INTELLIGENT EGRESS IN A HISTORICAL BUILDING

Matteo Pugnalin, Gianluigi Guidi, Monica Capobelli, Linda Caira

Guidi & Partners S.r.l.
Via Rigosa, 6
Zola Predosa, Bologna, 40069, Italy
web: www.guidiandpartners.com
e-mail: matteo.pugnalin@guidiandpartners.com

ABSTRACT

The “adaptive reuse” of the building heritage should be linked to an adequate response to needs of people who use the spaces itself, in terms of functionality. Since the historical buildings are protected sites it is often impossible to modify the internal layout in order to achieve the requirements imposed by the prescriptive rules. This paper aims to show the approach used to ensure the Life Safety in an Italian Villa that has been chosen to be reused as University building. The old ancient estate is spread out over 4 floors, connected by wide monumental stairs, and all the didactic activities will take place within the building (in classrooms, laboratories, study-rooms, common areas, etc.). Furthermore, the new furniture, that will be used in the building, will be supported by a certificate of European fire classification, in accordance with the Italian Guidelines. The main features of the performance based design, such as the choice of performance levels, the definition of fire scenarios and the analyses based on advanced thermo-fluid-dynamics will be presented in the following paper. In particular, an accurate analysis of the development of the fire and smoke spread has been performed using Fire Dynamics Simulator (FDS) 6.6.0. The analysis of the human wayfinding has led to develop new strategies for the evacuation in emergencies. In particular, the Intelligent Active Dynamic Signage System has been considered to redirect people, indicating the viable and non-viable exits, depending on the position of the fire source identified by the automatic detection system. These solutions have a low impact on the building since they do not need any layout modifications. In contrary to “passive” signage, “active” (intelligent) wayfinding systems monitor human egress process, spreading of the fire and damages to building, and suggests the best escape paths depending on these conditions.

INTRODUCTION

On the Italian national territory there are many historical buildings on which there are architectural constraints in order to preserve the historical heritage. Often many of these buildings are used for activities subject to fire prevention controls, according to national regulations.
The impossibility of adapting existing buildings to prescriptive standards often leads to the need for fire engineers to develop alternative solutions to ensure an adequate fire safety level, at least equivalent to that resulting from the application of prescriptive standards.
The application of fire safety engineering represents one of the possibilities to achieve safety objectives, designing a series of "tailor-made" measures to ensure the safety of the occupants and the preservation of architectural heritage.
Italian national legislation allows the use of fire safety engineering methods in application of national laws and international standards (ISO, NFPA, SFPE documents, etc.).
The achievement of fire safety objectives is thus no longer achieved by the punctual application of prescriptive standards, but by defining objective evaluation parameters in order to verify safety for the specific activity.

PROJECT DESCRIPTION

The project object of this study is related to a historic building, built in the sixteenth century, now used as one of the location of the University of Bologna. The building under analysis has historical restrictions given by national authorities because it has wooden ceilings with frescoes and valuable architectural elements (see Fig. 1). The changes allowed to adapt the building to the fire prevention regulations are limited and it is therefore impossible to apply the prescriptive standards.

Figure 1: Pictures of the historical building.

Building Description

The building is 4 floor tall (1 basement and 3 levels above ground); each floor has an area of about 1.200 m^2. The building is internally divided into various fire compartments.
The escape route system consists of 3 emergency staircases that lead to 7 final emergency exits directly overlooking open space (see Fig. 2).

