HADMÉRNÖK

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EVACUATION SIMULATION CASE STUDY

Absztrakt

Nowdays computers have a significant role the preparation of decision-making. The systems are simulating (modeling) the human decision-making process, based on the knowledge of the experts of the field, and on their induction methods [1]. One of the most advanced method for planing in an engineering approach, is the computer evacuation simulation. With the help of this program, we can determine the certain premise or premise sections, also with the help of graphical visualization we can introduce the movement of the people during the whole evacuation process [2]. However, we cannot forget that computers only support us, they do not replace us, human beings. Because every model is a simplification of reality, hence it can only instruct part of the features. Also we must not forget that the program calculates through probabilites and it can signal particular possibilities based on solid circumstances. Therefore the results of the computer simulation can only be interpreted with sufficient knowledge, hance it can only give us acceptable result with supplementary knowledge [3].

Az utóbbi időkben egyre jelentősebb szerepe van a döntés-előkészítésben a számítógépnek. A rendszerek az emberi döntéshozó folyamatot szimulálják (modellezik) számítógépen, a szűkebb szakterület szakértőinek ismeretére, tudására és következtetési módszereikre alapozva [1]. A kiürítés számítógépes szimulációja a jelenkori mérnöki megközelítés alapú tervezés egyik legfejlettebb eszköze. A program segítségével meghatározható az egyes helyiség vagy helyiség csoport, illetve a teljes épület kiürítéséhez szükséges idő és a grafikai megjelenítés segítségével jól bemutatható az emberek mozgása a kiürítés teljes folyamata alatt [2]. Ne feledjük azonban, hogy a legfejlettebb számítógép is csak segíti és nem helyettesíti az embert. Mivel minden modell a valóság egyszerűsítése, így a tulajdonságok csak egy részéről tájékoztathat. Emellett fontos azt is szem előtt tartani, hogy a program valószínűségekkel számol és a térbeli körülmények alapján jelezhet bizonyos lehetőségeket. Ezért a számítógépesszimuláció eredményét minden esetben csak megfelelő szaktudással szabad értelmezni, mivel a kiegészítő ismeretekkel együtt adhat elfogadható eredményeket [3].

Kulcsszavak: *kiürítés szimuláció, modellezés, programok, személyek, haladási sebesség ~ Keywords: Evacuation simulaion, modeling, programs, persons, travel speed*

MODELING PROGRAMS

Right now there isn't a modeling program, which can process every event, it must be chosen for a specific task and goal, because every one of them have their own features and limits. There are models solely made for simulating movement, which are basically hydraulic flowing modells. And there are those, in which we can use people's behavior patterns particatlly or fully (for example: procrastination, tracking grouped behavior patterns, handleling coherent people, or applying artifical intelligence). The dynamic development running wordwide points to the latter, however it is the most difficult technical task, because it must shape a human or sociological symptom to an algorithm [4,5]. According to the Fire Protection Technical Guideline (FPTG) – Simulation 4.1.2. point there are currently 4 recommended program, which usage is accepted by the authority in the authorization process.

The aim of modeling

According to the current regulations, computer simulation programs can be used to verify the safe evacuation from the building, which are need to be created and documented accordingly to the recommendations of the FPTG – Simulaton, and they need to be authorized by the competent fire protection authority (currently the NDGDM[1]).

The results can be the following:

- determining the evacuable number of staff based on time;
- transmitted number of persons over time [7];
- evacuation or escape time and its phases;
- escape lift efficiency during evacuation [8];
- verifying the capacity of safe spaces (such as gathering place, in case of large number of evacuation, the environment of the building) and temporary protected areas (such as smoke-free stairwells, separate rooms);
- presenting the process of evacuation/escape with the incidental pilling (for example, escape lift's environment, escape aeffect contrary to the direction of the traveling persons, the impact if barriers) [9].

When using computer simulation it must be controlled and verifyed that the evacuating persons can leave the monitored area (premises, fire passage, building, structure, open space):

- within the norm time (ie, examination of physical evacuablity) [10],
- or within a certain period determined by fire and smoke propagation simulation (ie comparing the values of RSET and ASET) [11,12].

