FIRE SAFETY ENGINEERING: THE COMPUTATIONAL SIMULATION OF THE ESCAPE IN A HISTORIC BUILDING IN BOLOGNA

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ABSTRACT: *In the field of Fire Safety Engineering (FSE), virtual reality has increasingly assumed an important role, especially for the simulation of fire and escape.*

The present work aims at comparing the potential of virtual simulations of the escape of occupants in case of emergency to simulations based on traditional calculations. Above all, the goal is to highlight the greater adherence to reality of the simulations that use behavioural models compared to those that use hydraulic models.

Simulations are performed for the case study of a listed historic tower in Bologna city centre and calculate the Required Safe Escape Time (RSET) in various evacuation scenarios using the innovative Pathfinder® software which, in addition to using flow-based models, is "agent-based", as it manages the variables related to behavioural factors and can model complex escape scenarios faster than hand-made calculation.

Case study results show that RSET times calculated with the behavioural steering mode in the virtual environment are 15-19% higher than the hydraulic mode (SFPE) and therefore demonstrate that the Steering mode is more realistic, as human behaviour significantly influences the evacuation process.

Anyway, all the realistic simulations return safety margin times above 100% of the RSET as asked by national law, highlighting that it is possible to guarantee the safety of the occupants in a particular historical building using innovative Fire Safety Engineering (FSE) approaches, even if the prescriptive rules are not respected.

KEYWORDS: *FSE, Virtual reality, Emergency Escape, ASET/RSET.*

1. INTRODUCTION

Optimizing the fire prevention of a human activity means to identify technical solutions aimed at achieving three primary objectives: the protection of human life, the protection of assets and the protection of the environment. Therefore, in Fire Safety Engineering the chosen escape strategy, i.e., the one that ensures that the occupants can reach a safe location, independently or with assistance, before the fire causes incapacitating conditions, represents one of the most important and most complex designing strategies.

The international legislation as well as the Italian one is increasingly moving from a prescriptive approach (with defined rules to be strictly applied), towards a performance approach with Fire Safety Engineering (FSE) which better allows to deal with the most complex situations.

This new and innovative FSE approach is certainly more suitable for a specific assessment of the individual case under study, and it allows greater flexibility and gives greater autonomy and responsibility to the designer on the basis of rigorous scientific modelling.

Scientific modelling brings a new responsibility to be taken on by the designer and this requires a greater knowledge of FSE processes and having new modelling skills. Virtual reality becomes very important as the scientific-predictive simulation software of the movement of people during the escape manages to model complex escape scenarios and gives data output quickly and efficiently, therefore a better understanding of the phenomenon is achieved even if environmental and specific conditions vary.

The research work under this paper deals with the problem of escape in case of fire in listed historic buildings and in particular compares the results returned by an innovative simulation software with those obtained with other traditional calculation methods.

The case study concerns the museum part of a historic tower in Bologna, the eighteenth-century Astronomical “Specola” Tower, in Bologna, built inside Poggi Palace, which is a historic building listed since 1911. Simulations of the escape were carried out assuming different emergency evacuation scenarios using the Pathfinder® software.

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In the case of historic buildings, the second objective of fire prevention, i.e., the protection of assets, assumes particular importance and it can be said that among the most complex situations that a designer has to face there are certainly those of protected historic buildings. In these buildings it is very often difficult, or maybe even impossible, to comply with the safety requirements established by the fire regulations due to their particularity or uniqueness and to the constraints to which they are subjected, constraints that are of an artistic, historical, cultural nature and refer both to the building itself and to the context in which it is built. In many cases, the needed structural and MEP renovations could be unsustainable, both in terms of impact and in terms of cost. In fact, many time happens that the minimum dimensions prescribed by the regulations for escape routes are not respected (widths often less than 80 cm, heights less than 1.80 m), or the number of exits is inadequate, or the escape paths (unidirectional and otherwise) are too long, or it is impossible to build external stairs, and so on.

With these situations, for which it is impossible to apply the measures provided for by the national technical rules, it is allowed to turn to the Fire Safety Engineering method (FSE) as considered by the New Italian consolidated Fire Prevention Code (Decreto del Ministero dell'Interno - DM - 2015, 3 August, updated by DM 2019, 18 October) and as presented by the ISO international standards (ISO/TR 13387:1999). Therefore, the designer can use the FSE-based performance approach, which is aimed at the purpose of safety rather than at the rules to achieve it and can apply alternative solutions well-adapted to the specific case that create an equivalent safety level of performance.

Given to the complexity of the application rules of FSE, the support of an escape simulation software such as Pathfinder® is needed. The software application allows the translation of simulation constraints into quantitative values, which can be inserted within a mathematical model of evacuation. In this way, not only the physical and geometric aspects of the structure, but also the qualitative, behavioural and physical aspects of the occupants (children, elderly, disabled, with their own speed and specific decision-making processes, etc.) can be modelled.

2. METHODS

The case study concerns the Specola Tower Museum (Fig.1, 2, 3) which develops entirely inside the tower, from the fourth to the eighth floor (47 m altitude), while the first three floors are included in the structure of Poggi Palace (Fig.1 right). The work involved numerous inspections in collaboration with the museum managers to carry out all the necessary surveys including measurements and identification of all the components of fire safety system.