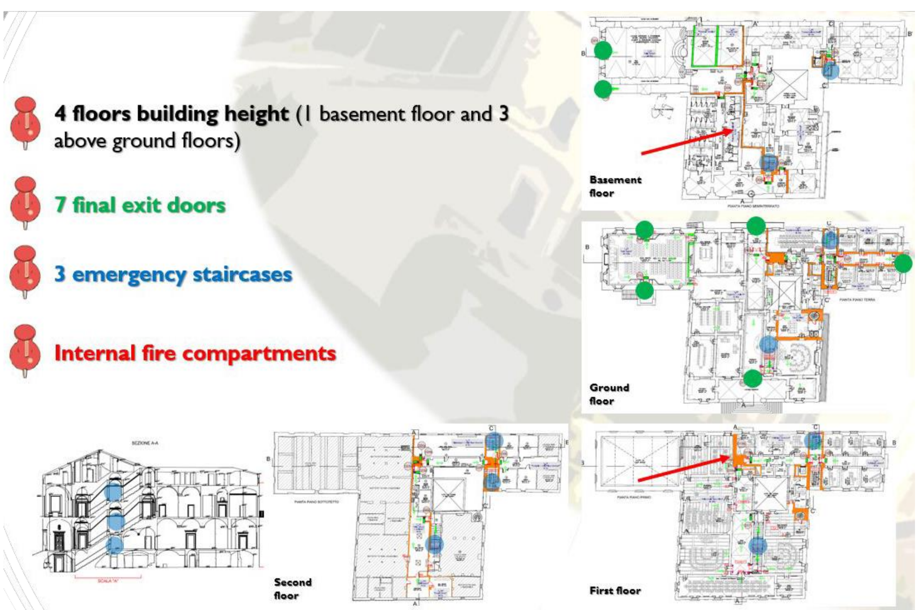


Figure 2: Building description.

Activity Description

The building is used as an international postgraduate school, attended by students from all over the world. Inside are present:

- classrooms,
- study halls,
- kitchen and dining halls,
- gym,
- administrative offices,
- meeting rooms.

Figure 3 shows the location of different activities inside the building

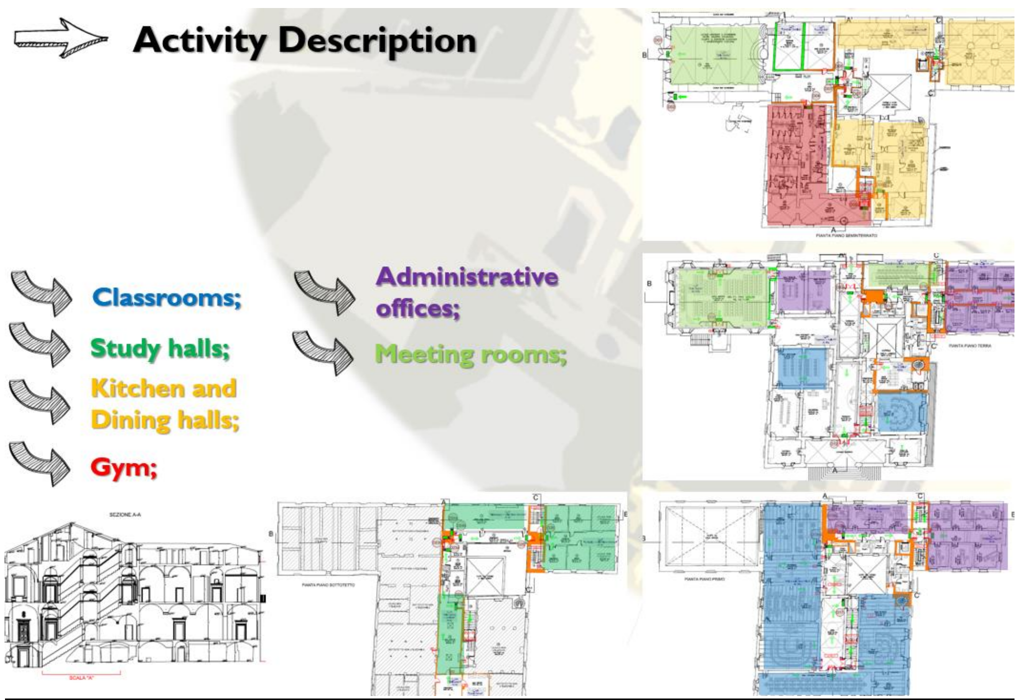


Figure 3: Activity description.

Occupants Description

The occupants of the activity are considered familiar (the courses last at least 6 months) and awake (there are no dormitories); according to ISO 16738 they have been classified as type "A".
The total crowding of the building was evaluated in maximum 250 people present at the same time (among students, teachers and service staff).
The presence of foreign students was considered in the development of the fire safety management system.

CRITICAL POINTS

The punctual application of the prescriptive standards requires that the escape stairs are of a protected type or that an external emergency staircase is built. The presence of historical constraints on the building does not allow interventions on the monumental staircase inside the building nor the realization of an external staircase that changes the aesthetic appearance of the building.
Moreover, the presence of frescoed ceilings does not allow the installation of a sprinkler system able to control a possible fire.