The parameters of modeling

During the modeling multiple input date is required, that may vary from program to program, but they basically fall into three main categories [13]:

- The geometric data of the building, with the most accurate input. With this, we define the evacuation's frame: the size of the premises and their locations, the data of the doors used for the evacuation, the data of the installations and personel which are obstructing the evacuation.
- The qualities of the persons involved the evacuation can significantly affect the progress of the evacuation. Mostly size and speed are decisive. (In case of behavioral models the varios behavioral traits may be important) [14].
- If the evacuation modeling program allows and date from other fire modeling program is available, the toxical effects of fire, heat and smoke needs to be given in a function of time, which can be taken into account by the program evacuation process.

[1] National Directorate General for Disaster Management, Ministry of the Interior (NDGDM)

The adjustment of the persons

Dimension data can be accessed through surveys and studies alike, but most likely these need to be changed int the course of the modeling process. Since there are no measurment data available in Hungary, so we need to use internationally accepted and used anthropological measurments. One of the generally accepted guidelines for desinging – Metric Handbook [15] – below determines the avarege human size. Figure 1. shows the median value of the percived avarege based on English measurments, which are 465 mm for men, and 395 mm for women. In figure 2. shows examples of how individuals tools may appear in form, and the amount of the demanded avarege space.

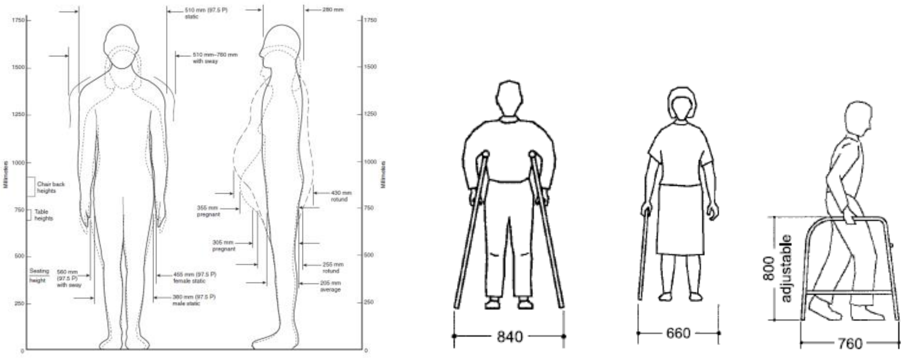


Figure 1-2 – Typical measurments of people and injured people

The course of the normative calculating speed needs to be determined with the averaging of all person (since the equations do not distinguish between young, old, children or crippled) and it needs the necessary safety margin to operate. Of course, this does not mean that everyone can just move forward with the speed of reality, beacause of this, the process of computer modeling the maximum amount of speed can be misunderstood. If we reflect the escape process, it is expected to be at the front of the door, in which case, people can only move at slower pace. We can only take this phenomenon into account as the avareged speed. While in case of computer modeling programs are able to show the effect of an internal deceleration equation and if needed with a stop [15]. The maximum amount speed values are only recommended to give by measured published data.

The available space affects the freedom of movement and the interpersonal distances, which may couse discomfort, unwanted activities like pushing. In over the density of 3.5 persons/m2 crowd, pushing cause a pressure wave propagation which leads to the squeeze of people, causing them to move beyond their will. In Table 1 I summerized the number of different desities which affect movement speeds [16].

Table 1 – Affect of number density on movement speed

Density (person/m^2)	Attributes
≤ 0,5	People's movement is not limited, the presence of other persons does not affect movement or staying in one place
0,5 – 1	People's movement is not limited, sometimes evasive action is required, other persons will not affect movement or taying in one place
1 – 2	Walking individuals have to be caution not to bumb into others, and waiting individuals are aware of other people's presence
2 – 3	Progress is only possible shuffling. The movement is directed by the crowd. There is no, or little chance to move againts the crowd
≥ 3,5	Progress is almost impossible, movement is only possible if every member in the crowd is moving and thus space is created.

THE PARAMETERS OF CASE STUDY

In this case study I will examine that how much difference does the calculated evacuation time by using the manual method of calculation or simulation. In addition, since there is a significant difference between the speed of healthy and disabled person, it is important to consider that how much difference is shown by using the different speeds. I will investigate a fictitious hospital building site of rehabilitation center.

