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Simulation of evacuation as a consequence of Industry 4.0

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Abstract: Evacuation presents very important, complex and always open and actual task and problem. Experience showed that even well calculated evacuation plans can have errors, mistakes and oversights. As an example, it is almost impossible to predict humans` behavior in stress and panic situations what can extremely endanger evacuation and cause many new victims. As a standard evacuation procedure, during construction of some object, it is necessary to calculate evacuation time needed for evacuation. But, even with a proper calculation, suppresses and unpredictable events are frequent. So, it is the best way to predict as many possible evacuation scenarios. One of the best ways for that purpose is the use of simulation software. The simulation software, as a consequence of Industry 4.0, enables many benefits in the sense of precision, prediction, calculation of evacuation times, determining of evacuation routes and their optimizations. In the future, this software will be consolidated with artificial intelligence with optimized results.

In this paper, several typical evacuation examples were presented with use of simulation software Pathfinder (version 2023), for high residential buildings as a particularly complex and hard objects for evacuation.

Key words: *simulation, Industry 4.0, human, safety, prediction, evacuation*

Introduction

Industry 4.0 as a technical revolution has brought advance and progress in many nature and social spheres of human`s life and work. With developing around its main environment, so called smart manufacturing, Industry 4.0 has overwhelmed many aspects of human`s life and work. New ways of communication, new ways of design, new ways of change and storage of information enable new unexpected possibilities through new technologies such as Internet of things, cloud systems, smart manufacturing, robots, drones, simulation, augmented reality and many others. These new technologies provided completely new views of the problems, offering new and better solutions. One of the very important new technology, with unbelievable possibilities is simulation.

Simulation provides digital view of the product or process in the aim of identification of potential problems, eliminating production expense, resource waste, potential danger situations and similar. Generally, Industry 4.0 has a wide range of 3D simulations. By using of simulation, it is possible to design virtual physical models of machines, products, process and humans, digital twins and digital shadows. Whole real processes, events, occurrences can be simulated in real time, decreasing needed time and increasing the quality of the products or processes, without any kind of risk. These models are presented on figure 1.

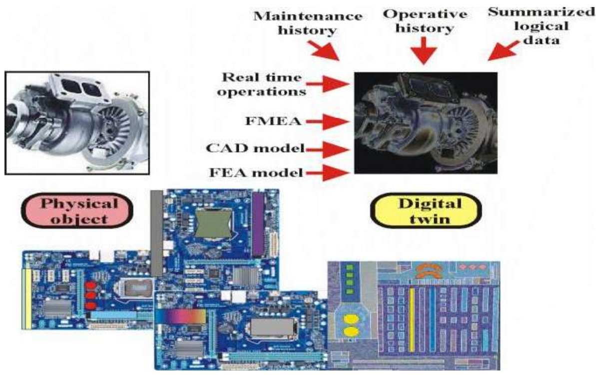


Figure 1. Simulation, digital twin and digital shadow in Industry 4.0

Design by simulation, digital twin presents virtual model of the real product, process, system, problem, task etc. It was defined as digital concept of happening of elements and system`s dynamic, realised during functioning, with possibility of optimisation of its characteristics. Theoretical information and knowledge, calculations but also and real information collected from sensors can be used to improve digital twin in real time. Digital shadow presents very detail and precise information view related to processes from development, manufacturing, functioning etc. It provides simulation of manufacturing chains, production flows and many different happening with complete virtual analyse related to potential problems, errors, hazards, accidents or similar, before the beginning of the process, system, happening or similar itself. That provides elimination of any potential risk, in the sense of human`s life, manufacturing hazard, accident, expenses of testing and similar [1]. For example, potential digital twin for fire safety could be presented as on figure 2.