These considerations lead to the need to use a performance approach instead of the classic prescriptive approach.

FIRE SAFETY STRATEGY

The fire strategy followed in order to ensure the achievement of the safety objectives covered the following aspects:

- reduction of the combustible materials present and replacement, when possible, of existing furniture with new ones with fire reaction characteristics, in order to reduce the spread of fire growth;
- installation of fire doors in order to increase the fire compartments within the activity and reduce the spread of fire inside the building;
- development of a dynamic egress system (Intelligent Active Dynamic Signage System, IADSS), connected with the fire detection system, able to modify the signs and escape routes according to the position of the fire;
- analysis of the egress times in order to evaluate the RSET parameter, also taking into account the slowdowns due to the possible unavailability of some egress paths, based on the programming logic of the IADSS system;
- CFD analysis, conducted with the FDS software, in order to evaluate the time available for the exodus (ASET) of the occupants considering different fire scenarios;
- implementation of the fire safety management system in order to ensure compliance with the measures identified and the proper training of employees and occupants of the activity.

Intelligent Active Dynamic Signage System (IADSS)

Considering the impossibility of modifying the existing monumental scale, a dynamic egress system has been developed that can modify the emergency signs and vary the exodus routes. Figure 4 shows the logic of the system, in which the emergency signage, through different colors, modifies the escape routes according to the position of the fire. This system is able to prevent occupants from using unsafe escape routes due to the lack of compartments.

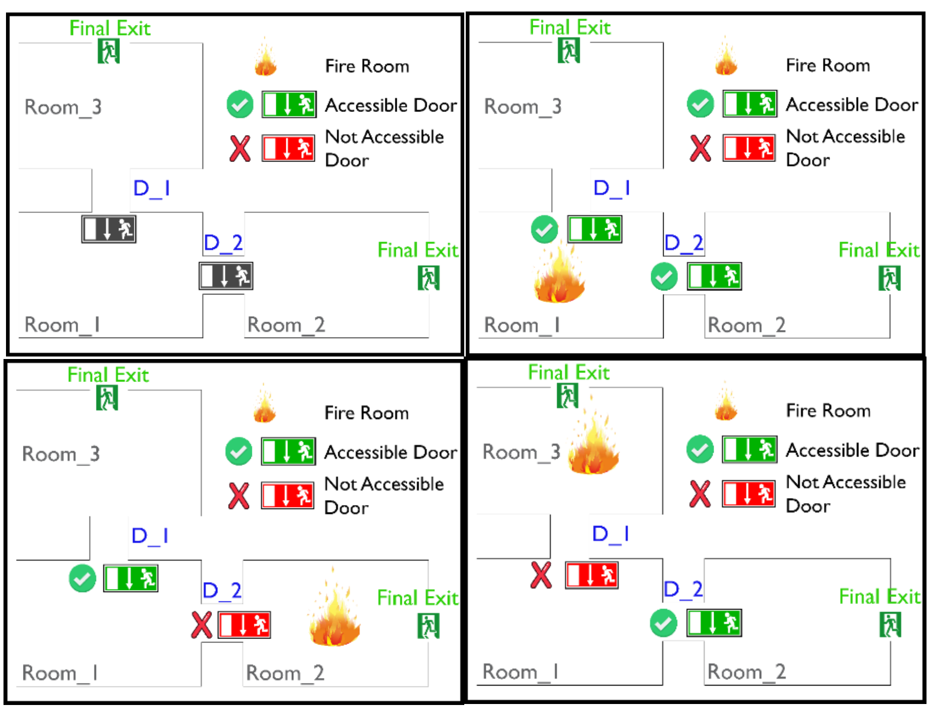


Figure 4: IADSS philosophy.

In order to program the system, a matrix has been developed in which the status of the emergency signage has been indicated according to the first trigger compartment. Figure 5 shows an excerpt from this matrix processed to define the programming logic of the IADSS system.

Compar. Fire Scenrio	C_01	C_02	C_03	C_04	C_05	C_06	C_07	C_08	C_09	C_10	C_11A	C_11B	C
Door signal	Emergency Signal Status												
D_01	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_02	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_03	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	
D_04	✗	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_05	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	
D_06	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	
D_07	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	
D_08	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	
D_09	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_12	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_14	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	
D_15	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	
D_16	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_17	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	
D_18a	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	[illegible]
D_18b	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_19a	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
D_19b	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	[illegible]
D_20	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

Figure 5: IADSS matrix.

