THE USE OF NUMERICAL SIMULATION TO PLAN A MASS EVENT DURING PANDEMIC

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ABSTRACT

The paper describes the analysis developed for the ATP finals event in Turin during November 2021. The event has been organized under Covid-19 restrictions on the basis of Italian regulations. Numerical simulations (CFD and pedestrian analyses) were used to support the safety plan.

CFD analysis has been performed to evaluate how to use the mechanical ventilation (air change) to dilute a generic concentration that represents the potential viral load produced by people in the indoor arena.

Crowd analysis has been performed to evaluate the people behavior during the phase of ingress and egress. In this case the calculation domain includes the indoor sporting arena that can host up to 12000 people and the outdoor sponsor village. Queue time and density have been monitored to compare alternative design solutions regarding the number of gates, in particular in the entrance phase.

The critical points of these analyses were the external gates where gatherings were most likely to happen during the ingress, due to the checking points for the EU Digital COVID Certificate, and during the egress, because of the simultaneous exit from the whole arena.

The ingress and the ordinary egress simulations considered the social distance according to the guidelines of the Italian scientific committee and World Health Organization.

INTRODUCTION

Concentrations of large amounts of people (crowds) form every day in cities at rush hour or around events of different natures. These events have high concentrations of people that must be handled properly to minimize their exposure to any hazard. Crowd management is the discipline in charge of handling these events, through systematic planning and supervising the formations of gatherings and the organized movement of the crowds [1].

Crowd management in the literature is applied to a wide range of mass gatherings:

- As religious gatherings, including Muslim pilgrimages to Mecca [2], where mobile apps and Electronic bracelets are proposed to help the organizers and the pilgrims reach their goals and stay close to their groups, and a catholic papal mass [3], where simulations are used to reduce the waiting time to access into the event.
- Also, entertainment events as the carnival celebration at Ivrea in Italy [4], where simulations were used to reproduce the normal behavior of tourists into an old town streets and festival, and then the evacuation of squares in the case of an emergency, and music festivals [5], where the evacuation of up to 65000 persons was simulated in the case of fires or bomb alerts.

- And sports events, as in [6], where the whole process of the crowd management in a college football event is analyzed with an app as the way to obtain information and react to the crowd movements.

Regardless of the kind of gathering that is analyzed the risks that are associated to mass gatherings can be classified in three groups:

- human stampedes, impulsive mass movements of a crowd that result in subjects injured or deceased [7]. Some examples are the Torino stampede in 2017 (panic in a mass gathering in a square, after the shooting of pepper spray), the Astroworld festival stampede in 2021 (caused by violent behavior of a crowd around a concert venue), among others;
- Terrorist attacks, Violent acts committed by individuals who are associated with terrorist organizations or to further ideological beliefs [8]. Some examples are the shootings as the ones of Buffalo 2022, or the attack in las ramblas, Barcelona in 2017;
- Illnesses and diseases, related to the exacerbation of underlying medical conditions, the outbreak of airborne, water-borne or food diseases, among others.

Out of these three, in the last years the interest associated to the illness propagation during mass gatherings has increased due to the world-wide sanitary and economic crisis caused by COVID-19 [9], resulting in more measures to minimize the spread of the disease among people present in a mass event.

Specifically, during November of 2021, the COVID-19 restrictions enforced in Italy were:

- the EU Digital COVID Certificate was compulsory to enter any public event. A certification obtained after getting the two doses of the COVID vaccine or making a COVID test in the last 48 or 72 hours. The certification has a QR code to ease the verification process;
- using a mask was obligatory inside closed venues.

The event considered in this analysis is the Nitto ATP finals, that was realized in the Pala Alpitour in Turin. The event was composed of 15 sessions of games distributed from the 13th to the 21st of November. The goal of the analysis was to guarantee a smooth flow of the spectators during the ingress and egress phases of the event, with a focus also in the safety of the participants regarding COVID contagion.

In this sense the fluent flow of people had to be guaranteed during:

- the queuing towards the ingress doors, specific to every sector of the venue;
- the admission control, where both the ticket and green pass had to be checked;
- the egress phase, reducing the accumulation of people towards the exits.

And the safety had to be guaranteed by:

- minimizing the queue time inside areas with a high density of spectators;
- minimizing the time during which two spectators where at less than 1m of distance during ingress or egress;
- evaluating the risk of contagion among the spectators while they are in the stadium seats.

