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COMPARATIVE ANALYSIS OF EVACUATION CALCULATION AND PATHFINDER SIMULATION MODEL OF MULTISTORY PUBLIC BUILDING

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1. Introduction to Fire in Buildings

- *Statistics from USA indicate that on average 15700 fires reported each year on multistory building.*
  - ***53 lives*** - ***546 injuries*** ***- $ 235 million/year***

- *Multistory building < fatalities than low rise building. However, due to the possible high number of people involved **attention is turned** in this type of building which may cause a significant number of fatalities.*

- *To study the high-rise fire problem, researchers have carried out thorough analyzes of memorable incidents.*

- *The study was focused on the application of **hydraulic movement models** taking behavioral factors into account.*

1. Introduction to Fire in Buildings

- *Evacuation calculations are becoming gradually part of* ***performance-based analyzes*** *to evaluate the* ***level of safety*** *in buildings situations.*

- *Engineers use* ***hand calculations*** *and* ***computational evacuation models*** *to evaluate the safety of life.*

- ***Evacuation models*** *are often used as part of the* ***performance-based design approach*** *in the security design process.*

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2.1 Performance-Based Design in FS

- *The main concept of a performance-based approach is **not to fix solutions** but rather demonstrate that the **recommended design meets defined goals**.*

- *The performance-based design process begins with determining the **acceptable risk** for the building, its **systems** and the appropriate **levels of performance**.*

- *The basic **idea of acceptable risk** is the maximum level of **buildings' damage** that can be **tolerated** in connection with probability of a **realistic risk event**.*

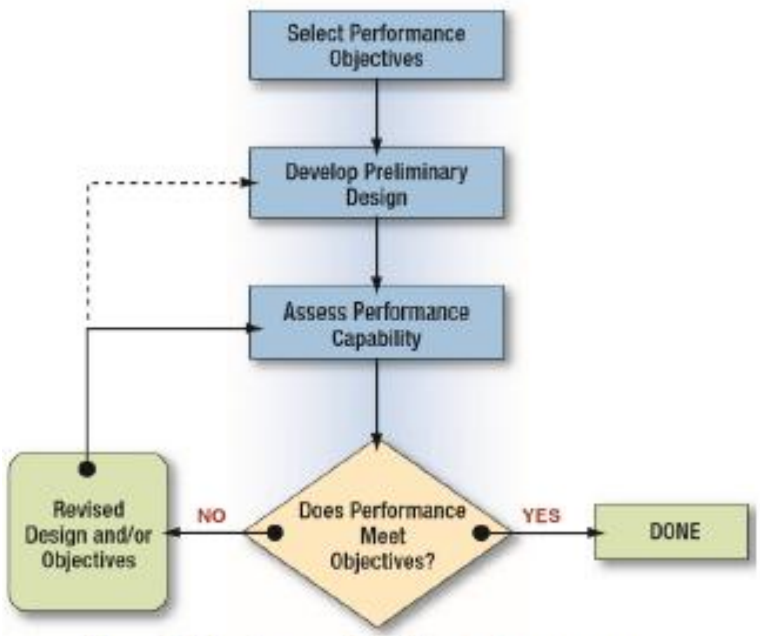

Figure 2. 1 Performance Base Design flow diagram. (International Code Council, 2009)

2.1 Performance-Based Design in FS

- ***Performance Based Design*** *requires to compute both* ***ASET*** *&* ***RSET****.*
- *The* ***Available Safe Egress Time (ASET)*** *is defined as the time when* ***fire-induced*** *conditions become* ***unsustainable*** *within an occupied space.*
- *The* ***Required Safe Egress Time (RSET)*** *is the amount of* ***time needed for occupants to evacuate*** *a building or space and reach the exterior of the building or a* ***protected exit*** *enclosure*
- *A candidate design is acceptable if the* ***ASET exceeds the RSET*** *after an appropriate safety factor has been applied*

$$RSET = \Delta t_{det} + \Delta t_{warm} + \Delta t_{pre} + \Delta t_{trav}$$

Where:

Δt_{det} ➔ Detection time is known as the time from **fire ignition to detection**

Δt_{warm} ➔ Alarm time is the time from **detection to notification**.