Egress Time Evaluation

The study of the effectiveness of the IADSS system has been carried out starting from the evaluation of the egress times, considering the different fire scenarios and the consequent different egress paths. Particular attention was paid to the queuing times, due to some escape routes were not considered usable.

The calculation of the RSET (see Figure 6) was carried out according to the ISO TR 16738 standard, through the determination of the parameters that make up the value of the total evacuation time.

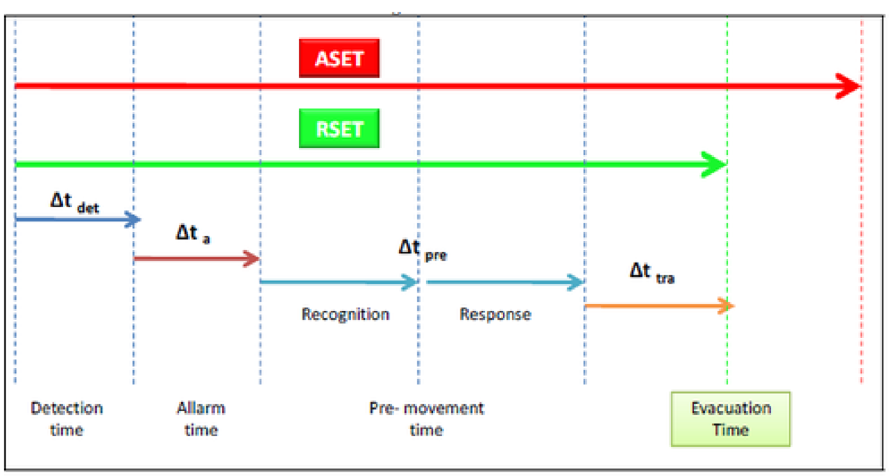


Figure 6: RSET scheme.

The calculation of the time of passage through the doors, due to the greater localized crowding, has been calculated with the formulas proposed by the ISO TR 16738 standard; table 1 shows an example of calculation of the passage time.

Table 1: Travel speed and time for passage calculation.

HORIZONTAL TRAVEL SPEED				
Area	A=	85,00	[m^2]	Note *Travel Speed*
People	p=	185	[p]	
People Density	D=	2,18	[p/m^2]	D > 3,8 --> 0
k factor	k=	1,40		0,54 ≤ D ≤ 3,8 --> S = k - akD
a factor	a=	0,266		D < 0,54 --> 1,19 m/s
Egress speed	S=	0,59	[m/s]	
MAXIMUM FLOW RATES				
Density	D=	2,35	[p/m^2]	Note *Flow Rate*
Egress Speed	S=	0,52	[m/s]	F_s = SD
Specific flow	F_s=	0,99	[p/m s]	D > 1,9 --> F_s = 1,9S D > 3,77 --> F_s = 0
TIME FOR PASSAGE				
Egress door widht	L=	0,80	[m]	Note *Time Passage*
Specific Flow	F_s=	0,99	[p/m s]	
People	p=	185	[p]	
Flow per time	F_c=	47,42	[p/min]	T_p = p / F_c
Time for passage	T_p=	3,90	[min]	
		235	[sec]	

For each of the four design fire scenarios determined following the fire risk assessment and the NFPA 101 guidelines, the specific RSET value was calculated (see Table 2).

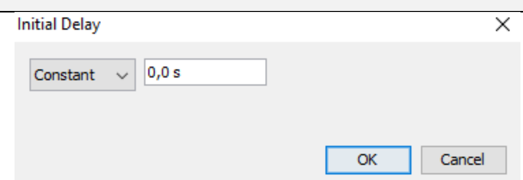
Table 2: RSET values for different fire scenarios.