CASE STUDY

Description of the site

The site of the event consisted in:

- an indoor arena divided in 4 sectors (A, B, C, D);

- a safety ring between the arena and the outdoor village;
- the outdoor sponsors village where the access gates are placed.

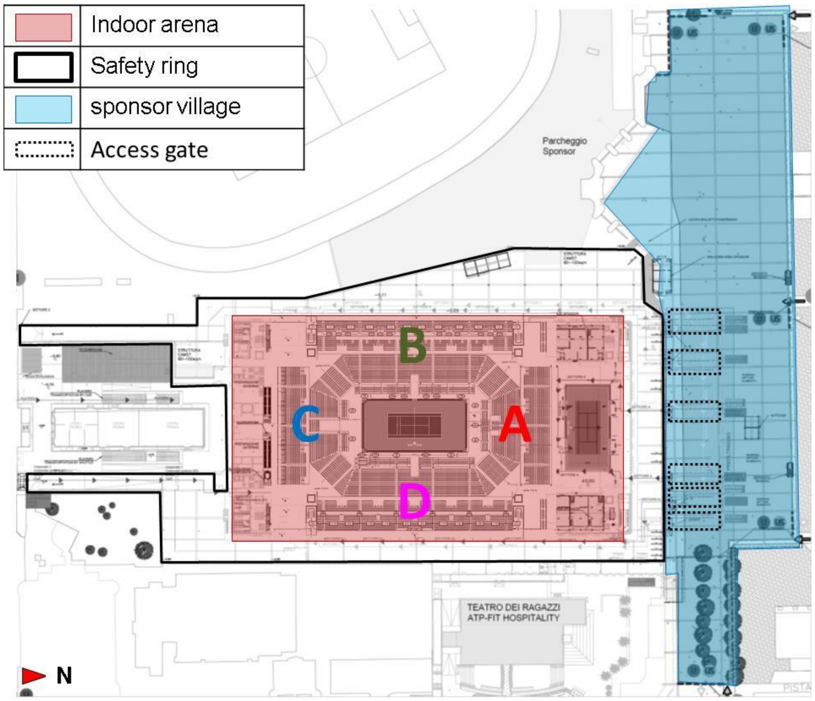


Figure 1: site event plan view

Arena capacity

The capacity of the arena is 12246 seats. Due to the constraints dictated by the Covid-19 health emergency it was necessary to reduce the capacity of the arena to guarantee the safety of the people.

In Table 1 are reported the values of full and reduced capacity considered in the analysis for each sector.

Table 1 Total seat at full and reduced capacity

	Seats available per sector				Total seats available
Capacity	A	B	C	D	
100%	2511	3719	2016	4000	12246
75%	1883	2789	1512	3000	9184

The event

The event lasted 8 days, each day was divided in two sessions:

- session 1: afternoon session started at 11.30 a.m. with the gates opening at 10 a.m.
- session 2: evening session started at 6.30 p.m. with the gates opening at 5 p.m.

Ingress

Figure 2 shows the access gates and the paths to the seats for each sector.