Δt_{pre} ➔ Pre-Evacuation time includes two periods, **recognition time** Δt_{rec} and **response time** Δt_{resp}

Δt_{trav} ➔ Travel time is known as the time needed for occupants to **evacuate to a safer place**.

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2.1 Performance-Based Design in FS

- ***Pre-Evacuation time*** *includes two time periods, recognition time “**Δt**rec” and response time “**Δt**resp”.*

- ***Recognition*** *is a period after an **alarm becomes apparent**, but **before the occupants start to respond**.*
- *The **response time** is a period after the occupants **recognize the alarm signals** and begin to respond to them, but **before the travel phase begins***

- ***Evacuation time*** *is the sum of the **pre-evacuation time** and **travel time**. Available **margin of safety** is the difference between the **ASET** and **RSET***

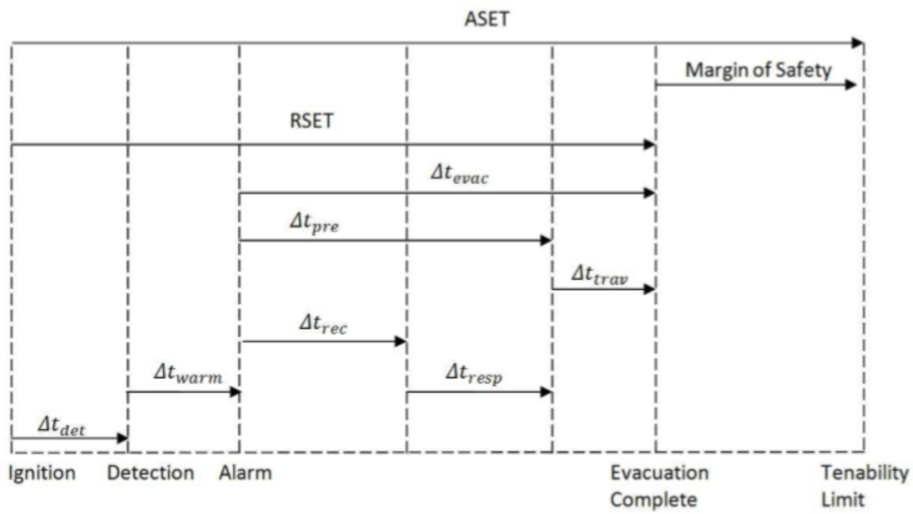

Figure 2. 2 Egress timeline. (ENRICO RONCHI, 2012)

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2.2 Prescriptive Approach in Fire Safety

- ***Prescriptive codes*** *are measurable and* ***rely on fixed values*** *arranged by the codes for achieving a* ***reasonable level of fire safety*** *as well as reasonable levels of safety from other hazards such as* ***earthquakes****,* ***floods*** *and* ***high winds****.*

- ***Prescriptive obligations*** *are based on wide* ***classifications of buildings and occupancies*** *and are usually indicated in* ***terms of fixed values*** *such as* ***distance travel****,* ***fire resistance****,* ***permissible area and height*** *and* ***structural design***

- *Obligations contained in prescriptive codes are* ***considered to be only the minimum*** *needed for protection of* ***public health****,* ***safety****, and* ***well-being****.*

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2.2 Prescriptive Approach in Fire Safety

- *By following the **guidelines of the prescriptive approach** documents, the **fire safety standard** required by **national codes** is often **achieved**.*

- *These include **general guidance for typical buildings** and usually include **evacuation**, **structural performance**, **fire containment** and **firefighting facilities**.*

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3. PathFinder Evacuation Model

- *In order to obtain a more **accurate evacuation** calculation or a more effective solution, engineers looked for **computer models** to help evaluate **key aspects of the life safety** characteristics of a building.*

- ***Pathfinder** is an **agent-based egress simulator** intended to satisfy the practical requirements of fire protection engineers working with **construction models** that are **increasingly complex**.*

- *The simulation model of **Pathfinder** takes advantage of **developments in motion** modelling based on **agent methods** that enable more **complicated actions and interactions** between occupants*

- ***Pathfinder** also offers opportunities for modelers to **generate simulation input** from current information and view outcomes using **high-quality visualization** methods.*

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3. PathFinder Evacuation Model

- *In **PathFinder**, each occupant has **individual characteristics**, **objectives** and **perceptions** and can take **different actions** based on that information.*