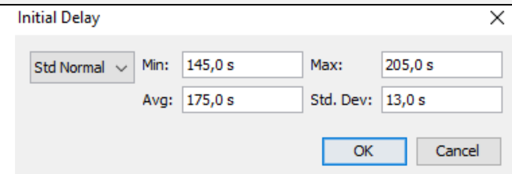
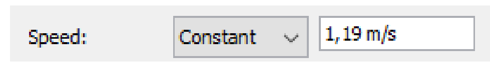
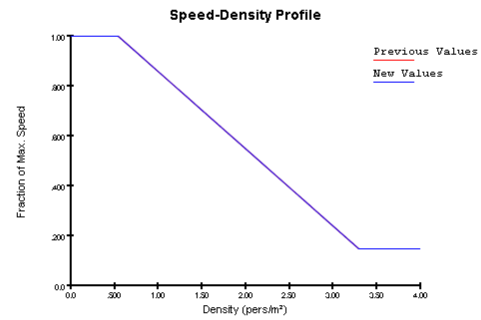
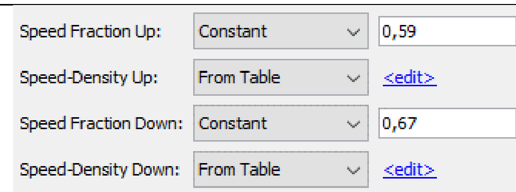
Design Fire Scenario	t_{det}	t_a	t_{pre}	t_{tra}	RSET	t_{marg} 10%RSET e ≥ 30s	RSET + t_{marg}
S_01	85 s	0 s	120 s	235 s	440 s	45 s	**485 s**
S_02	85 s	0 s	120 s	125s	330 s	35 s	**365 s**
S_03	85 s	0 s	120 s	125s	330 s	35 s	**365 s**
S_04	85 s	0 s	120 s	125s	330 s	35 s	**365 s**

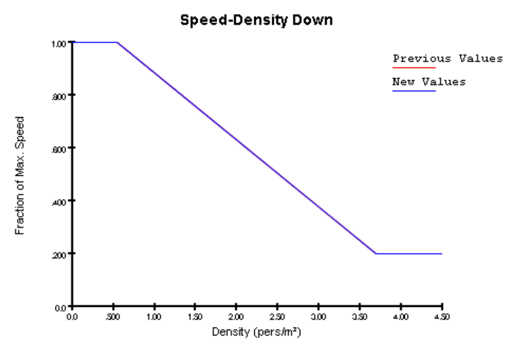
Pathfinder in-depth analysis

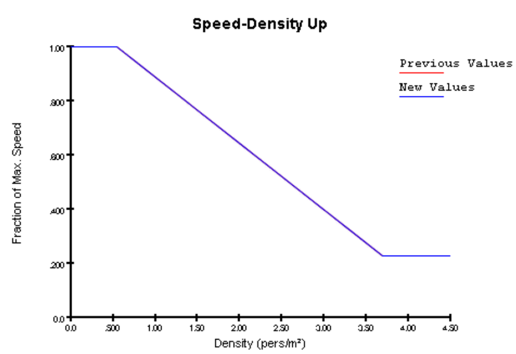
In order to validate the calculations carried out for the determination of the RSET, an in-depth study was carried out with the software Pathfinder, reconstructing the model of the building and simulating the egress in different design fire scenarios. Table 3 shows the input parameters used in the exodus simulation software.

Table 3: Pathfinder input data.

Parameter	Standard Reference	Pathfinder input data
Egress data		
t_{start} (fire room)	t = 0 s (according to AHJ)	

<table>
<tr><th>Parameter</th><th>Standard Reference</th><th>Pathfinder input data</th></tr>
<tr><td>t_{pre}</td><td><u>ISO TR 16738</u>
1° percentile: 60 s
99° percentile: 120 s
Normal distribution</td><td>
</td></tr>
<tr><td rowspan="4">t_{tra}</td><td><u>ISO TR 16738</u>
horizontal travel speed S_o = 1,19 m/s.</td><td>
</td></tr>
<tr><td><u>ISO TR 16738</u>
$S = k - akD$
con
➢ S = travel speed (m/s);
➢ D = people density (p/m²) with [0,54 ≤ D ≤ 3,8];
➢ k = 1,4;
➢ a = 0,266</td><td>
</td></tr>
<tr><td><u>ISO TR 16738</u>
Vertical travel speed:
➢ $S_{V,d}$ = 0,8 m/s = 0,67 S_0;
➢ $S_{V,u}$ = 0,7 m/s = 0,59 S_0.</td><td>
</td></tr>
<tr><td><u>ISO TR 16738</u>
$S = k - akD$
con
➢ S = travel speed (m/s);
➢ D = people density (p/m²) with [0,54 ≤ D ≤ 3,8];
➢ k = 1,0;
➢ a = 0,266