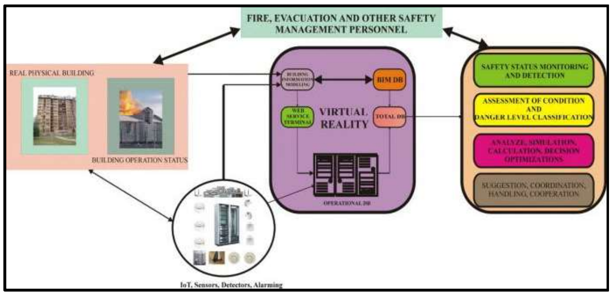


Figure 2. The presentation of the digital twin in fire safety and evacuation related to Industry 4.0 model

Simulation generally demands very strong software. The design and realisation of simulation software purports huge knowledge, experience, work and understanding of concrete subject. Simulation software are used to design virtual conditions in virtual ambient or environment. Beside many benefits, one of the most important benefits related to simulation is completely safety and absence of any kind of danger without any penalties (expenses, waste, errors etc.). In real, it is impossible to realise. Simulated problem enable insight, analyse and view about every potential problem, task, threat or similar what can significantly rise chances for problem solutions. Of course, simulation software in technical sense demands strong hardware back up- strong processor, lot of RAM memory, strong graphic card etc.

Evacuation has always presented very complex and open task and problem. No matter what was the reason for evacuation, evacuation of lot of people, animals or material properties from endanger to the safe place, location, object, area or similar has always

been very complex, for many different reasons. Ono of the most complex tasks related to evacuation is human behaviour during evacuation. Of course, it is always easy to explain what to do and how to behave in the normal conditions; during evacuation there can be lot of other factors that can cause panic, fear and instability such as fire, flame, smoke, explosions, crashes etc. So, it is the crucial task to somehow, as much as possible, determinate human`s behave, because only collected, calm and composed humans can realise successful evacuation. Particularly complex and hard for evacuation are objects with presence of lot of humans and special designed objects. These objects include high residential buildings intended for human's life.

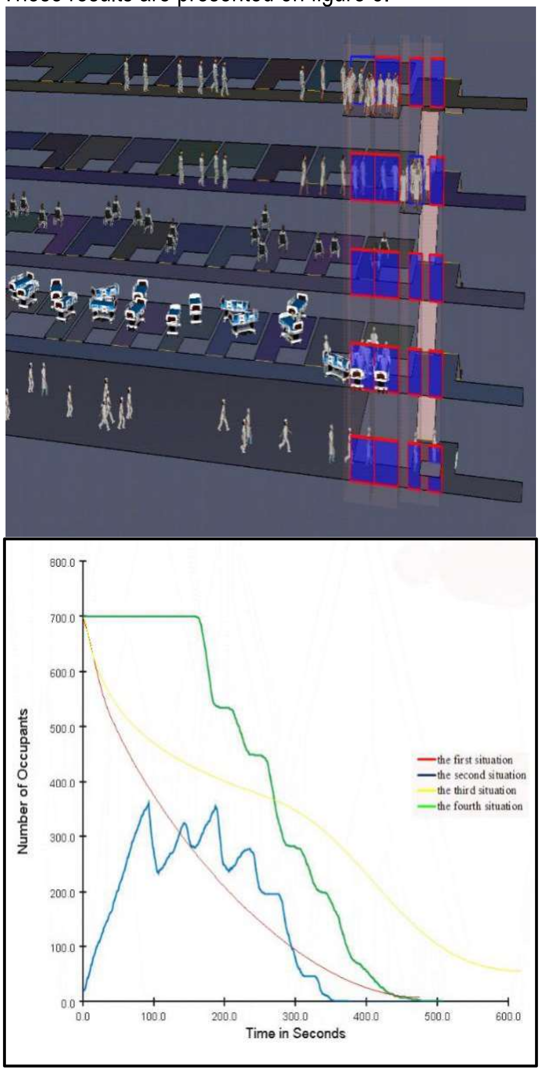
One of the best ways how to solve noted problems lies in the simulation software developing and usage. This software has great potentials in evacuation, calculating needed evacuation times, analysing every potential evacuation scenario proper evacuation and decreasing evacuation time. In the presence, there are more different simulation software on the market.