- *Such systems enable **realistic behavior to arise** as occupants **move** and **organize themselves***

- ***Pathfinder** uses a **triangulated mesh** to move occupants in constant **3D space**.*

- *This **motion mesh** provides **regions** where the occupants can walk, and **the triangulated geometry** enables it to **accommodate** with **excellent precision***

- ***Pathfinder** is a simulation software of **movement/partial behavior** and it uses two methods to model the process of evacuation, **SFPE mode & Steering Behavior mode**.*

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3. PathFinder Evacuation Model

- *The simplest degree of modelling sophistication is the use of the **hydraulic method** described in the SFPE handbook by Gwynne and Rosenbaum in which **analytical calculations** are used to calculate the RSET.*
- *This method permits the calculation of evacuation times using a series of expressions that **approximate human movements to a hydraulic flow**.*
- *The second method is an **agent-based model**, the Amor's redefined model of **steering behaviour**.*
- *Occupants are embodied as circles moving within a **continuous 2D** surface with triangles.*
- *The navigation system transfers occupants **along their courses** and makes it easy for each occupant to **interact** with the other occupants and the location.*

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3. PathFinder Evacuation Model

- ***Pathfinder*** *offers many ways to* ***create the mesh*** *needed from occupants in order to* ***move*** *or* ***escape*** *from fire. The mesh can be created:*
  - *directly using the* ***software drawing*** *instruments*
  - *users can* ***import geometry*** *from input files such as* ***DXF****,* ***PyroSim****, and* ***FDS***

- ***Pathfinder*** *involves a profile scheme that regulates* ***velocity****,* ***delay****,* ***size*** *and* ***appearance settings*** *for occupant organizations.*

- ***Specific exits*** *can also be appointed to the occupants.*

3. PathFinder Evacuation Model

*As it is seen in figure below, **Pathfinder** offers real-time output **3D visualization results**.*

Figure 3.1. 3D Visualization of occupants while they are leaving the hall. (C. Thornton R. O'Konski B. Hardeman & D. Swenson, 2011)

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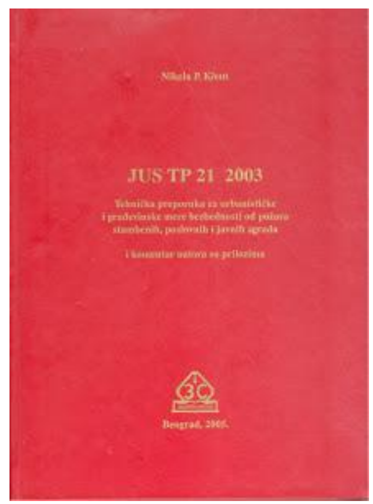
4. Serbian Standard of Fire “SRPS TP 21”

- ***SRPS TP 21***: *Technical recommendations for urban and civil engineering measures of fire safety for residential, commercial and public buildings.*

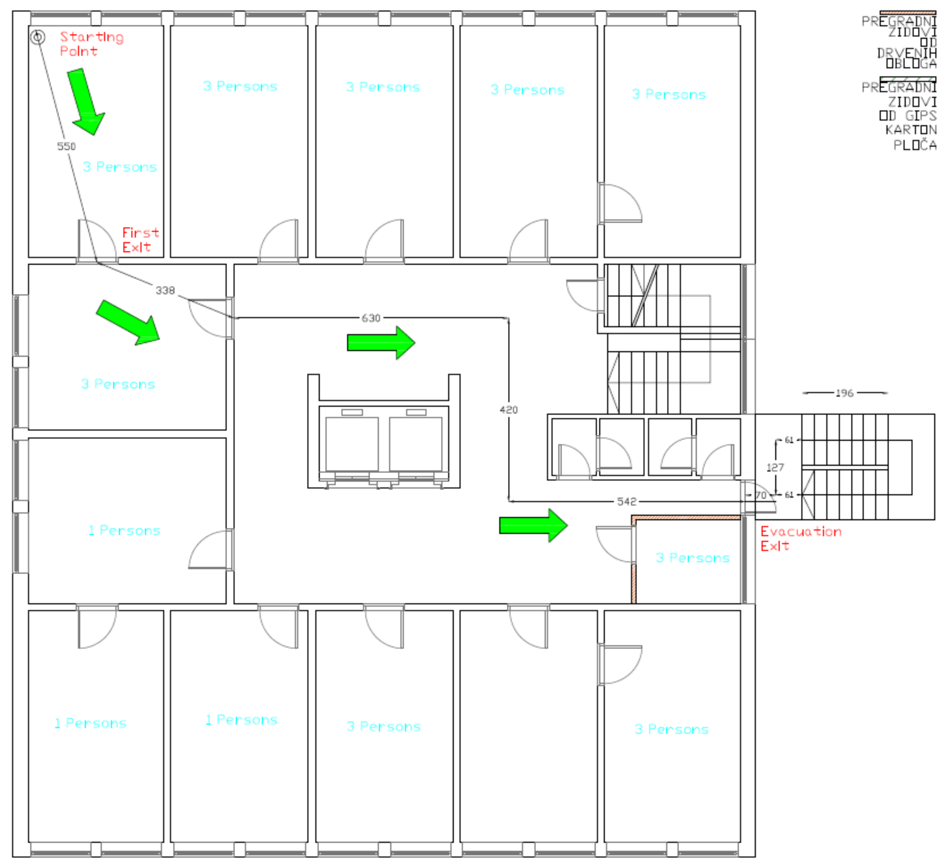
- *According to **SRPS-TP-21**, residential, public and office buildings should be **designed** and **built** to provide **safe evacuation** in the event of a fire.*