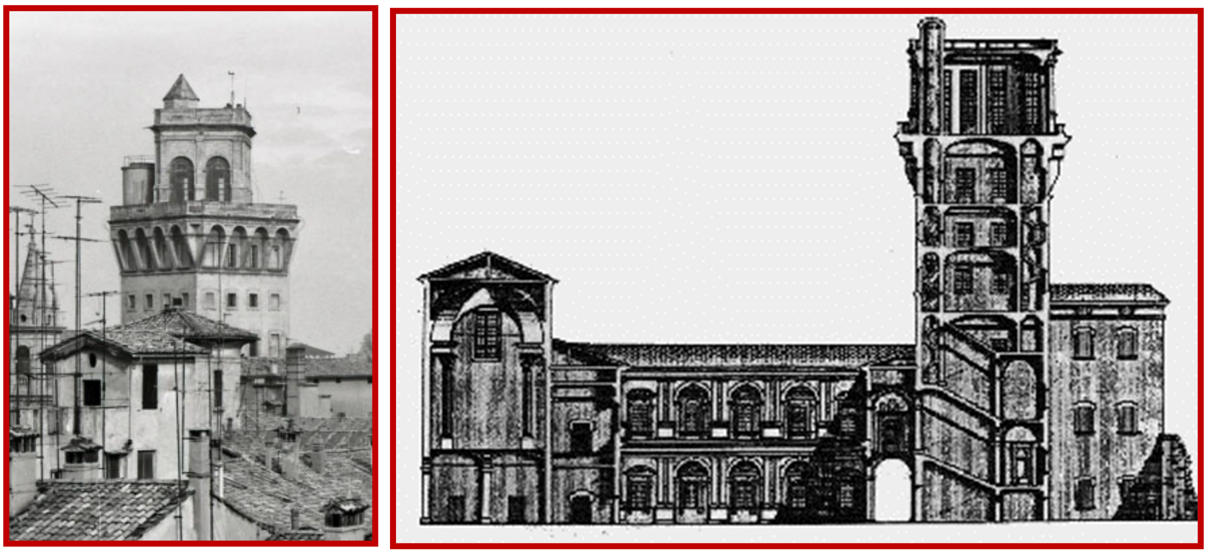

Fig. 1: Picture by Monti P. (1974) of the Specola tower (left) and an 18th century reproduction in section (right)

Fig. 2: Staircases: from the ground floor (left); access to the museum area from the 3rd to the 4th floor (right)

Fig. 3: Spiral staircase from the 4th to the 7th floor of the tower

2.1 The fire safety compliance solution in application of the rules

It should be noted that the New Italian consolidated Fire Prevention Code provides for rules valid for all human-based activities (the so-called “Regola Tecnica Orizzontale” RTO or "Horizontal Technical Rules") and specific rules for historic buildings (the “Regola Tecnica Verticale” or "Vertical Technical Rules" RTV10 and RTV12).

The analysis of the case study was based on the life risk profile, R_{vita} (given by the characteristics of the occupants and the rate of growth of the fire), as well as on the maximum crowding of each room of the structure. The designers found that the rigorous application of the compliance solution for evacuation was not possible, as the prescriptive rules of the Code (RTO) and of the RTV10 specific for museum activities in buildings subject to protection, were not all fulfilled.

• the heights and lengths of escape routes and dead-end corridors comply with the requirements.

• each floor is a specific fire compartment (there are two activities that are not pertinent to each other: museum and offices/services, which are not in separate compartments).

• the stairway area, with annexed landings and corridors, essential for emergency evacuation, is correctly compartmentalized and would constitute a temporary safe area; however, since it is a multi-storey building of considerable height (47 m), the standard requirement is that the current single compartment of the stairwell delimited by REI fire doors is divided into at least three compartments in order to be able to be considered as a temporary safe location (maximum 18 m for the RTV10).

• the width of some horizontal escape routes (Fig.4 on the left) is not compliant with the law (72-73-75 cm, while the limit is 80 cm for the RTV10) and also the width of the spiral staircases (Fig.4 on the right) from the fourth to the eighth floor is not compliant with the law (71-75 cm, while the limit is 80 cm for the RTV10).

• there is only one way out, which, although admitted, is problematic due to the physical characteristics of a part of it, being a spiral staircase, 5 floors long and rather narrow and steep.

compartment	R_{VITA}	width per person (mm/pers)	crowding (persons)	minimum width L_0 (mm)	minimum width (RTV10) (mm)	real width (mm)
4th floor	B2/B1/A2	4.1	36	147.6	800	730
5th floor	B2/B1/A2	4.1	22	90.2	800	820
6th floor	B1/A2	3.8	18	68.4	800	1070
7th floor	B2/B1	4.1	27	110.7	800	850
8th floor	B1	3.6	23	82.8	800	720

compartment	R_{VITA}	width per person (mm/pers)	crowding (persons)	minimum width L_V (mm)	minimum width (RTV10) (mm)	real width (mm)
stairwell (from 4th to ground floor)	B1	2.85	126	359.1	800	820
stairwell (from 5th to 4th floor)	B1	3.1	90	279	800	750
stairwell (from 6th to 5th floor)	B1	3.4	68	231.2	800	750
stairwell (from 7th to 6th floor)	B1	3.8	50	190	800	750
stairwell (from 8th to 7th floor)	B1	4.25	23	97.75	800	710

Fig. 4: Comparison between horizontal (left) / vertical (right) exit widths required by rules and those of the case study.