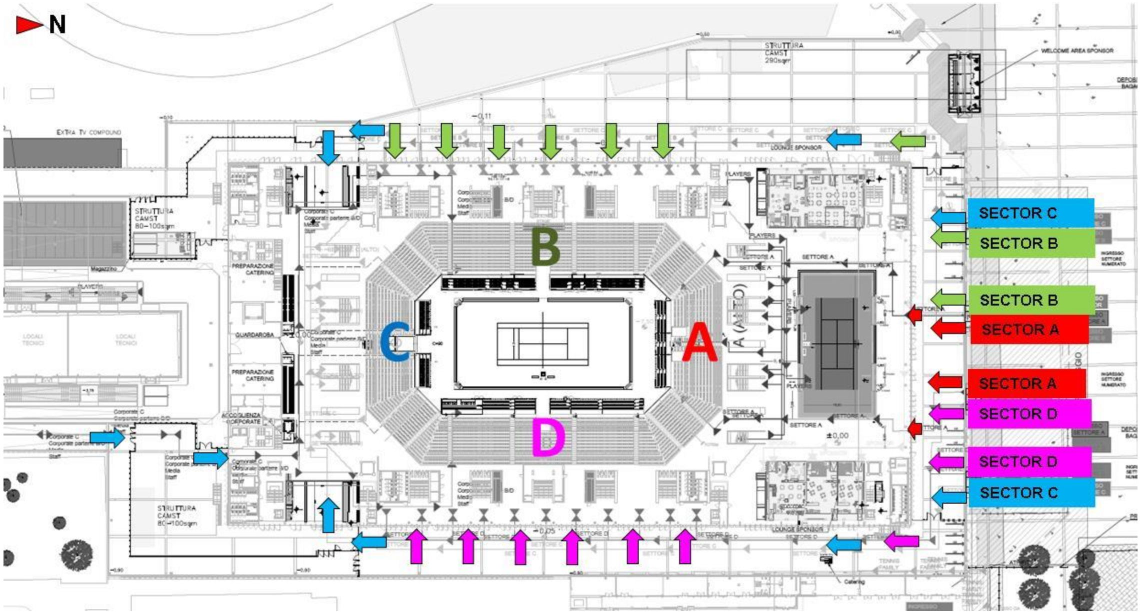


Figure 2: ingress paths

At the access gates a checking point verified the validity of the EU Digital COVID Certificate. The verification was carried out by 4 people in each gate. The curve of expected arrivals to the gates was provided by the organizing committee (Figure 3).

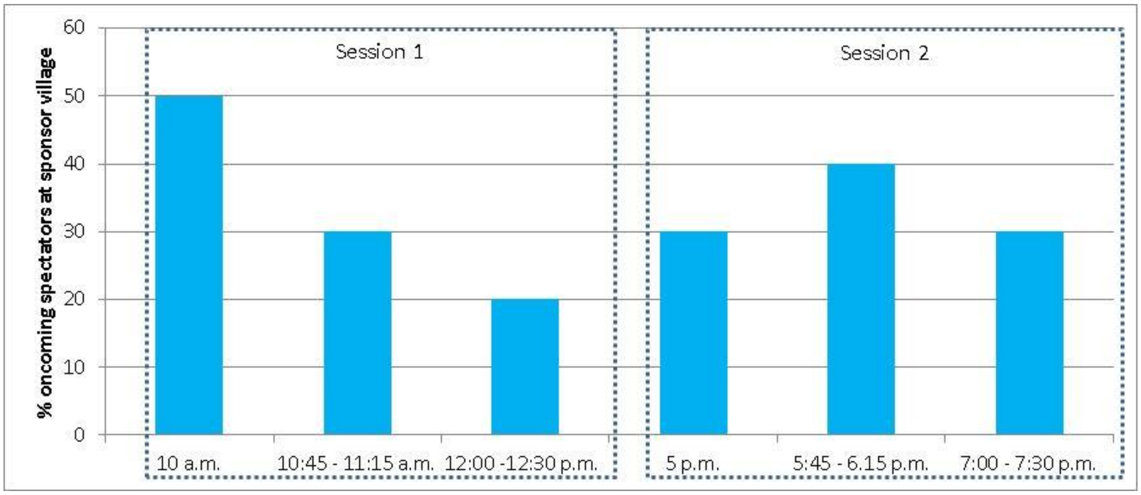


Figure 3: expected arrival curves at the sponsor village

Egress in ordinary conditions

In Figure 4, the egress paths used at the end of each session are shown.

