latitude, with Intel® Core™ i7-1185G7 (4 Core, 12M cache, base 3.0GHz, up to 4.8GHz, vPro) processor and 16 GB of RAM memory.

ANALYSIS OF RESULTS

Analiza rezultata

The simulation results for the first scenario showed that the time needed for school evacuation for the first case, when both of exits were open, was 348.8 seconds; for the second case, when only the first exit was open 388.78 seconds and for the third case, when only the second exit was open 718.5 seconds (Figure 10).

The simulation results for the second scenario showed that the time needed for school evacuation for the first case, when both of exits were open, was 344.21 seconds (figure 11); for the second case, when only the first exit was open, was 368.34 seconds and for the third case, when only the second exit was open, was 687 seconds.

The conducted simulations showed slightly better results in the sense of evacuation times in the case that occupants (pupils, professors and school staff) were exactly arranged, which is appropriate to the second scenario. Generally, in the facility with lot of people, better evacuation times can be achieved in the cases with better order and arrangement. Fewer persons inside the facility in most cases do not require strict order and arrangement.

Simulations showed that in cases of higher occupant's speeds, there were occurrences of getting stuck. That is es-

pecially expressed in the third case of the first scenario (figure 11) and for the third case of the second scenario, for occupants' speeds of 3.4 m/s and 4 m/s. Higher speeds, although they could be achieved, would certainly lead to problems at the stairs in the sense of falls, jams, and getting stuck. This assertion can be confirmed in the comparison with some other examples of facilities, such as residential buildings or medical facilities (Jevtić, 2021), (Jevtić, 2021).

However, facilities with the architectural form of the simulated school indicate a need for another exit or even stairs in the form of emergency stairs. Although simulations results showed some shorter times in the cases when occupants were exactly arranged than in the cases when occupants were randomly arranged, organisation and calming of panic and stress with children present a very difficult task, especially with short times and in situations of crisis.

CONCLUSION

Zaključak

School as facilities with many younger and older children inside present very a demanding and complex facilities for evacuation. Firstly, there is the presence of fear, stress, and panic on children which creates a very complex and chaotic situation. Obviously, it is almost impossible to achieve some level of organisation in those situations needed for a calm and safe exit from the facility. Secondly, there are architectural characteristics and potentials of the facilities - schools. The lack of space, exits, and emergency stairs can significantly complicate and endanger the evacuation.

Because of the above-noted reasons, the best method for a safe evacuation is good planning and prediction. The use of simulation software such as Pathfinder enables precise calculation of evacuation time, prediction of potential evacuation scenarios, spotting of potential jams and locations for getting stuck, the use of elevators in evacuation, design scenarios with occupants with mobility difficulties or immobile occupants and others, and all with different parameters (speeds of occupants, capacity and speeds of elevators, stairs capacity (riser, tread, length, width) and other important parameters that could have an influence on evacuation. Therefore, evacuation can be predicted in a safe, secure, and cheap way, which can be of crucial importance in real situations. As is evident, the benefits of simulation software use are significant. Some disadvantages of simulation software use exist – a comparatively high price and the impossibility of using more complex ways to exit. Simulation software, not only for

evacuation but other purposes as well, must present a mandatory engineering tool (Jevtić, 2014, Jevtić, 2021, Jevtić and Dimić, 2023).

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