This paper was written to show the significance and importance of simulation software usage on concrete examples realised in Pathfinder simulation software, related to high residential buildings as a particularly complex, hard and interested objects for evacuation [2-4].

Pathfinder Simulation Software

Examples showed in this paper were realised in the simulation software Pathfinder. Pathfinder generally presents an agent-based egress and human movement simulator, providing a graphical user interface for simulation design and execution. Both 2D and 3D visualization tools for results analysis are available. There were several different versions of this software from its design. Every new version was significantly improved from earlier versions and provided a lot of new possibilities in the sense of efficiency and analysis. The minimum hardware requirement purports, as example, 64-bit Windows 8 Pro with an Intel Core i7 2.60 GHz processor, minimum 8 GB of RAM (as much RAM memory is desirable), and NVIDIA NVS 5200M graphics card.

Pathfinder enables graphic user interference intended for design and running of simulation models. Beside visual simulation results (3D), it also provides reports and calculations in 2D form, such as graphics or diagrams. These results are presented on figure 3.



a) b)

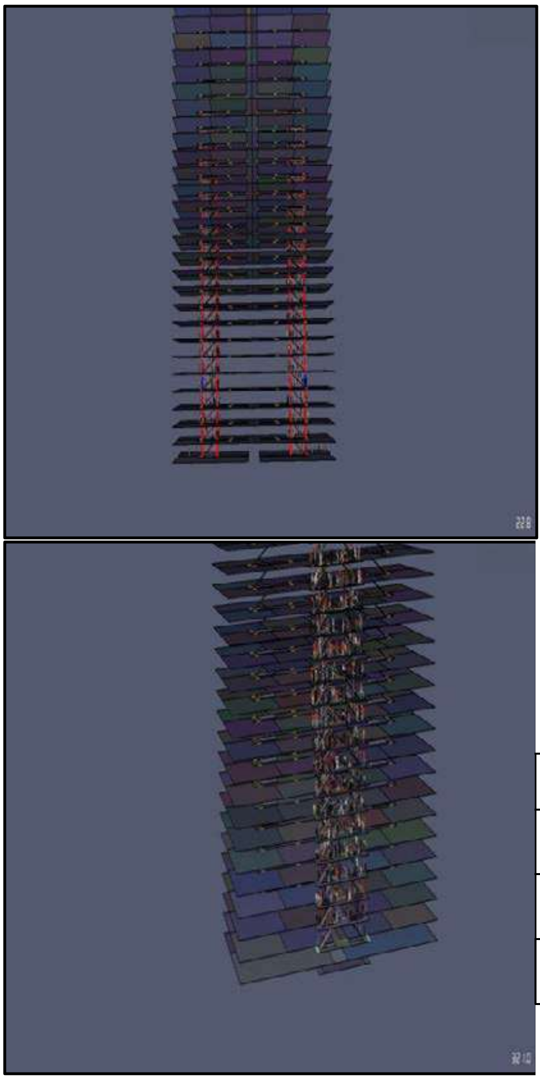
Figure 3. Different ways of simulation solution representation (a) 3D view and (b) 2D view as graphic

There are two different simulation mods for calculations available. The first mode presents the so-called SFPE mode, while the second presents the steering mode. SFPE mode purports that humans-occupants don't try to avoid one another, with some limits related to doors and velocity. Steering mode purports that humans-occupants are moving and behaving as much as possible as in real, and can interact between themselves. It is possible to realise simulation on both ways. Pathfinder has lot of benefits and advantages, but one of the most important is the possibility that this software can import files from some other computer program (Pyrosim, AutoCAD or some other), what significantly shortens the time and improves the effect. There are lot of different objects with high importance in strategic way that can be used in simulations, such as stairs, elevators, ramps, escalators, moving walkways etc. Also, very big improvement is the potential to use immobile or hard mobile persons (persons in wheelchair or medical bed); potentials to design behavior of humans-occupants in the sense of delaying, waiting, assisting, walking to certain room or location etc. [5-7].