The hospital ward is on the ground floor with patient's rooms, which includes an indoor and an outdoor gym, medical and physiotherapist rooms as well. The hall building and the ward can be reached via the main lobby, where is a large, unobstructed reception and administration desk. From the external waiting room could be reachaded a small gym, where the patient has been discharged come up treatment and monitoring, without affecting the inside ward. After the reception desk is available in the building's vertical transportation core, four large elevator lobbies and their associated staircase (in my case study I did not take into account the escape possibilities of other levels of the building). The middle of ward is a living area that is suitable for a long time patients for community space as well and to receive visitors, and a common dining options too. From this space open the care rooms, the gym area, and the staff areas. The hospital ward is designed for 38 beds, 2 person in each room, independent barrier-free bathrooms inside, which are formed two sides of a long corridor. At the end of the corridor – the sole purpose of escaping – 1.80 m wide net, symmetrical double doors away. (The architectural layout in Annex 1.) Basically there are two exit doors available, both with double symmetrical design, net 1.80 m in size, and are available for the whole duration of the evacuation process.

The individuals are placed in the following breakdown: 38 patiens, who are in the patient's rooms, in the living room and in gym. 19 people in the lobby and outside the gym. 5 patients who came from other department are in inside gym. 7 visitors who may be in the patient's room and the living room. 10 pyhsiotherapist who are in the internal and external gym, or staff quarters and a total number of 11 staff member (reception, nurses, doctors). So 62 disabled people and another 28 healthy people are staying in the model area (a total number of 90 people).

METHOD OF MANUAL CALCULATION

During the audit, the equations lockable manual calculation method set out in the Fire Protection Technical Guideline (FPTG) – Evacuation legislation section apply it.

The test layout for the two positions I hold to be critical in terms of evacuation, so they will examine: one for the gym opened inside the far corner of a small room, rooms on the other hand the rear exit door farthest back in bed (the top line). It takes exactly the amount the person is in the manual calculation of the specific areas as is the person in the employ of simulation layouts.

The calculation is based on a small room next to the gym evacuation time of 1.56 minutes (ie 93.6 s duration), and the patient's room evacuation time of 0.94 minutes (ie 56.4 s duration). In both cases, the distance-based computing has the maximum calculated time. Based on the results seen in this case with the actual layout and the number of distance-based inspection gives the maximum calculated time, so through put of the doors is not a determining factor.

THE APPLIED SIMULATION PROGRAM AND IT'S ADVANCED OPTIONS

Brief description of the program

The Pathfinder is based on a person's evacuation simulator that utilizes the characteristics of movement of persons evasive behavior. The program essentially creates a kinetic model, however, thanks to regular improvements we can simulate certain behavioral patterns with the help of proper timing and application of the various management options. The program is „only" examining the possibile physical evacuation of the area, typically it does not take into account neither in the heat of smoke and toxic effect, nor any effect of panic on people. With the latest development it was possible to adapt results made by other programs in terms of heat and smoke propagationl (although I did not use this possibility in the present study). The simulator consists of three modules: a graphical UI, Simulator, 3D-visualization of the results. (The program was developed by the American Thunderhead Engineering Consultants Ltd by and it can only be used via licence).

This evacuation program is controlled by two main methods: the SFPE[2] Handbook [17] and the „steering[3]" evasive method [18]. The program uses a three dimensional geometric model during its operation. Within the geometry model it creates a navigation mesh in which movement of person is actually happening (mesh). The navigation mesh unilaterally interpreted in a special plane, which divide the program into triangles that are used to determine the movement in later calculations. The basic model space consists of the following elements: room, stairs/ramp door and exit. The program provides an opportunity to take a variety of ways to enter the width and speed of people, and it has basic settings for each value too. In addition, some special features can be set which can affect the base data during the simulation: compressibility value, comfort distance, deceleration factor, response time, door election method, but is only recommended to deviate from the basic values in appropriate cases! The program gives possibilities for individual and group housing of persons. In either case, you set the properties of placed persons. [19] During the simulation, people can basically use any exit. Mainly thely choose the shortest route, and during the change of circumstances they take the estimated waiting time into account, and if necessary, they

[2] The Society of Fire Protection Engineers (SFPE) was established in 1950 and incorporated as an independent organization in 1971. It is the professional society representing those practicing the field of fire protection engineering

[3] steering: one of the simulation of the Pathfinder by which the state of the art algorithms are used in th course of robotics developments

modify their route. In addition, it is possible to control the people, when only a certain exit can be used, but this must be determined in light of the actual tasks.