2.2 The alternative FSE-based solution in application of Section M (Fire Prevention Code)

As the compliance solution is not fully applicable, the designers have switched to the performance approach as proposed by FSE and an alternative solution, provided for by section M of the Code, was proposed to calculate the escape time.

By using the FSE-based performance approach, the designers can propose alternative design solutions that provide an equivalent fire safety level of performance and are sustainable both in terms of architectural and environmental impact and in economic terms.

The alternative solution involves comparing the Available Safe Escape Time (ASET), i.e. the time available for the escape guaranteed by the building, and the Required Safe Escape Time (RSET), i.e. the time actually taken by the occupants for the escape, from the moment the fire is triggered to the moment they reach a safe location to save themselves. The established engineering criterion is that ASET > RSET and that the difference between the two, i.e. the safety margin (t_{marg}), is greater than or equal to 10% of the RSET, and in any case not less than 30 seconds, in the event that the ASET derives from a reliable calculation (obtained by using fire simulation models such as FDS, for example, which is one of the most used software), or is greater than or equal to 100% of the RSET, otherwise. In the case study presented, the reference is the latter, because the ASET was not simulated, but data from examples relating to listed buildings taken from the literature were used.

To calculate the escape time, it is necessary to obtain the RSET time.

The international standard ISO/TR 16738 of 2009 (implemented in the Fire Prevention Code - Fig. 5) defines the RSET as the sum of 4 components:

$$RSET = t_{det} + t_a + t_{pre} + t_{tra}$$

where

t_{det} is the detection time
t_a is the alarm time
t_{pre} is the pre-travel activity time, PTAT
t_{tra} is the travel time

Of these 4 components, only the calculation of the movement time, Time of travel (T_{tra}), was carried out because the other 3 components of the RSET time are calculated with the European standard (ISO/TR 16738:2009) and were assumed equal respectively to: 60 seconds the T_{det} (*which is considered cautionary since in the museum there is the presence of an automatic fire detection and alarm system-IRAI*), 0 seconds the T_a (as there is an automatic *IRAI with optical-acoustic panels*) and 30 seconds the T_{pre}, which is a low value, because it is due to the *presence of awake occupants, without motor disabilities and trained guides who always accompany visitors to the Museum and who help them with wayfinding*.

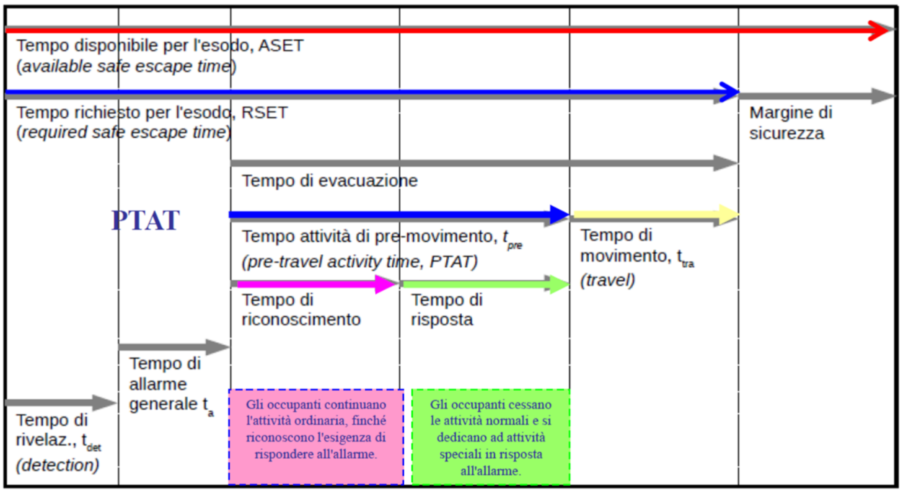

Fig.5 - Comparison between ASET and RSET (Illustration M.3-1 of the Code DM 2019, October 18, modified)

For the calculation of the movement time (t_{tra}) two alternative methods can be used:

1. *flow-based models (hydraulic): they are macroscopic models that represent people as a homogeneous group and in which the movement of the crowd is considered similar to the flow of a fluid.*
2. *ABM agent-based models (behavioural): they are microscopic models that take into account human behaviour, as well as movement, and in which the occupants are considered individually.*

2.3 Escape simulation software and Pathfinder®

Simulation software are essential for the development of behavioural models because they are able to manage a multiplicity of factors: technical, physical and geometric considerations are accompanied by many components connected to the human behaviour of the individual occupants.

These software have been categorized from each other by NIST - National Institute of Standards and Technology (E. Kuligowski, *et al*. 2010) based on the different characteristics: modelling method, model purpose, type of structure, model view of the occupants, behaviour of the occupants, type of movement of the occupants, ability to enter fire data, ability to import CAD data, visualization and validation methods.