High residential building evacuation simulation

Modern and technological improved way of life demands new rules and new solutions because of many things. Cities become bigger and bigger with the lack of space, parking's, green areas etc. Because of noted facts, residual buildings must be tall and must be in possibilities to provide safe home for their residents. There are many examples where height of building there are examples where the height of the building exceeds several tens or even several hundred meters (Burj Khalifa with 828 m and 163 floors; Merdeka 118 with 678.9 m and 118 floors; Shanghai Tower with 632 m and 128 floors; Abraj Al-Bait Clock Tower with 601 m and 120 floors; Ping An Finance Centre with 599 m and 115 floors; Lotte World Tower with 555 m and 123 floors; One World Trade Center with 541.3 and 104 floors; Guangzhou CTF Finance Centre with 530 m and 111 floors; Tianjin CTF Finance Centre with 530 m and 98 floors; CITIC Tower with 528 m and 108 floors and many other). High buildings can be designed only for residents, but also and for offices, hotels, work place etc. Related to determined information, the tallest residential buildings in the world have height from 305 m and 80 floors (Etihad Tower 2, Abu Dhabi, United Emirates) up to 472 m and 98 floors (Central Park, New York, USA). Such buildings are equipped with modern fire protection systems that enable fast and safe fire extinguishing and evacuation. It is purported that they must have fast and numerous elevators, fire escape stairs, sprinkler and drencher systems etc. But, even with all that available resources, accidents are happening. So, well calculated, organized and as much as possible prepared evacuation presents serious and important task. Related to the construction measurements, every residential building should have a large approach intended for fire vehicle; but, today, in the lack of space and huge traffic jams, this very important condition is not always realized. Very often, the usage of fast elevators is not possible because of many reasons (mechanical malfunction, the lack of the electricity power supply, presence of danger products such as carbon monoxide or carbon dioxide etc.), so, the only way for evacuation present ordinary stairs and emergency stairs.

The first simulated object example presents high residential building, constructed as two connected buildings, what is very often case of construction in the sense of stability. Each of them has basement and 50 floors. Maximal height of each building was 132.6 m. Maximal base surface of each building was 400 m^2. Related to room`s arrangement, every floor in both buildings, except basement, consists of four flats, four elevators, one ordinary stair and exit to emergency stairs, where the surfaces of flats were 84 m^2, 84 m^2, 87 m^2 and 47 m^2. Every flat was designed to have ordinary rooms (bed rooms, sitting rooms, kitchen, bathroom, ante rooms and hallways) with ordinary furniture (beds, desks, dressers and similar). Simulation condition was that occupants-humans were in their flats in the moment of evacuation start. Simulations were realized for four different scenarios. The first evacuation scenario purported evacuation from building but only by ordinary stairs usage. The second evacuation scenario purported evacuation from building but only by emergency stairs usage. The third evacuation scenario purported evacuation from building by ordinary stairs and emergency stairs usage. The fourth evacuation scenario purported evacuation from building by ordinary stairs and elevators usage. Every of four scenarios were realized for different speeds of occupants-humans: 0.8 m/s, 1 m/s, 1.2 m/s, and 1.4 m/s. Some of simulation moments are presented on figures 4 (a, b) [8, 9].