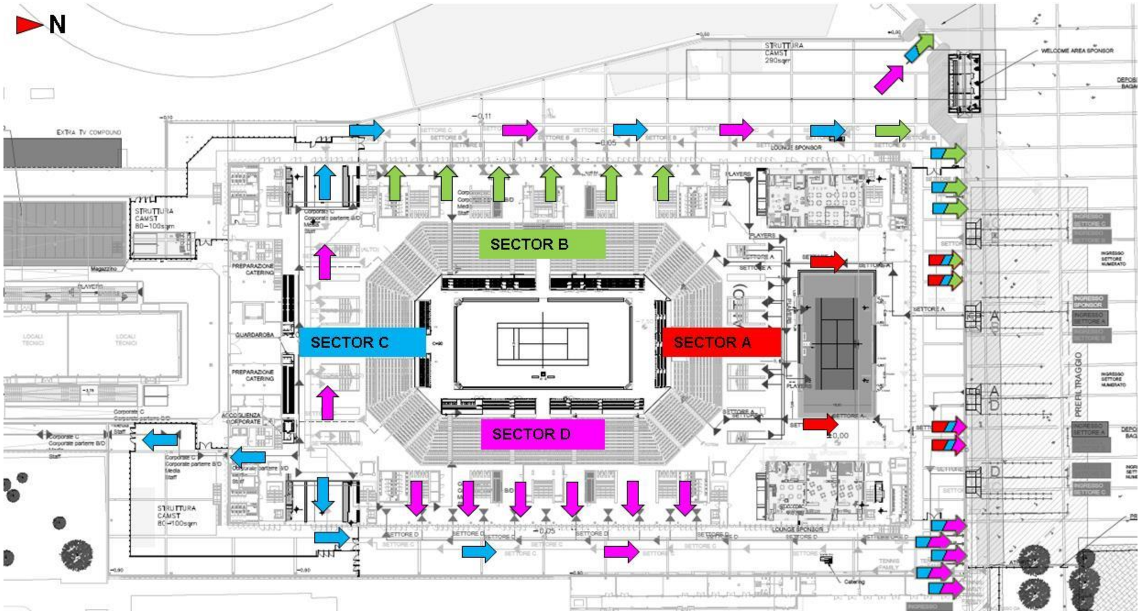


Figure 4: paths egress, ordinary condition

At the end of each session the spectators have to leave the arena and go towards the sponsors village:

- sectors A, B and C follow the paths used during the ingress phase;
- half of the sector D uses the ingress paths and northeast exits;
- half of the sector D uses the ingress paths and northwest exits.

The spectators in sector D leave the arena with a phased egress to avoid bottlenecks and gatherings due to the crossing flows between exiting sectors.
During the egress the spectators from every sector could stop at the food corners in the safety ring (red boxes in Figure 5).

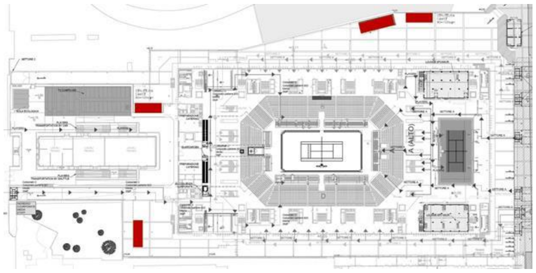


Figure 5: food corners

Egress in emergency conditions

Figure 6 shows the egress paths used in case of emergency. During an emergency all the exits on the perimeter of the arena are available.

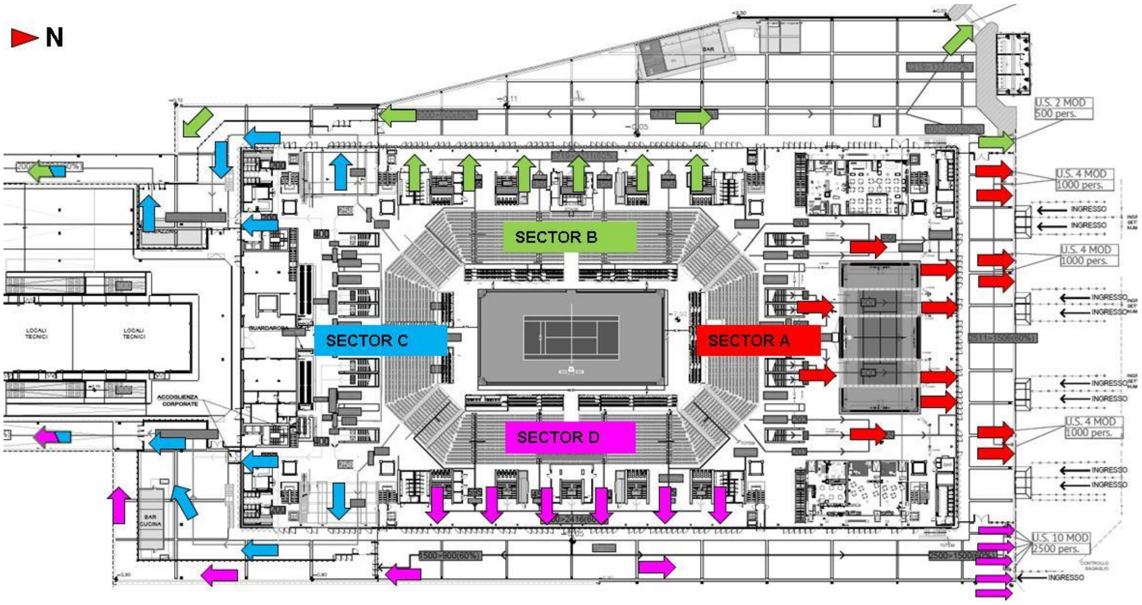


Figure 6: paths egress, emergency condition

Scope of the work and performances

The scope of the work is to understand the movement of the people during the ingress and the egress, varying the capacity of the arena, to help the definition of the safety plan:

- in ordinary conditions restrictions due to the Covid emergency are taken into account (social distancing during the ingress and the egress);
- in emergency condition the efficiency of the means of egress is evaluated.