The software chosen for the case study is Pathfinder® by Thunderhead Engineering, an agent-based simulator. In addition to being based on the hydraulic models that describe the movement, Pathfinder® manages the behavioural variables, describing complex behaviours and reciprocal interactions. Each occupant is defined by a set of parameters which determines its behaviour during the evacuation phase and the interactions with the other occupants. Pathfinder® is designed to simplify the input phase of the many information managed, but what is more important is that it has *a powerful 3D graphical interface that shows the filmed sequence of the virtual evacuation in a very realistic way.*

Pathfinder® uses a three-dimensional geometry model, however, for simulation purposes, the elements considered are only of the two-dimensional type, to reduce the calculation complexity. The Pathfinder® movement environment (3D continuous space model) is automatically transformed into a 2D navigation triangular mesh (represented by adjacent triangles) on which the occupants are free to move. The use of triangular meshes for the geometric representation allows the software to discretize even curved surfaces quite effectively. Obstacles (up to 1.8 meters away from the floor) are represented in the navigation mesh as empty spaces, which prevent the occupants from being able to move in spaces that house walls, furnishings, objects and therefore in fact they can only move on the navigation mesh. The navigation geometry is organized into irregularly shaped rooms, with boundaries that cannot be crossed by the occupants. The passage from one room to the adjacent one can be done through *connecting doors*. A door that does not connect two rooms and is placed on the outside boundary of one room is defined as an *exit door*. See Figure 6 as an example of a navigation mesh, where occupants are indicated with blue dots, doors with orange lines, and the exit door with a green line. Any mesh zone can be classified as one of four types: open space (room or ramp), staircase, connecting door and exit door, each with a different effect on the occupants' behaviour.

In the user interface, *each person can be assigned their own profile and behaviour*. The profile defines the fixed characteristics of the occupants (i.e., maximum speed, size, colour). The behaviour defines a series of actions that the occupant performs in the simulation (for example moving to a room, waiting time, exiting, route stops). Based on individual characteristics, each occupant makes autonomous decisions on which path to take. It is possible to define groups of occupants with the same behavioural properties who look for each other and who maintain a minimum distance between them (such as families, colleagues, students), associating them with a leader profile (for example a tour guide in a museum).

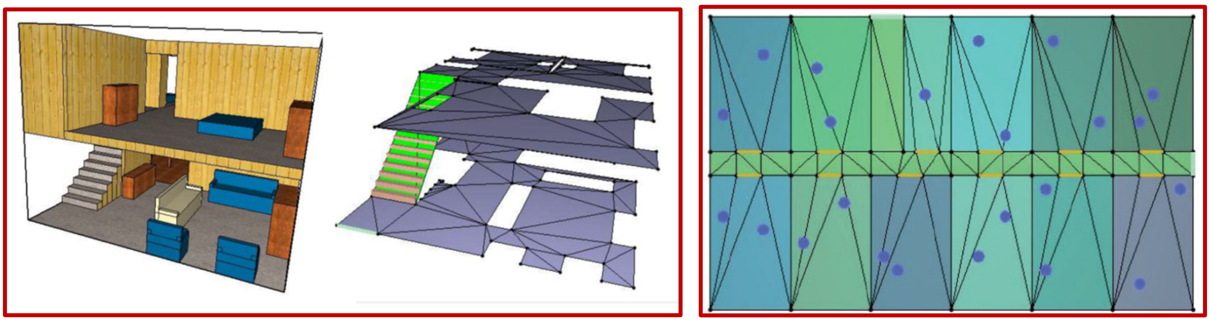

Fig. 6: Example of 3D geometry and related 2D navigation mesh with evidence of rooms, doors and exit doors (Pathfinder Technical Reference Manual, 2022)

Pathfinder® provides two modes of occupant movement simulation:

- *SFPE (hydraulic model)* which reproduces the concepts and calculations defined in the "SFPE Handbook of Fire Protection Engineering, 2016" and in the "SFPE Engineering Guide: Human Behavior in Fire, 2019" and considers the movement of the occupants as a flow model where walking speeds are determined by the density of occupants within each room and flow through doors is dictated by their width. In SFPE mode the occupants do not attempt to avoid each other but may overlap. The main parameters used in SFPE mode are the following: maximum occupant density for the room, effective width of the door (Boundary Layer), specific flow through the doors, movement speed of an occupant.

- *Steering (behavioural model)* which reproduces human behaviour and movement as much as possible and is based on the studies carried out for the first time by C. Reynolds ("Steering behaviours for autonomous characters - 1999"): through a combination of guidance and collision management mechanisms (with people, walls or objects), it allows each occupant to proceed towards his goal while avoiding other occupants and obstacles along the way, proceeding in lanes in the case of counter-current occupants, following other faster occupants, etc. The movements of each occupant in the different possible directions are evaluated and the optimized direction is then determined. The main parameters used in Steering mode are the following: maximum speed of each occupant, maximum acceleration and occupant density.

2.4 The calculation of the T_{tra} with Pathfinder® in the case study

Firstly, *hand calculation* for escape time computation was carried out with a hydraulic model and then Pathfinder® was used to develop the simulations in the two methods provided: SFPE and Steering.

The simulations were carried out to determine how the evacuation time varies according to the different hypothesized scenarios, which differ from each other in terms of the number of occupants, their type and their location.