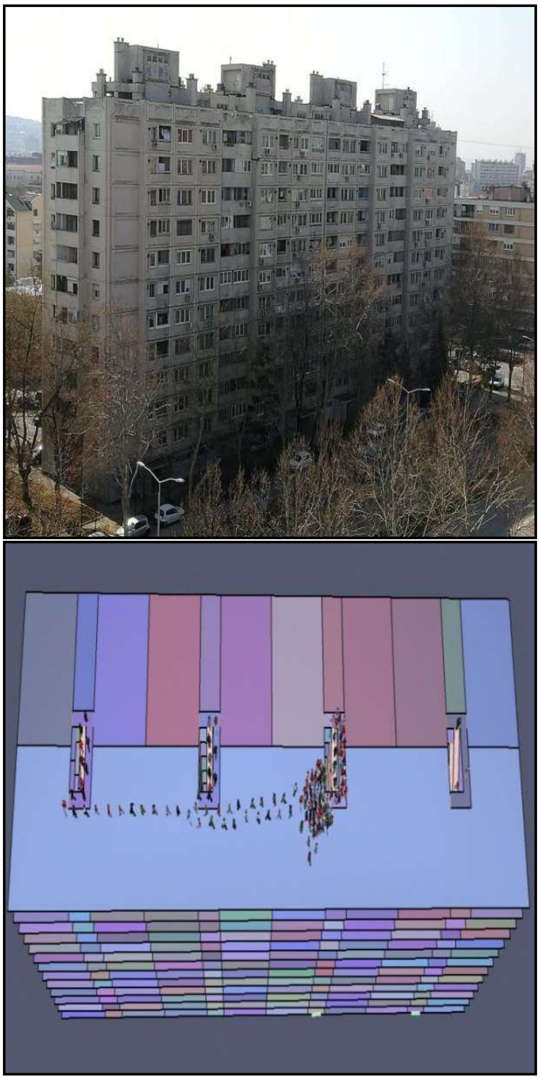
a) b)

Figure 4: The examples of evacuation from high residential after 22.8 seconds after simulation start (a) and and after 321.0 seconds after simulation start (b), both for occupant`s speeds of 1 m/s.

The second simulated object example presents high residential building, constructed as four connected buildings, what is very often case of construction in the sense of stability on earthquake. This building is real and it is located in Niš, in Bulevar Nemanjića street with numbers from 58 to 64. Completely, these connected buildings have four exits/entrances without emergency stairs, so the purpose of the simulation was to had insight in the possibilities of evacuation without any additional resources except elevators, stairs and common terrace exits. Every of four building in structural sense is the same-it has base floor, ground floor, next ten floors and terrace. Terraces present connection between buildings. In the case of evacuation, these connected terraces can present the only potential evacuation exit, where occupants should cross in neighbor building via them. Every separate building has four flats at one floor and two elevators, one with totally capacity of four persons and one with totally capacity of six persons. Smaller elevator had speed of 1,1 m/s, while the bigger elevator had speed of 0,92 m/s. The maximum height of the building was about 38 m. There were four difference scenarios for different speeds of occupants-residents (0.75 m/s, 1 m/s, 1.25 m/s, and 1.5 m/s and 1.75 m/s). The first scenario was realized for all four entrance/exits opened with enabled or disabled elevators. The second scenario was realized for one entrance/exit blocked and tree other entrance/exits opened (complete 9 cases). The third scenario was realized for two entrance/exits opened and two entrance/exits blocked (complete 12 cases). The fourth scenario was realized for one entrance/exit opened and three entrances/exits closed (complete 8 cases).

Complete building and simulation model in Pathfinder for the third scenario, where the third and the fourth entrances/exits were blocked and elevators were disabled and where the occupant`s speed was 1.5 m/s are presented on figure 5 (a, b)[9-11].