<table>
<tr><th colspan="2">Exit route element
mm</th><th>k</th></tr>
<tr><td colspan="2">Corridor, aisle, ramp, doorway</td><td>1.40</td></tr>
<tr><td>Riser
mm</td><td>Tread
mm</td><td></td></tr>
<tr><td>191</td><td>254</td><td>1.00</td></tr>
<tr><td>178</td><td>279</td><td>1.08</td></tr>
<tr><td>165</td><td>305</td><td>1.16</td></tr>
<tr><td>165</td><td>330</td><td>1.23</td></tr>
</table></td><td>


</td></tr>
</table>

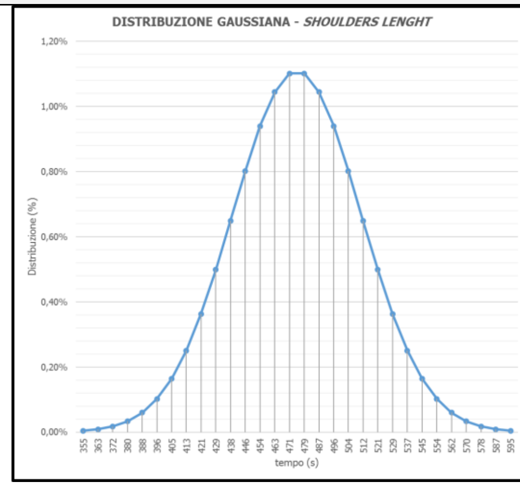
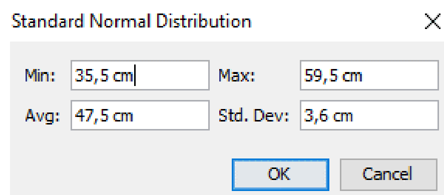
Parameter	Standard Reference	Pathfinder input data
Occupants Data		
SL **(*Shoulder Lenght*)**	**<u>University of Florence data</u>** 5° percentile = 417 mm 95° percentile = 533 mm che presenta una larghezza di 533 mm. Normal distribution	 

Figure 7 shows some screenshots of the fluid dynamics simulations performed for the different fire scenarios of the project.

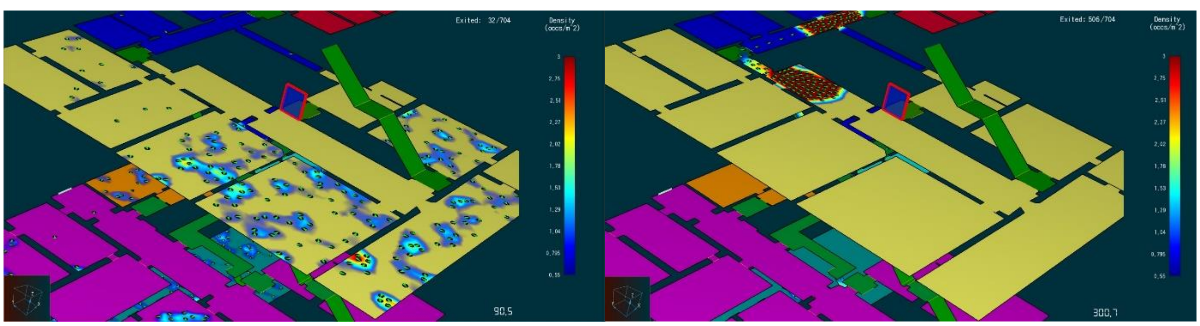


Figure 7: Pathfinder simulations.

Table 4 shows the comparison between the results of the RSET value calculated by ISO and Pathfinder; the hand calculations are more conservative, about 10%, and have been used as an element of verification of the achievement of fire safety objectives.

Table 4: Pathfinder and hand calculation data comparison.