The working procedure was as follows:

- Setting the geometric characteristics of the building by importing the *3D DWG files* into the software (Fig.7 on the left)
- creation of *5 occupant profiles* (guides, adults, elderly, children and staff) with specific characteristics (travel speed, shape, size, reduction factors, etc.). In Fig.7 on the right the input interface of the "child visitors"
- assignment of a *behaviour* (choice of exit, priority, initial delay, assistance to others, waiting for assistance, etc.) for each profile
- choice of *10 scenarios* (see list in Fig.9):
  - *5 "realistic" scenarios* with 28 occupants (different in type and location), of which 20 visitors admitted at the same time, 2 guides and 6 office workers (in Fig. 8 on the left, the simulation for scenario II in which the mixed visitors - children in yellow, adults in red, elderly people in green and guides in black - they are partly on the 8th floor and partly on the 7th and the office workers, in blue, are all on the 4th floor)

- *1 "theoretical*" scenario with 126 occupants, maximum occupant density admitted by Code (in Fig.8 on the right)
- *4 intermediate "theoretical" scenarios* (with 90, 74, 56 and 29 occupants)

- Calculation of T_{tra} for each simulation with analysis of the speed of the occupants and any critical situation.

10 simulations in Steering mode and 2 in SFPE mode were performed: Fig.9 shows the results obtained.

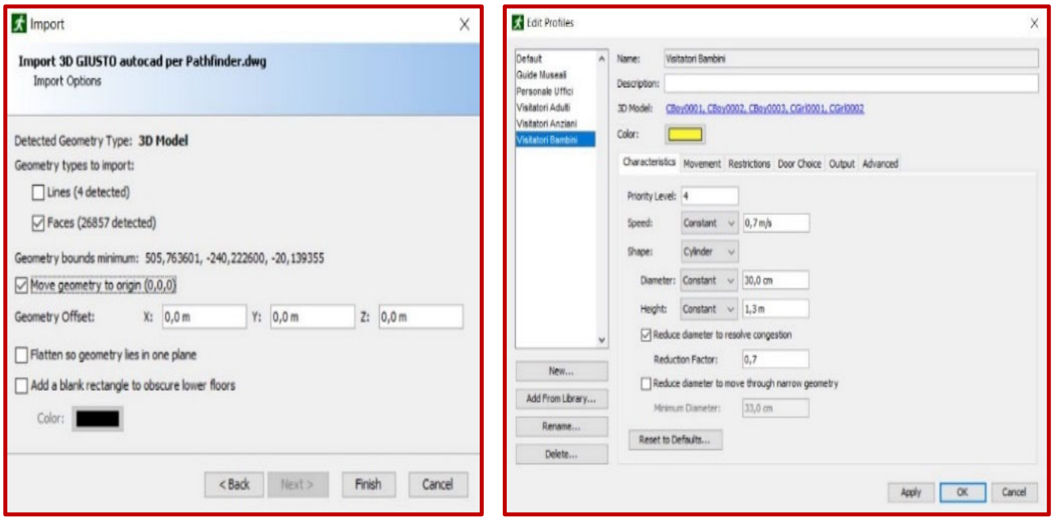

Fig. 7: Pathfinder® user interfaces for importing the 3D DWG file (on the left) and for the characterization of the "Child Visitors" occupants (on the right)

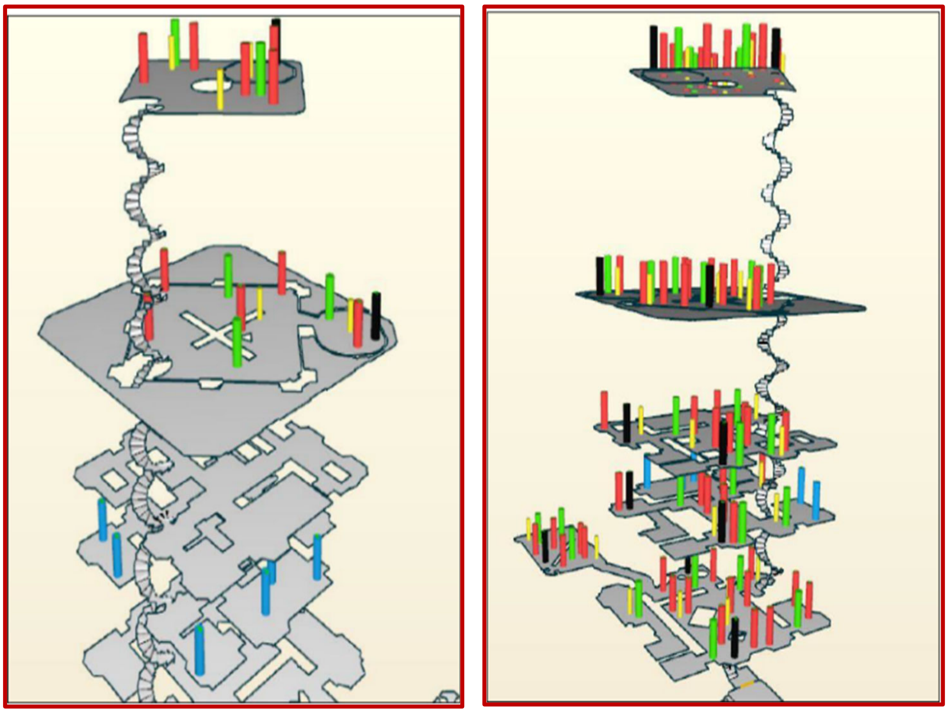

Fig. 8: View of the occupants in simulation II (mixed typology) and in VI (126 people)

The *main outputs* of the software consist of *realistic 3D graphic elaborations and 2D graphics* that allow to reproduce the evacuation and to analyze, even with video still images, any critical situation (queues, high density areas) and the speed of the occupants (see by way of example Fig. 11 and Fig. 12).