Scenario	I	II	III	IV	V	VI	VII
Occupants used ordinary stairs							
Occupants used fire stairs							
Occupants used elevators							



a) b)

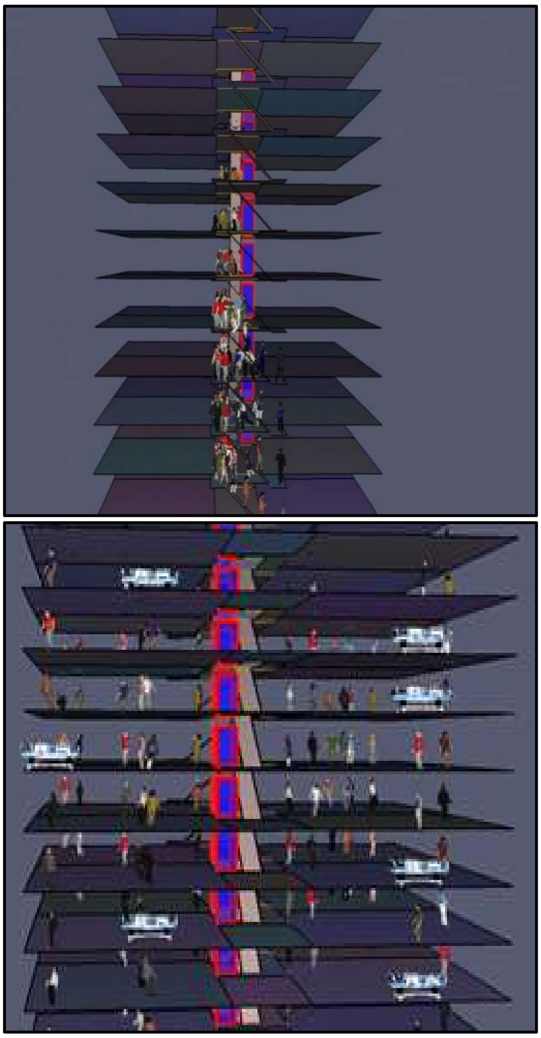
Figure 5: Building in Bulevar Nemanjića street, from 58 to 64 (a) and the third scenario, where the third and the fourth entrances/exits were blocked and elevators were disabled and where the occupant`s speed was 1.5 m/s b)

The third simulated object was the building with dimensions of 17 m x 17 m and twelve floors above. The dimension of each floor was 17 m x 17 m x 2.54 m, and all of them has four flats, two bigger with approximate surface of 70 m^2 and two smaller with approximate surface of 55 m^2. Floors also had a corridor and they were connected with ordinary stairs, emergency stairs and elevators. The width of ordinary stairs was 1.25 m, while the width of emergency stairs was 0.95 m. Building had two elevators for residents; one with four persons capacity and one with eight persons capacity. The speeds of elevators were different; the speed of smaller elevator was from 1 m/s to 1,3 m/s while the speed of bigger elevator was from 0,6 m/s to 0.9 m/s, in dependence of weight. For this building, there were seven different evacuation scenarios realized and calculated and these scenarios are presented in table 1.

Table 1. Realized scenarios for residential building with different possibilities

The speeds of occupants, for every of seven scenarios, were 1.2 m/s, 1.5 m/s, 1.8 m/s, 2.1 m/s and 2.5 m/s. Immobile occupants were in wheelchairs and medical beds. Speeds for wheelchairs were from 0.4 m/s to 1.3 m/s, while speeds for medicals bed were from 0.2 m/s to 1.2 m/s.

There were three different cases for every of seven scenarios: without immobile occupants, with 5 % of immobile occupants randomly arranged (10 immobile occupants, 5 with wheelchairs and 5 with medical beds) and with 10 % of immobile occupants randomly arranged (20 immobile occupants, 10 with wheelchairs and 10 with medical beds). Some simulation moments for this building are presented on figure 6 (a, b) [12, 13].



a) b)

Figure 6: Simulation moments from the fourth scenario and the third case (a) and for the first scenario and the second case (b)

Analysis and discussion

of simulation results

As it was noted, for realisation of computer simulation and usage of simulation software, very strong computer or laptop is required, with strong processor and lot of RAM memory.