Base data of persons

During the different evacuation versions I set the width and speed values which can be seen in Table 2. For each version both healthy and disabled people's parameters had been determined based on a published book called, 'Body Space'[20].

Table 2 – Applied personal settings

type of person	size		speed		
	age-group (years)	shoulder size (cm) {min, avarage, max, spread}	age-group (years)	speed (m/s) {min, avarage, max, spread}	color
avarage people (women and man mixed)					
FPTG avarage	19 – 65	39,5- 46,5	-	0,67	medium gray
healthy people					
men staff	19-65	42,0 – 46,5 – 51,0 – 2,8	20-60	1,50 – 1,84 – 2,17 – 0,23	dark green
women staff	19-65	35,5 – 39,5 – 43,5 – 2,4	20-60	1,44 – 1,73 – 2,06 – 0,22	light green
people with disability (women and men mixed)					
research result avarage	19 – 65	39,5 – 46,5	-	19 – 65	dark orange
wheelchair users (research result)	-	76,0 – 90,0	-	-	pale yellow
1 crutch/stick (research result)	-	66,0	-	-	pale purple
2 crutch/stick (research result)	-	84,0	-	-	dark purple
frame/rollator (research result)	-	80,0	-	-	light blue
without aid (research result)	19 – 65	39,5 – 46,5	-	19 – 65	orange

Results of evacuation versions

Since I used randomly set values for each evacuation version, I made several runs (20-20) and processed the results. Among the re-runs the placed people positison did not change (ie, they started from the same starting point), they only recived new starting values based on size and speed settings.

Avarage speed determined by the FPTG

In this version, all housed people can move towards the exit at the maximum speed of 0.67 m/s specified in the FPTG - Evacuation. Repeated runs virtually didn't change people's speed, only their dimensions.

The final evacuation time according to this showed a slight divergence, between 78.4 s and 81.2 s, from which the avarege evacuation time was 79.7 s. The small difference supports my theory, that the designed test site throughput of doors does not affect the evacuation time, as it would be a greater impact on canhes of width dimonsions of persons.

Figure 3 – Starting state (0 s)

Figure 3 sets the starting state (0 s). Figure 4 shows the execution of the evacuation in the moment of 60 s. It seems that so far all people left the starting area and the evacuation is only taking place in the corridor areas. By this time, only the staircase and the lobby isn't empty. Figure 5 shows the end of the evacuation at the main entrance, which will be completed in 81 s. This is less than the 93.6 s duration using the FPTG calculation with the same starting speed values. The explanation for this may be that during the modeling different numbers of density limit speed reduction occurs, a sin the case of handheld calculating.

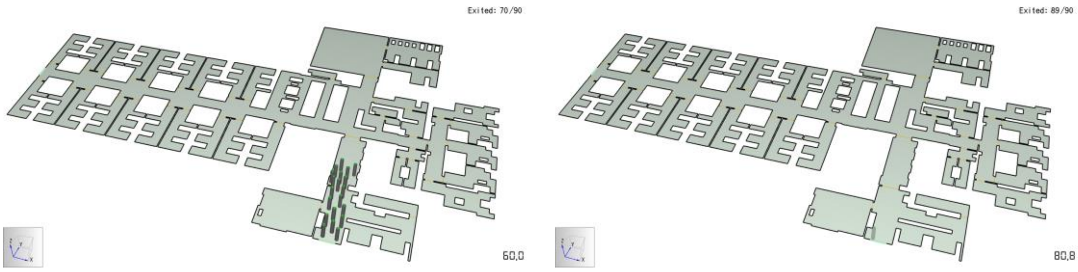


Figure 4-5 – Evacuation process (60 s and 81 s)

The figures show that the evacuation progress steadily, individuals with avarage speed leave the area one by one without extrusion.

Research results concerning impaired people's avarage speed

In this version healthy people may proceed at maximum speed of 1.19/s specified in the SFPE Handbook [17], while the impaired people move with a 0,65 m/s maximum speed specified in my own research result. Repeated runs did not change the healthy people's speed, but people with disabilities have changed the speed of random values accordance with the normal distribution function.