Particularly effective in terms of clarity for understanding the phenomenon are the video that reproduce the entire sequence of the evacuation with all its critical points in a very realistic way and with effective times.

scenario (Pathfinder "Steering")		total crowding (persons)	guides (persons)	adult visitors (persons)	elderly visitors (persons)	children visitors (persons)	office workers (persons)	pre-travel time (PTAT) (sec)	travel time (sec)	evacuation time (sec)	RSET (sec)
I	low crowding mixed typology visitors all on the 8th floor	28	2	10	5	5	6	30	272.5	302.5	362.5
II	low crowding mixed type visitors both on the 8th and 7th floors	28	2	10	5	5	6	30	264.5	294.5	354.5
III	low crowding mixed type visitors adults on the 8th floor, others on the 7th	28	2	10	5	5	6	30	241.3	271.3	331.3
IV	low crowding adults visitors only all on the 8th floor	28	2	20	0	0	6	30	219	249	309
V	low crowding children visitors only (or elderly only) all on the 8th floor	28	2	0	0	20	6	30	288.3	318.3	378.3
VI	high crowding mixed typology visitors in all floors (compliant solution)	126	11	55	27	27	6	30	366	396	456
VII	mixed typology visitors as scenario VI except 4th floor	90	8	38	19	19	6	30	355.5	385.5	445.5
VIII	mixed typology visitors as scenario VI except 4th and 5th floors	74	6	31	16	15	6	30	315.8	345.8	405.8
IX	mixed typology visitors as scenario VI except 4th, 5th and 6th floors	56	4	23	12	11	6	30	302.5	332.5	392.5
X	mixed typology visitors as scenario VI only 7th and 8th floor	29	2	11	5	5	6	30	275	305	365
hydraulic hand method	mixed typology visitors as scenario VI only 7th and 8th floor	28	2	10	5	5	6	30	184.3	214.3	274.3
Pathfinder "SFPE" (hydraulic)	mixed typology visitors as scenario VI adults only, 8th floor only	28	2	20	0	0	6	30	181.3	211.3	271.3
Pathfinder "SFPE" (hydraulic)	mixed typology visitors as scenario VI mixed typology on all floors	126	11	55	27	27	6	30	292	322	382

Fig. 9: Escape simulation times processed with Pathfinder® in the case study

3. RESULTS AND DISCUSSION

3.1 Effectiveness of the alternative solution in the case study

The calculations and simulations carried out demonstrate how it is possible to guarantee the safety of the occupants in a particular historical building using alternative measures, even if the prescriptive standards are not respected.

Therefore, it was possible to evaluate the efficiency of the design system and to show that the fire safety measures adopted in the case study are sufficient to guarantee an adequate level of protection of life and assets. All "realistic" simulations, in fact, return safety margins higher than 100% of the RSET time.

It must be said that concerning the case study, an historic tower museum, some important management fire protection measures have been adopted by the museum organization, that help to increase the safety margin, reducing the RSET:

- the non-simultaneity of the two activities carried out inside the building (museum and offices/services).
- the limitation of the maximum crowding of museum visitors, divided in no more than two groups (one for each of the two museum guides).
- the ineligibility of visitors with motor disabilities.
- the access of visitors only accompanied by properly trained guides, who lead people who otherwise would not be familiar with the place.

In addition to these safety measures, an important role is played by the preventive and protective measures adopted by law, i.e. the presence of an automatic fire detection and alarm system (IRAI); the entire active protection system for extinguishing the fire (fire extinguishers and internal fire hose reels) built in all the museum spaces; a clear signal that facilitates the wayfinding process; the compartmentation of the escape routes (staircases and corridors on the ground floor) open to the public, with the insertion of suitable REI fire doors; the limitation of the fire loads in these paths (because of this they can be considered as temporary safe locations). In consideration of the above fire protective measures, it can be said that the overall safety is excellent, as the horizontal paths in the various floors are very short.

However, as already mentioned, the ASET time taken as a reference would require a more precise calculation using fire simulation models, i.e., deterministic models based on the principles of physics and chemistry. For this reason, in this study, a safety margin equal to 100% of the RSET was always considered, as required by the international and local regulations. Furthermore, again to play on the safe side, not all the management fire protection measures mentioned above and actually adopted, were considered as present in the simulations.

3.2 Utility of the escape simulation software

The simulations (Fig.9) show that the movement time obtained with the SFPE mode (181.3 sec) is more or less equivalent with the one obtained with the hand calculation with the hydraulic model (184.3 sec). Therefore, using the software in SFPE mode, which uses the hydraulic model, there is no significant qualitative improvement of the results compared to the hand calculation, but only a greater computing speed.