For the first example, simulation results showed that the shortest evacuation time was for fourth scenario (802.12 seconds and occupants-residents speed of 1.4 m/s) while the longest evacuation tie was for the third scenario (2456.79 seconds and occupants-residents speed of 1.4 m/s). Also, realised results enable determination of speeds for jams could be occurred, and the critical points in the building (doors, stairs, passages etc.). Occupants-residents were set to have the same or different speeds, but it was possible to set that occupants-residents had different speeds, so as different gathering points, different directions of evacuation etc [6].

For the second example, simulation results showed that the shortest evacuation time was for first scenario with enabled elevators (209 seconds and occupants-residents speed of 1.75 m/s) while the longest evacuation tie was for the fourth scenariowith elevators disabled and the first entrance/exit opened, while the second, the third and the fourth entrances/exits blocked (1729.3 seconds and occupants-residents speed of 0.75 m/s). For this example, also, calculation showed that the speed when the jams occurred can be determined, with critical points in the building [9].

For the third example, simulation results showed that the shortest time for evacuation was for the first case of the first scenario (150.2 seconds for occupant`s-residents speed of 2.4 m/s), while the longest evacuation tie was for the third case of the seventh scenario (754 seconds for occupant`s -residents speed of 1.2 m/s). This example was particularly interested because the presence of immobile persons in wheelchairs and medical bed was noted. Possibilities for jams were very high, because occupants in wheelchairs demanded at least two other occupants-residents for help and assistance while occupants-residents in medical beds demanded at least four other occupants for help and assistance. This example also included deep analyses related to the arrangement of wheelchairs and medical beds, because there were big differences in evacuation times in cases when this kind of occupants-residents were concentrated at one or more floors instead of their random concentration [13].

Conclusion and future investigation

The most important task in every accident is to protect and save human lives. Because of that reason, evacuation must be carefully and precise planned, calculated and realised. The simulation software in evacuation calculations and analyses provides huge technological advantage, at the first place in prediction and in complex and enormous calculation. Design and realisation of many different evacuation scenarios enable prediction of evacuation, with optimised results. Powerful computers enable fast and precise realised simulations needed information. Evacuation with the lot of humans inevitably involved in panic and stress. Today, there are different algorithms which are constantly improving and which can describe and simulate human's behaviour, especially of huge group of humans.

Also, further technical innovations, as a result of Industry 4.0 enable higher level of simulation. At the first place, the prediction will be at significantly higher level. New virtual systems, designed by experts and artificial intelligence, will be in positions to predict every potential scenario in the sense of fire, earthquake or some other accident and disaster and will prepared appropriate services to react at time. New sensors (for example, sensors for door`s flow measuring, sensors for detection of stairs occupation, sensors for availability of determined evacuation route, gas sensor, temperature sensor, smoke sensors, humidity sensor etc.), in real time, can provide real and current information, what can change evacuation (way, direction, timing etc.) in real time and redirect evacuation or take over some other step in the correlation with different services (such as fire brigades, police, first aid etc.). For bigger objects or bigger supervised areas, supervision will be task of drones, sensors, robots and AI, what will achieve unimaginable successes at the field of evacuation. With "fresh" information, occupants will be able to evacuate at safety area on the safe and fast way. They will be able to avoid areas or rooms with the presence of "accident consequences", such as fire, flame, smoke, carbon monoxide, carbon dioxide, different physical obstacles etc. Also, other modern innovations will be available for evacuation, such as dragons from aluminium and canvas, slides, different types of descents, different type of jump canvas etc. It is predicted that future applications installed on smart phones will have possibilities to communicate with sensors and to alarm and worn their owners about situation in real time.

References

[1] V. Majstorović, D. Đuričin i R. Mitrović, *Industrija 4.0-Renesansa inženjerstva*, Beograd, Univerzitet u Beogradu, Mašinski fakultet, 65-68, Srbija, Beograd, 2021.