The final evacuation time showed a large difference between 117.3 s és 258.9 s, of which the avarage evacuation time was 183.9 s. The difference may be because in case of the impaired people not only the simple avarage had been defined, but based on the normal distribution between the minimum and maximum values, significant differences can be observed. Thus, if the simulation randomly given speed is rather close to the minimum, that can significantly worsen the final evacuation time.

Figure 6 shows the starting state (0 s). Figure 7 shows the evacuation process at the time of 30 s, which shows that in case of a few patient's room and the gymnasium, there are still a few people with disabilites in these areas. After this time only a few impaired people are moving towards the back exit, and it can be seen that the slower speed that had been set up for them is literally affect the evacuation process.

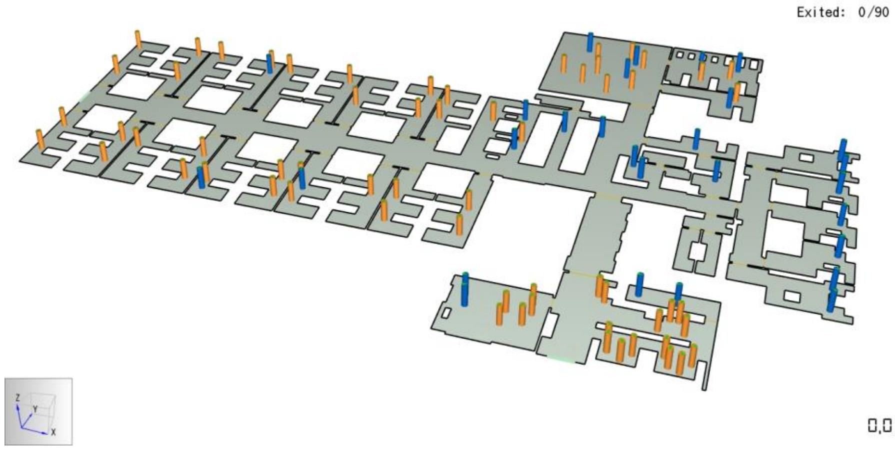


Figure 6 – Starting state (0 s)

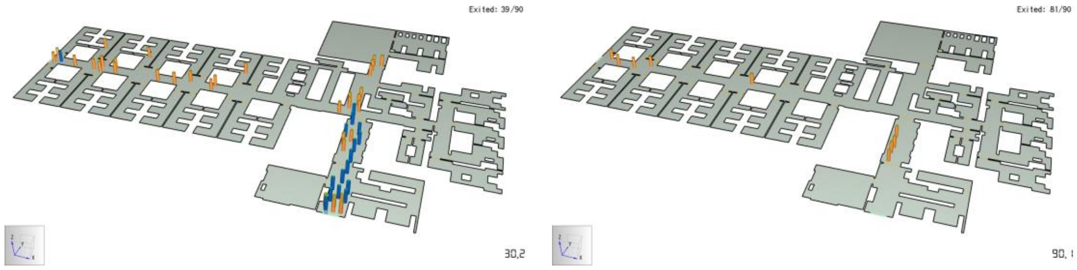


Figure 7-8– Evacuation process (30 and 90 s)

Figure 8 shows the evacuation process at the time of 90 s. At this time there are still slower people moving onwards. And there are still a few people moving towards the lobby. At th end of evacuation porcess only one person was moving towards the back exit. Double checking his speed in the model, his random speed was 0.23 m/s, which occurs in accordance with the normal distribution curve. The end of the evacuation at the time of 259 s, when the last person leaves the area through the back exit.

Applied group speed based on research results

In this version healthy people can move with maximum speed considering age and gender, definied by the Pedestrian Dynamics Handbook, which I fixed in the program with the normal distributional curve [21]. For people with disabilites can run at maxumum speed based on the research results, a hypothetical tool with user distribution, they can move towards the exit with the specified normal distribution curve.

The placed people's gender distribution was only considered in this version, in which case for the medical staff and physiotherapists 20% of men and 80% of woman were taken into account, while for vistiors 50% men and 50% women. Also in this version a variety of injury have been provided: people using wheelchair 31%, people using one cruth/stick 15%, people using two cruth/stick 22%, cane users 22%, frame/rollator users 14%, and unaided people were 18% placed in the model.