The simulations carried out with the Steering (behavioural) mode, on the other hand, show a significant difference compared to the simulations in SFPE mode (hydraulic model). It emerges, in fact, that the calculated times are 15-19% higher than those of the SFPE mode. This occurs because the SFPE mode admits the physical overlapping of the occupants in the queues that form in the exits and does not properly consider the interactions between the occupants themselves, which makes this mode clearly less adherent to reality (see Fig.10).

Fig. 10: Occupant overlay at stair entrance using Pathfinder® SFPE mode

Furthermore, with the behavioural steering mode, some critical situations clearly emerge which strongly affect escape times. Queues are created in emergency escape and gatherings near the access sections from the floors to the stairs, i.e., at the intersection (so-called "converging nodes") between the evacuation flows of the occupants who come from the floors and those who come from the spiral staircases. This demonstrates how the Steering mode is much more realistic, as human behaviour significantly influences escape times. The Pathfinder® software has various ways of representing these critical situations. Firstly graphs with the progression of the evacuation (Fig. 11 on the left) and secondly the flow rates in the reduced access sections (Fig. 11 on the right); then the 3D graphic elaborations with crowding densities (Fig. 12 on the left) and the graphic elaborations that represent the so-called Level of Service (LoS), that is the criticalities in the queues, in the walkways, and in the movement on the stairs (Fig. 12 on the right).

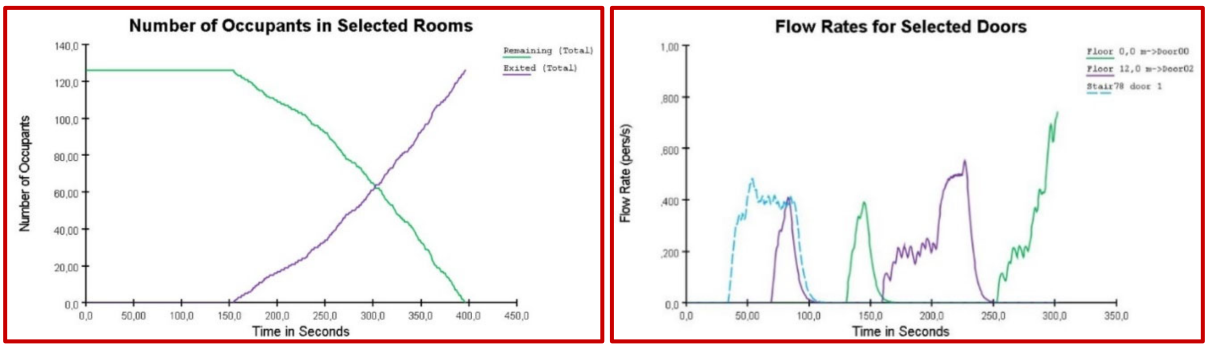

Fig. 11: escape simulation times in scenario VI (left); flow rates at the significant gates in scenario I (right)

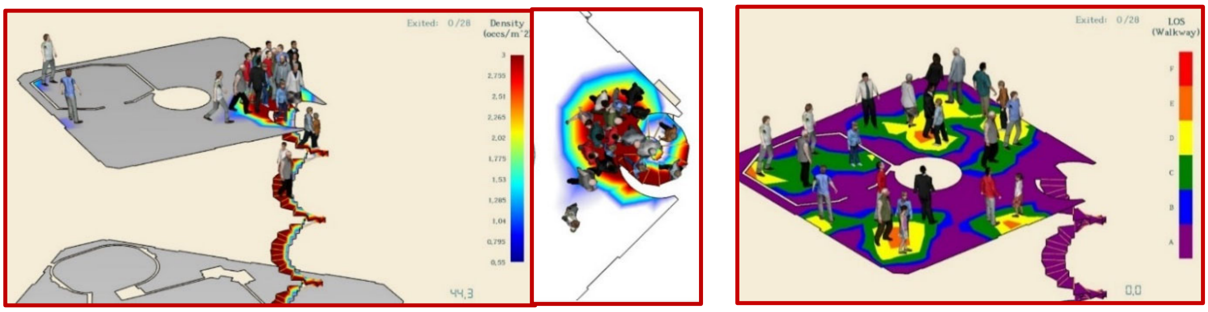

Fig. 12: Scenario I - on the left occupant density in the critical section of the stairwell at the exit of the 8th floor - on the right Service level (Walking LoS) in the most critical location on the 8th floor

These simulations also show that the presence of visitors with reduced travel speed (children and the elderly) strongly limits the evacuation from the building (times longer by about 30%, as shown by the comparison between scenarios IV and V - Fig.9).

Even the most critical simulation among the realistic ones (scenario V - school group of 20 children all on the 8th floor) appears to be in compliance with the prescription of the alternative solution of the FSE (safety margin must be greater than 100% of the RSET). The comparison of the assumed ASET and RSET gives as results the following equation:

$$ASET - RSET = 106\% \ RSET.$$

For the sake of completeness, an unrealistic hypothesis was also developed. This hypothesis foresees the maximum crowding allowed by the compliant solution, equal to 126 total occupants (scenario VI). In this case, due to the numerous queues and gatherings that are created above all on the 6th and 7th floors in the access door to the stairwell, the criterion provided for by the Code is not respected, but there is still a wide time margin:

$$ASET - RSET = 71\% \ RSET.$$

Another interesting evaluation uses simulations IX and X in order to estimate the maximum crowding which allows, with the assumed scenarios, compliance with the criterion t_{marg} = 100% • RSET = 390 seconds. The number of occupants is obtained by interpolation of the linear function referred to the two simulations IX and X and is equal to an estimate of 54 people (see the graph in Figure 13).