4. Serbian Standard of Fire “SRPS TP 21”

Terms of Standard Related to Evacuation

- *The Starting Point (SP)*
- *Safe Place (SPl)*
- *The Corridor Evacuation (CE)*
- *The First Exit (FE)*
- *The Evacuation Exit (EE)*
- *The Final Exit (FiE)*
- *Evacuation Speed (Ve)*
- *Total Evacuation time (te)*
- *Preparation Time for evacuation (tp)*
- *Time of evacuation (tk)*



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4. Serbian Standard of Fire “SRPS TP 21”

Evacuation Speed and other Parameters

- *The **design speed** of the undisturbed movement of a man on a flat floor is **Vo = 1.5 m/s**.*
- *The **projected velocity** of motion is the product of the velocity of unimpeded movement and the deceleration factors in.*

$$Ve = u * Vo$$

- u = 0.8 for moving down the stairs;

- u = 0.6 - 0.05d for movement along the staircase where d is the number of fictitious floors of 3 m

- *For each turn at an **angle greater than 30°,** and **lower than 60°** and a ramp, it takes **2s** for every **10 persons**. For each turn at an **angle greater than 60°,** a **lift** or **staircase**, an additional **5s** for every **10 persons**. For access to the **doors**, the project time of **3s** for every **10 persons** is added.*

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4. Serbian Standard of Fire “SRPS TP 21”

Evacuation Speed and other Parameters

Stage 1: Starting Point (SP) ➔First Exit (FE) (30s)

Stage 2: First Exit (FE) ➔ Evacuation Exit (EE) (60s)

Stage 3: Evacuation Exit (EE) ➔ Final Exit (FiE) (180s)

Stage 4: Final Exit (FiE) ➔ Safe Place (SPl)