The performances analyzed are:

- ingress time:
    - time needed by a spectator to reach its assigned seat;
    - time needed to fill each sector of the arena;
    - time needed to fill the arena (All the spectators arrived at their seats).
- Egress time: in ordinary conditions, time needed by the spectators to leave the arena and the safety ring after a session;
- Evacuation time: in emergency, time needed by the spectators to leave the arena and sponsor village;
- Queue time: time spent in queues during the egress;
- Density (spectators/m^2) near the emergency exits.

To evaluate the safety of the people regarding the risk of infection by Covid-19, the following quantities are monitored:

- Social usage (SU): provides an estimate of the number of users within the social distance (1m) of every point of the domain [15];
- Exposure time: average time spent by all the spectators within 1-meter of distance of a specific whole number of people [15];
- Spatial distribution of the aerosol concentration emitted by a spectator during the event.

Thresholds values

For some quantities/performances there are threshold values that are taken from the Italian and European codes, shown in Table 2.

Table 2: threshold values

	Quantity/performance	Threshold value	Reference
Ingress in ordinary condition	Exposure time	15 minutes	**Error! Reference source not found.**
Egress in ordinary condition	Queue time	10 minutes	[1], section S.4
Evacuation in emergency	Evacuation time	8 minutes	[10]
	Density	3.5 spectators/m^2	[11]

Model settings

The domain analysis includes the indoor arena, the safety ring, and the outdoor sponsor village.
Walking speed is set to 1 m/s. This value corresponds to the unimpeded walking speed on a regular floor. The walking speed varies depending on the density of the rooms and the slope of the terrain.
The social distance is equal to 1m, according to the recommendations of the Italian Ministry of Health. This recommendation is considered in ingress and ordinary egress scenarios enabling the *personal distance* in the profile of the agents.
Analysis is carried out with Pathfinder 2021.3.0901.

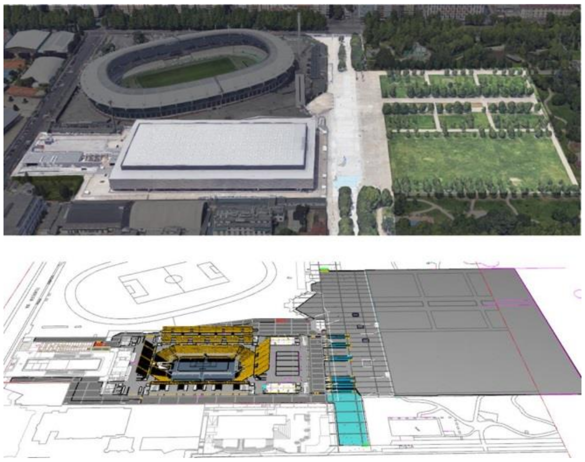


Figure 7: 3D view and 3D Pathfinder model

SIMULATION SCENARIOS

Ingress scenarios

In these scenarios, at t=0 the spectators are in the sponsor village and the arena is empty. When the simulation begins the spectators start to enter in the safety ring passing through the checking points at the access gates. The time spent by each person and the number of operators at the checking point are reported in *Table **3***, and were determined through a preliminary iterative process, varying the number of spectators approaching to the arena.
After the checking point, the spectators go to their seats and stop there. The simulation ends when all the spectators reach their seats in the arena.
The rows of the arena are modeled as refuge areas with a maximum capacity equal to the number of seats of that row. Each seat is a refuge area with a maximum capacity of 1.
Four behaviors are defined, one for each sector to direct the spectator from the access gate to the seat.

Different profiles have been defined to avoid that an agent goes to the wrong sector. The doors between the safety ring and the arena accept only the profile of the nearest sector.

The ingress of spectators in the domain occurred in correspondence of *occupant sources.*

Some issues have arisen during these simulations because Pathfinder 2021.3 was not yet optimized for the ingress modelling. In particular, an issue was the rows being very narrow, making the agents stop, blocking the rest of the agents that have the same target. This problem was partially solved modifying the characteristics of the agents in the profile menu. Specifically, the diameter of the agents was reduced to allow them to move through narrow geometries. For the social distance setting the *personal distance* is considered*,* instead of *social distancing,* in Pathfinder.