The final evacuation time showed a large difference between 104.6 s és 267.0 s, of which the avarage evacuation time was 190.6 s. The difference may be because in case of the impaired people not only the simple avarage had been defined, but based on the normal distribution between the minimum and maximum values, significant differences can be observed. This is significantly greater than the calulation made by the FPTG, which was 93.6 s.

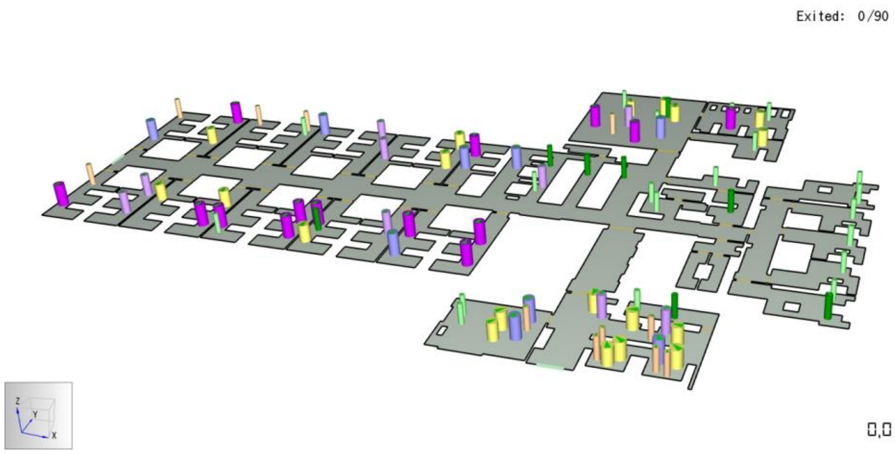


Figure 9 – Starting state (0 s)

Figure 9 shows the starting state (0 s), the groups are highlighted with different color. At 30 s time the patient's rooms are empty but there are still a few people in the gym.

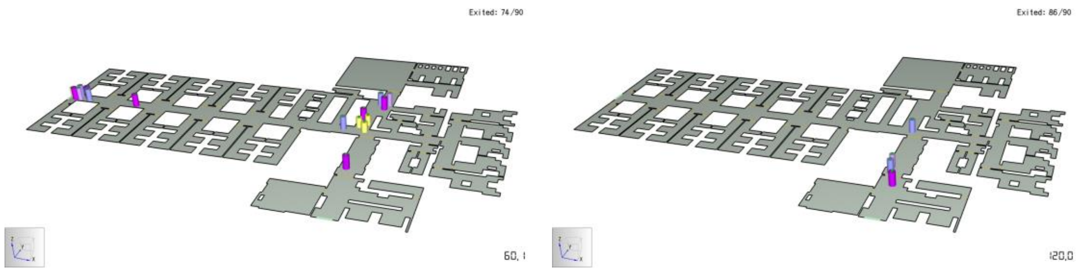


Figure 10 – Evacuation process (60 and 120 s)

Figure 10 shows the evacuation process at the time of 60 s. At this time only several people are moving in the corridor and the lobby. Figure 19 shows the evacuation process at the time of 120 s, when there are still 4 people inside. Double checking the slowlyest speed in the model, his random speed was 0.13 m/s, which occurs in accordance with the normal distribution curve.

Comparing the evacuation results of the

In Table 3 I summerized the different evacuation versions's results. Based on the completed execution results for the simulation run for the estimation of confidence intervals (normal distribution, 95% of the security level, the results of which also were recorded in the table.

Table 3 – Simulation results

Total evacuation time		Version A	Version D	Version E
Simulation values	avarage	79,7	183,9	190,5
	spread	0,90	43,5	46,2
	min	78,4	117,3	104,8
	max	81,2	258,9	264,9

I made a distinction between healthy and disabled people. For the healthy people I did not use avarage values, but values based on gender and age distribution, specifying normal distribution. Also in case of disabled people I did not use avarage values, but values based on the tools thely used calculated by my research, specifying normal distribution.