[2] Jevtić, B, Radoje, The fire simulation as a safety advantage in fire prediction and fire protection, *Safety Engineering, Vol. 5*, (2015), No. 1, pp. 21-28, ISSN-2217-7124.

[3] Jevtić, B, Radoje, The significance and use of simulation software in evacuation, Path to a Knowledge Society-Managing Risks and Innovation PaKSoM 2021, 3rd International Virtual conference, November 15 and 16, 2021.

[4] Jevtić, B, Radoje, Simulation of Evacuation Situations in Order to Protect Human Lives and Material Property,*NBP*-

Journal of criminalistics and law, 2016, No. 2, pp. 35-49, ISSN 0354-8872, UDC 343.98, Belgrade, Serbia.

[5] Pathfinder user manual, Thunderhead engineering, pp. 5-13, 2024.

[6] Jevtić, B, R, Simulation of Evacuation Situations in Order to Protect Human Lives and Material Property,*NBP-Journal of criminalistics and law*, No. 2, (2016), pp. 35-49, ISSN 0354-8872, UDC 343.98.

[7] Dimić, Violeta,Jevtić, B, Radoje, (2023) Application of Simulation Models for Predicting Population Evacuation in Traffic,*Proceedingsof 96th International Scientific Conference on Economic and Social Development* - "Era of Global Crises", 18-19. May, 2023, Belgrade, Serbia. ISSN 1849-7535 .

[8] Jevtić, B. R.: Example of evacuation simulation from a high-rise residential building**,** Vatrogaštvo i upravljanje požarima, Vol. X, No. 1-2, (2020), pp. 46-62, ISSN 1848-347X.

[9] Jevtić, B, Radoje, Safety in residential buildings - evacuation from residential buildings without fire escape stairs, *Vojnotehnički Glasnik, Vol 69*, (2021), Issue 1, pp. 148-178.

[10] Jevtić, B, R, Ničković, T,J, Simulation of residential object evacuation, (2013), 57th ETRAN CONFERENCE, Zlatibor, ISNB 978-86-80509-68-6.

[11] Jevtić, B, R, Ničković, T, J, **Object evacuation for different speeds of occupants**, 58thETRAN CONFERENCE, (2014), pp. RT6.6.1-4, Vrnjačka Banja.

[12] Jevtić, B, R, Fire and evacuation in high residential buildings, Facta Universitatis, Working and Environmental Protection, Vol. 15, Nº 2, (2018), pp. 123-134, ISSN 0354-804X.

[13] Jevtić, B, R, Residential Building Evacuation-Simulation of Potential Evacuation Scenarios with Presence of Immobile Persons, Tehnika Elektrotehnika, Vol 6, (2020), pp. 814-821, ISSN 0040-2176, UDC: 62(062.2) (497.1).

[14] Jevtić, B, Radoje, Simulation of a school facility evacuation-The case of the secondary school "Svetozar Marković"in Niš, *Vatrogštvo i upravljanje požarima, Vol. XII*, 2024, No. 1-2/2023, pp. 17-29, ISSN 1848-347X, UDK 614.84, Zagreb, Croatia.

[15] Negi, P, Pathani, A, Bhat, B C, A, Swami, S, Singh, R, Gehlot, A, Thakur, A K, Gupta, L R, Priyadarshi, N, Twala, B and Sikarwar, V S, Integration of Industry 4.0 Technologies in Fire and Safety Management, Fire , 7(10), 335, (2024), https://doi.org/10.3390/ fire7100335.

[16] Ferreira, L P, Ferreira, Andre, Costa, E and Ramos, A L, The Role of Simulation in the Context of Industry 4.0 in Building Evacuation, Proceeding of the 7th International Conference on Logistics Operations Management, GOL'24, Lecture Notes in Networks and Systems, vol 1105. Springer, Cham. https://doi.org/10.1007/978-3-031-68634-4_13, pp 134–141.

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