FIRE SCENARIO	RSET (ISO TR 16738)	RSET (Pathfinder)	Δ
S_01	440 s	390 s	- 13%
S_02	330 s	290 s	- 14%
S_03	330 s	310 s	- 6%
S_04	330 s	320 s	- 3%

CFD Analysis

The determination of the ASET was conducted with CFD analysis using the software FDS. The evaluation parameters, in accordance with the national reference legislation, were the following:

- visibility level calculated at 2 m from the floor level;
- air temperature calculated at 2 m from the floor level;
- thermal radiation level (HRRPUA) at 2 m from the floor level;
- air toxicity level (FED).

For each of the above listed parameters a threshold value has been assigned, according to the Italian reference standard.

The evaluation of the results of each simulation has led to the determination of the specific ASET of each specified quantity; we report, as an example, Figure 8 with the results related to the visibility of a scenario considered.

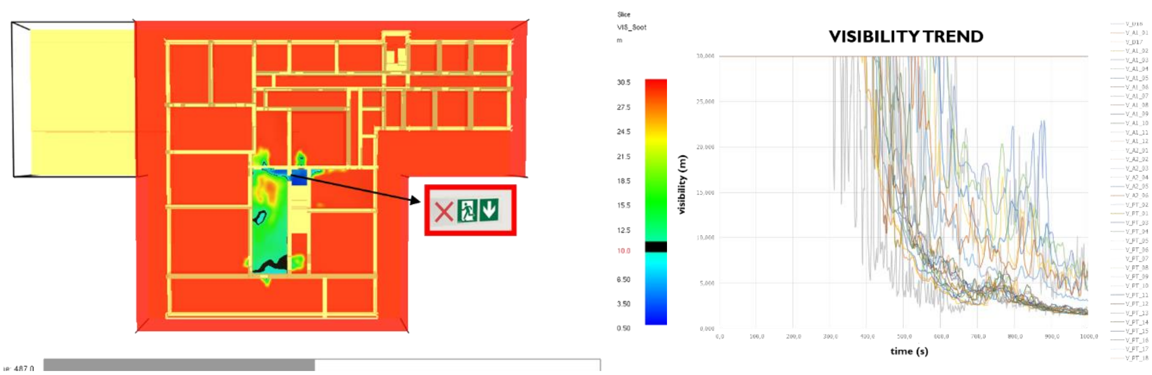


Figure 8: CFD simulations output.

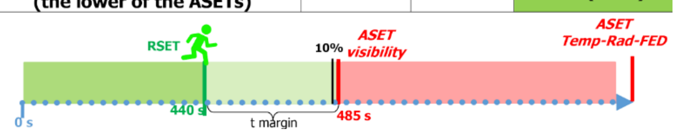
Results

The comparison of ASET with RSET, carried out for each fire scenario, has led to evaluate the fire safety of the developed system, also taking into account an appropriate safety coefficient required by Italian regulations.

Table 5 shows the comparison, for a project fire scenario, of the results obtained.

Table 5: ASET/RSET comparison.

FIRE SCENARIO S_01				
Criterion	**Level**	**ASET (s)**	**RSET (s)**	**t_{marg} (s)**
Visibility	10 m @ 2 m	485 s	**440 s**	45 s (10%)
Temperature	60 °C @ 2 m	**> 1000 s**		>560 s (> 127%)
Radiation	2,5 kW/m^2 @ 2 m	**> 1000 s**		>560 s (> 127%)
FED	0,1 @ 2 m	**> 1000 s**		>560 s (> 127%)
Total ASET (the lower of the ASETs)		**485 s**	**440 s**	**45 s (10%)**



CONCLUSION

The performance based approach has led to the development of a fire strategy to ensure the achievement of safety requirements for the activity analyzed. The IADSS system, modifying the egress paths according to different fire scenarios, ensures that the occupants use paths free from smoke and combustion products. It is important to underline that this type of system requires detailed planning and training of all occupants; therefore, it cannot ignore a development of the fire safety management system that guarantees the maintenance of the project conditions.

The interventions on the furniture and materials present affect the fire growth and also the production of smoke and combustion products, increasing the time available for a safe egress (ASET). CFD simulations have allowed a quantitative evaluation of the time available for the exodus, demonstrating the achievement of safety objectives.
The study conducted allowed to limit the architectural interventions on the building, without reducing the safety level. The preservation of human life combined with the preservation of assets is one of the major challenges for fire engineers, especially in areas where historic buildings are present pier.

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