Evacuation Time: $tk = tI + tII + tIII + tIV$

Total Evacuation Time: $te = tp + tk$

For residential buildings – tp=10min

For business buildings – tp=5min

For public buildings – tp=3min

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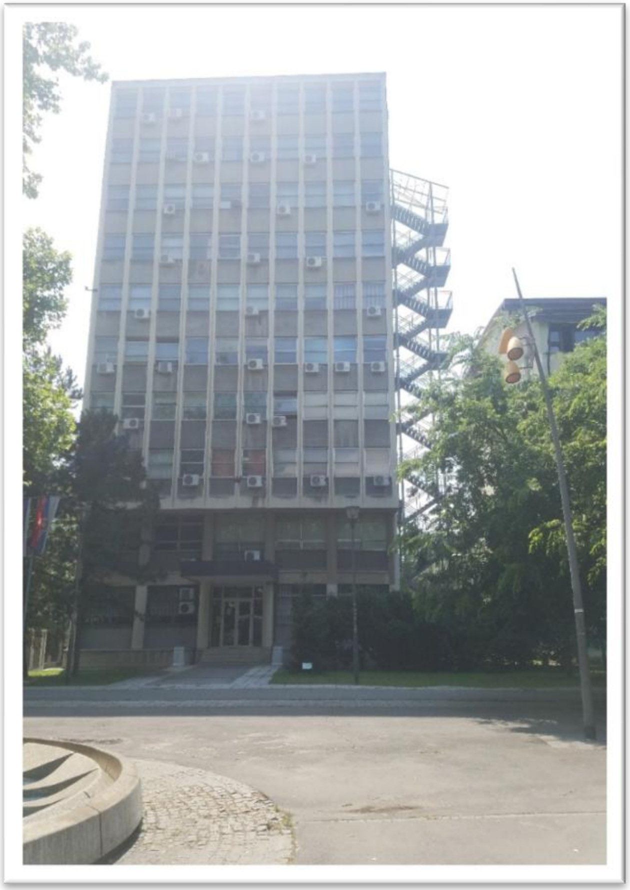
5. Case Study: Faculty of Technical Science “ Tower Building”

- *The **Faculty of Technical Sciences** is located in **Novi Sad, Serbia**, on the south-east side of the city, on Liman I, in the central part of the university campus. Building selected as a case study is “**Tower Building**” which is an administrative building.*
- ***Building** is designed for a total of **eleven floors** and approximately **28 meters** in height which makes this building to be categorized as a **multy-store building**.*
- *The building’s **floor height is 3 meters**, the surface of an individual floor is **275m2** and total area of the building is **3025m2**.*



5. Case Study: Faculty of Technical Science " Tower Building"

- *From **taken data's** the number of occupants per floor in building is provided in table below. There are **316 occupants** in total within the building.*

- *As you see they are distributed depending on the floor, the most populated floors are from first to fourth floor as there are main offices, some meeting rooms and conference rooms.*

Floors	Nr. Of Occupants
Basement Floor	3
Ground Floor	18
1st Floor	25
2nd Floor	30
3rd Floor	70
4th Floor	35
5th Floor	25
6th Floor	30
7th Floor	25
8th Floor	25
9th Floor	30

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6. Results & Comparative Analysis of both Calculations

Hand Calculation Cases I

*Hand calculations using Serbian Standard **SRPS TP 21** for **Case I** is composed into **two scenarios**.*

- ***Scenario 1** is the evacuation of **9^{th} – 2^{nd} floor** people through **external staircase**, there are **270 occupants** in total. Based on calculation these people take **52.2 minute** to evacuate.*
- ***Scenario 2** is the evacuation of **9^{th} floor** people through **external staircase**, there are **30 occupants** in total. Based on calculations these people take **14.3 minute** to evacuate.*

Analyse : *Analyzing the evacuation calculation of Case 1, it can be noticed that the **results are high** and **not real** due to some reasons:*

*- Serbian standard takes into consideration **too many factors** which effect directly the evacuation time. When number of occupants is higher also the evacuation time will be higher due to these factors.*

*- This standard considers **10 people as one group** and for each group is **added a factor** if they pass doors, stairs or turn at 60-90 degree.*

6. Results & Comparative Analysis of both Calculations

Hand Calculation Cases II

*Hand calculations using Serbian Standard **SRPS TP 21** for **Case II** has only **one scenario**.*

- ***Scenario 1** is the evacuation of **first**, **ground** and **underground floor** through **internal staircase**, there are **52 occupants** in total. Based on calculation these people take **5.5 minute** to evacuate.*

***Analyse** : Here we can observe that this standard is **mostly effective for small buildings** with small number of peoples. If we consider multistory building number of occupants will be higher and results will be unreal.*

Hand Calculations			
		No. of People	Evacuation Time (min)
Case 1	Scenario 1	270	52.2
	Scenario 2	30	14.3
Case2	Scenario 1	52	5.5

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6. Results & Comparative Analysis of both Calculations

Simulation Results Cases I

- ***Case 1** is considered as the **worst-case scenario** because some of occupants decide to **evacuate through internal stairs** even its **not allowed**.*

- *Even the results are approximately the same with Case II if this happen in real life it would be a problem because according to building users the area of internal stairs is not a refugee area since there is no isolation materials used while constructed.*