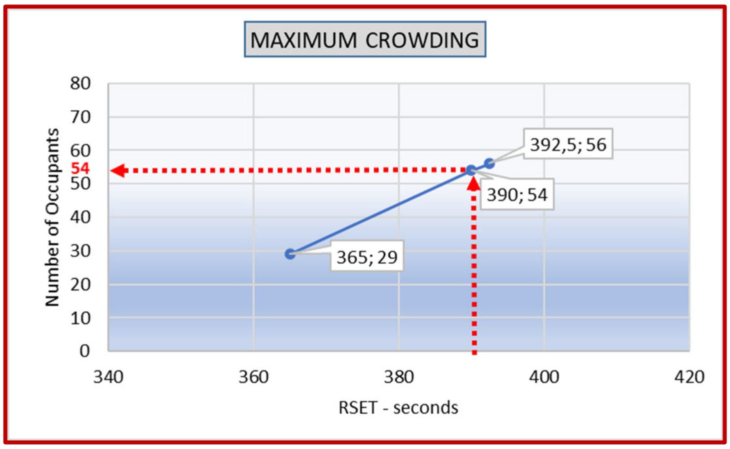

Fig. 13: Estimate of maximum crowding using the escape simulation times of scenarios IX and X

In Figure 14 there are two screen shots of the VI simulation with 126 occupants, taken from the video made with the simulation software, which shows the entire evacuation and gives an idea of the power of virtual representation of reality that Pathfinder® has.

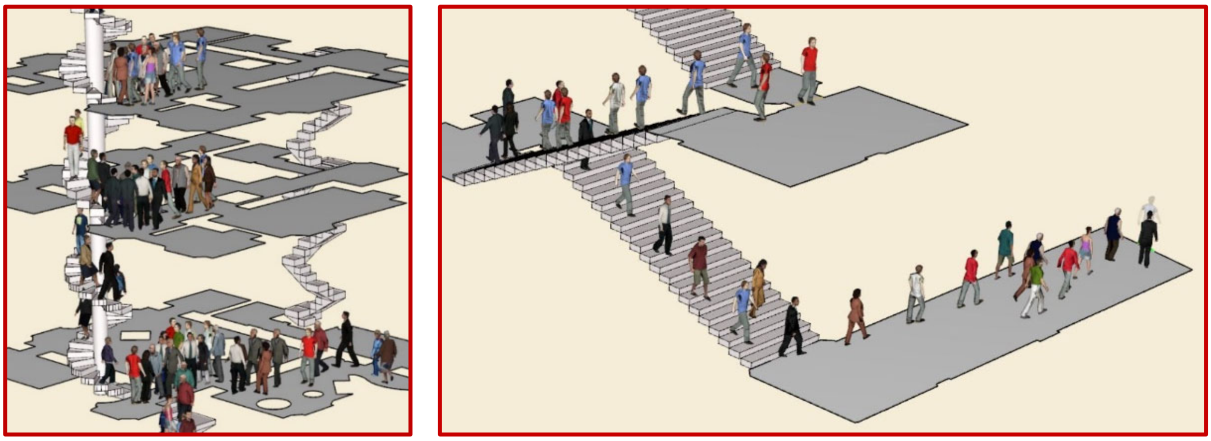

Fig. 14: Examples of 3D graphic visualization of the occupants in the escape simulations processed with Pathfinder® (Steering mode) in the case study

4. CONCLUSIONS

The most innovative escape virtual modelling software, such as Pathfinder®, are able to return high-quality results by means of video based visualization techniques that perfectly simulate reality and give an absolutely real perception of what can happen in the hypothesized situation. This software is used as a planning tool of the evacuation dynamics of an environment and allows to explore different evacuation cases and scenarios, varying the parameters of the simulation and the properties of the occupants. This makes possible to calculate the evacuation times in the various scenarios and to highlight the most critical ones.

The research work under this paper clearly shows hydraulic models are less in adherence to reality than behavioural models that are more reliable by using a scientific-predictive simulation software of the movement of people during the escape such as Pathfinder®.

Behavioural models are able to demonstrate how human behaviour significantly influences evacuation times and are able to give quantitative outputs, evaluated from a series of assigned parameters.

Due to their greater flexibility, these software bring out critical issues that otherwise could not be considered in the fire safety design phase, as for example delays in time due to congestion and queues in areas of restriction or intersection of multiple flows.

Anyway, the use of virtual simulation requires new skills and greater caution, as they are highly sensitive to some input parameters, but they contribute to a better understanding of the phenomena as they give quickly new results with the variation of the individual conditions.

Due to their characteristics, they can therefore also be of great use for simulating the evacuation of occupants in other emergency situations, such as earthquakes, terrorism or other cases in which people's safety is threatened.

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