In *Table **3***, the main hypotheses of the ingress scenarios are reported.

Table 3: ingress scenarios

Scenario	Reserved seats in the arena	Time spent at the checking point by each spectator	Number of operators at the checking point
I1	75%	25 sec/spectator	4
I2	100%		

The results show that the sector D have the longest ingress time in both scenarios. This longest ingress time of sector D is mainly a consequence of it being the sector with most spectators but having the same amount of access points as the other sectors, in *Figure **8***.

The queue time is always less than 10 minutes for at least the 80% of the spectators, in *Figure **8***.

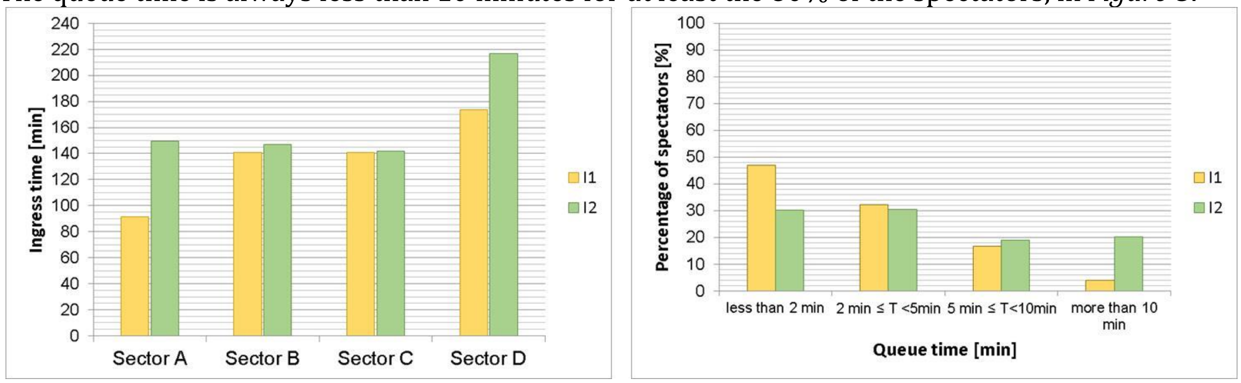


Figure 8: ingress – ingress time and queue time

From the health safety point of view, the exposure time was measured, obtaining that it is higher than 15 minutes only in the scenario I2 (arena capacity 100%), in *Figure **9***. *Figure **10*** shows the map of social usage where it can be seen that in the arena the interaction between spectators is very low.