Simulation Results		
Mode	**Steering**	**SFPE**
Nr. Of Occupants	316	316
Evacuation Time (s)	317.1	362.8
Completion Times for All Occupants (s)		
Min:	7.2	6.1
Max:	317.1	362.8
Average:	151.8	166.9
Standart Deviation:	93.6	109.6
Travel Distances for All Occupants (m):		
Min:	9.2	8.5
Max:	143.4	87.5
Average:	68.6	49.8
StdDev:	30.7	17.8

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Simulation Results Cases II

- ***Case 2*** *is considered as the* ***best-case scenario*** *because all occupants evacuate through* ***external stairs****, as they pass the corridor and go to external stairs, they are safe.*
- *Occupants are obligated to follow the path of evacuation sending them directly to the outside staircases, and are* ***forced not to use internal*** *stairs of building.*
- ***Theoretically*** *the issue in this case would be* ***overcrowded area*** *at external stairs which makes the evacuation process harder for occupants but after simulation the results are approximately the same as in Case I*

Simulation Results		
Mode	**Steering**	**SFPE**
Nr. Of Occupants	316	316
Evacuation Time (s)	315.7	362.8
Completion Times for All Occupants (s)		
Min:	7.2	6.1
Max:	315.3	362.8
Average:	151.6	166.9
Standart Deviation:	93.3	109.6
Travel Distances for All Occupants (m):		
Min:	9.2	8.5
Max:	134.3	82.5
Average:	63.5	46.1
StdDev:	26.3	17.1

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6. Results & Comparative Analysis of both Calculations

Comparative analysis between hand calculation and simulation model

- *While we compare both methods **hand calculation** and **simulation model**, we came to conclusion that during a **fire event**, the time needed to evacuate all occupants in the building **depends on a number of factors**, some of which are **very hard to predict***

- *In order to have a more **realistic evacuation process** all engineers are trying to use the **evacuation models instead of hand calculation**, because model gives the opportunity to have more **realistic results**, create **many scenarios** and have a **great visualization**.*

6. Results & Comparative Analysis of both Calculations

Comparative analysis between hand calculation and simulation model

- ***Based on the scenarios** created in model engineers can define **adequate evacuation roots,** implement **fire protection measures** and organize **sessions with occupants** advising them regarding evacuation rules.*

Hand Calculations			
		No. of People	Evacuation Time (min)
Case 1	Scenario 1	270	**52.2**
	Scenario 2	30	**14.3**
Case2	Scenario 1	52	**5.5**

Simulation Results			
	Mode	**Steering**	**SFPE**
Case 1	Nr. Of Occupants	316	316
	Evacuation Time (min)	**5.3**	**6.0**
Case 2	Nr. Of Occupants	316	316
	Evacuation Time (min)	**5.3**	**6.0**

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7. Conclusions

As it is visible from the results in this paper, the ***two methods*** *evaluate the evacuation time for a building with* ***drastic differences****. The* ***Serbian Standard*** *is too* ***conservative****, as it calculates to many factors such as turns, stairs and doors and give them much higher values that they should have. The sum of these factors* ***increases drastically the total evacuation time****.*

From the results, we think that Serbian code should ***reduce*** *the* ***factor of turning*** *at outside staircase, because it's the part that increases mostly the evacuation time knowing that it is a refuge area.*

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7. Conclusions

*On the other hand, the results gained by using **Pathfinder Model** give way to **low evacuation time**. But still these results are **closer to reality** than the ones from Serbian Standard calculations.*

*Also this model has some **unreal measures**, for example while we are simulating in Path Finder **all occupants start to evacuate immediately at the same time**, in real life this will never happen because maybe some of the occupants in building didn't hear the alarm of fire or are they don't know that there is fire in building.*

***Software model** makes it possible to **detect critical points** such as places where there is a **deadlock**, **piling of people**, **speed** and **density** of occupants movement.*

7. Conclusions

*Another advantage of using software is the possibility to attach **different types of occupants** with variations in speed and it is possible to follow the particular person at any moment of evacuation.*

*Something that Path Finder and other simulation models **cannot do is prediction of human behavior**. There is no model that can predict what an occupant can do in case of a fire, **model just assume** what he gone do but this assumption is **not one hundred percent correctly**.*

*The **scope** and **precision** of the behavioral models are limited*

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Thank you
for your attention

Andi GJOÇI

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