In my opinion in case of version E includes entering data as accurately as possible on scientific findings, only a minimum evacuation time growth occured in compared with using the avarage speed values. In the course of the estimation of reality it can be observed that in both the avarage and upper limit values, there is 6 s difference, but due to the safety provisions it can not cause a significant fire prevention risk. From the percentage differences the conclusion is that the maximum speed change is non-linearly dependent on the change of evacuation time during the simulation controls.

CONCLUSION

In the course of my study I revealed that the evacuation time calculated with the equations used by the regulations, none of the results are the same with the results made by the evacuation simulation in case of geometric monitoring.

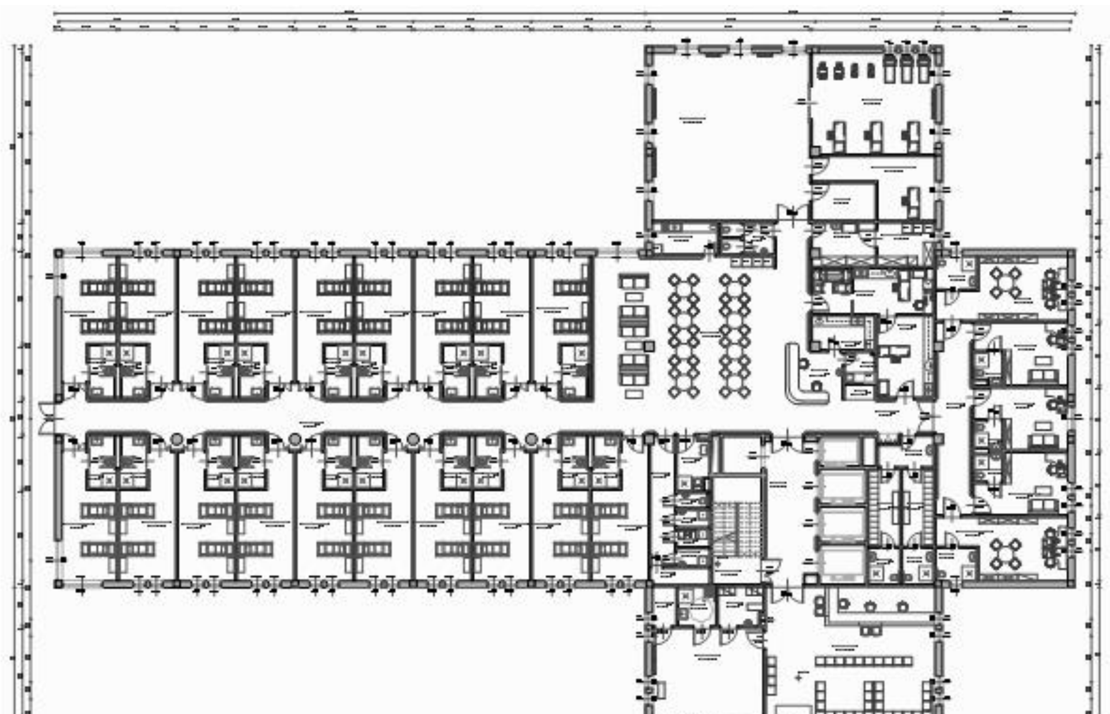
Using the equatopms of the FPTG I used only the speed values. The reason is that compared to the indicated 0.67 m/s avarage speed for disabled people which I measured an avarage speed of 0.65 m/s are shown only minimal differences.

For simulation A equations were applied manually, which means that the gap between the two methods were comparable with the same input parameters. The simulation result was 79.7 s, which is a bit less than the calculated 93.6 s. It's about ~15% reduction. Since in the model, extrusion did not occure, it's caused by the models calculated speed reduction method.

In the case of simulation versions the avarage values in the regulation and the distinction between healthy and disabled individuals evacuation version (Version A and D), the avarage evacuation time increased to 79.7 s and 183.9 s, which is more than twicefold increase. A difference of this magnitude justify to address the issue, because it can affect the safe use of the building.

In light of this, I recommend using in case of people with different excape capacity to use different movement speeds when planing and monitoring an evacuation. In current domestic regulations fireprotection regulation are only applied on special purpose building, so it's concrete useage is only possible this was, with keeping the current regulations, however only in these casese it can make this much of an impact on the evacuation time. In addition, in the existing domestic regulations I only see reason in using this in case of simulation, due to the low avarage speed used in the manual method.

ANNEX 1 - Architectural floor plan



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