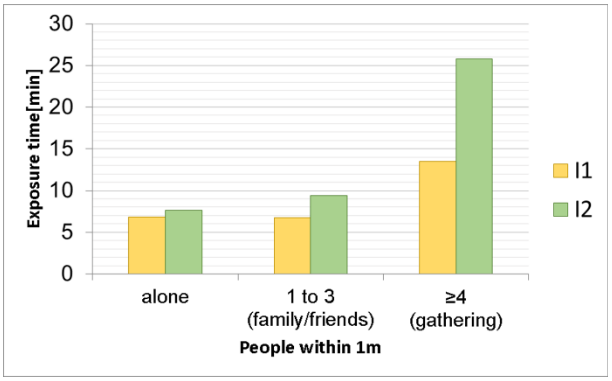


Figure 9: ingress - exposure time

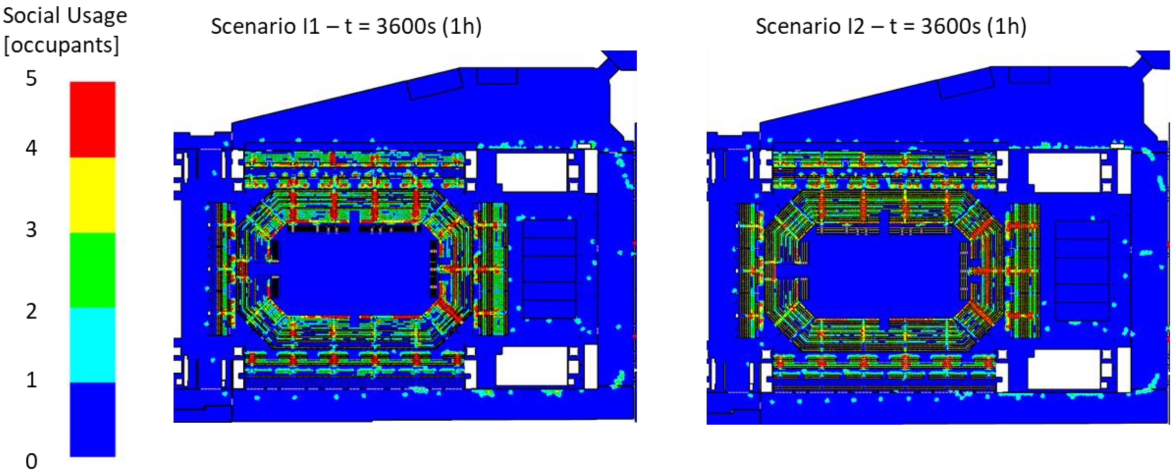


Figure 10: ingress – social usage

During the event

A CFD analysis has been developed to consider the aerosol emissions produced by a single person without a personal protective mask in areas where the density of seats is higher. The characteristics of the emissions and of the aerosol are taken from the scientific literature 16[18]. The mechanical ventilation of the arena is considered active, and it consists in:

- Supply vents on the roof. Total flow rate: 168 750 m^3/h;
- Exhaust vents under the seats. Total flow rate: 144 000 m^3/h.

Two scenarios are analyzed, as in Figure 11, changing the position of the infected person with respect to the ventilation system:

- Scenario 1: The infected person is in the sector D in a seat under the supply vents. In this position the turbulence around the subject is high;
- Scenario 2: The infected person is in the sector A, in a seat far from the supply vents. In this position the air is still.

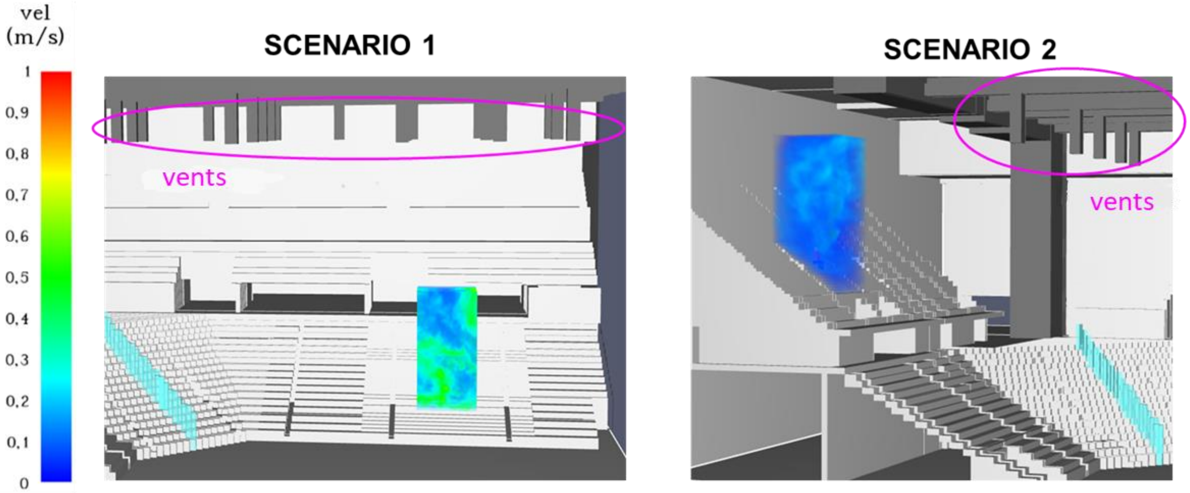
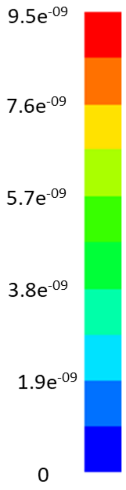
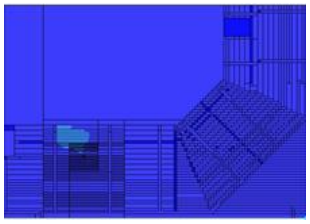
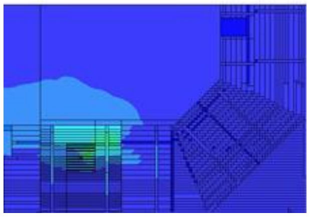
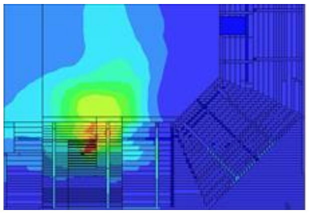
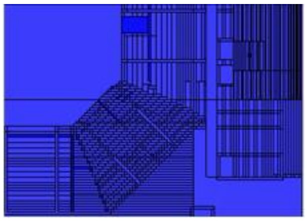
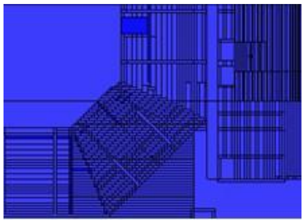
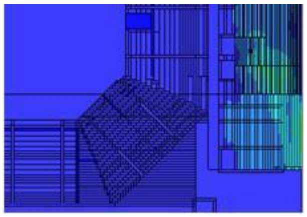


Figure 11 Location of the two scenarios and the velocity field around them

The results show that the aerosol deposition (*Table **4***) is concentrated around the infected person and the aerosol concentration (*Figure **12***) decreases by 50% over a distance of 1m.

Table 4: CFD results – aerosol deposition

Aerosol deposition [kg/m^2]	Sc.	5 minutes	10 minutes	20 minutes
	1			
	2			

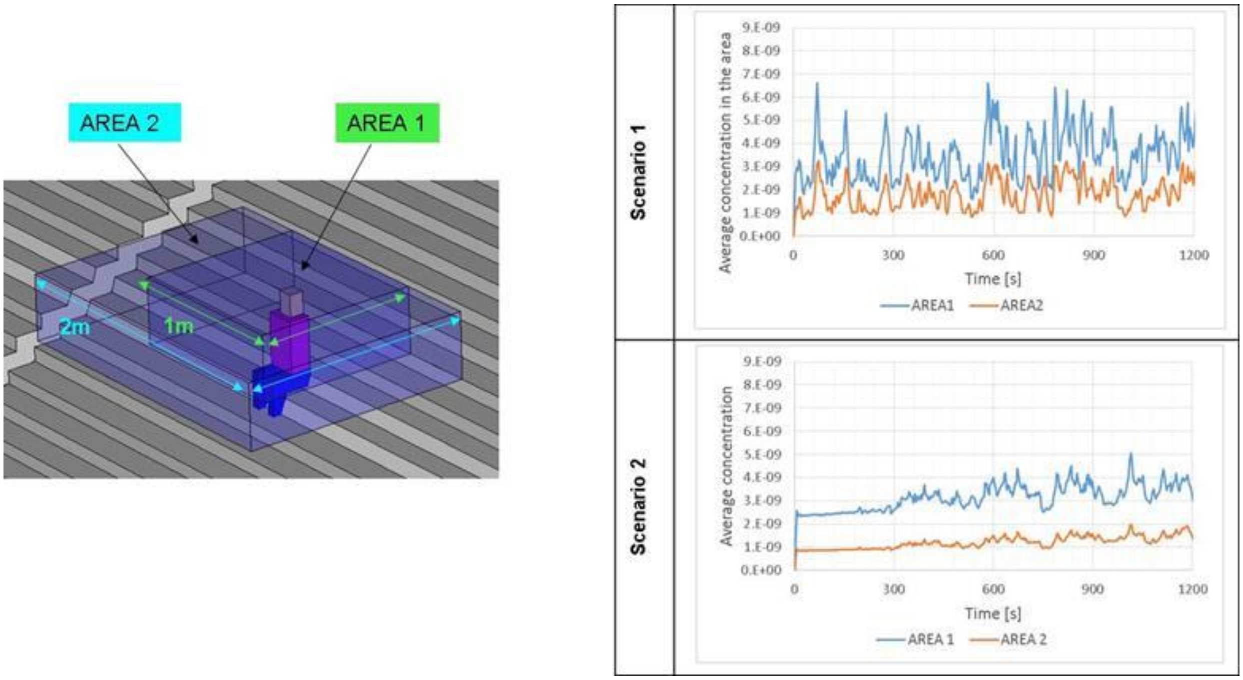


Figure 12: CFD results - decrease of aerosol concentration over a distance of 1m

Furthermore, the influence of the ventilation system in the scenario 1 was also analyzed. The scenario 1 was then simulated considering a 75% and 50% of the ventilation nominal capacity, other than the initial 100% considered in the *Table **4**Figure **12***. The results in Figure 13 show that the ventilation helps the propagation of the contaminated air produced by the sick individual, in the lower part of the arena. This happens since the ventilation pushes air from the higher to the lower part of the arena. The plume of slightly hot air emitted by the infected person is then bent towards the floor. This negative effect is reverted if the ventilation logic is inverted, with the supply under the seats and the extractions in the roof, as seen in Figure 14.

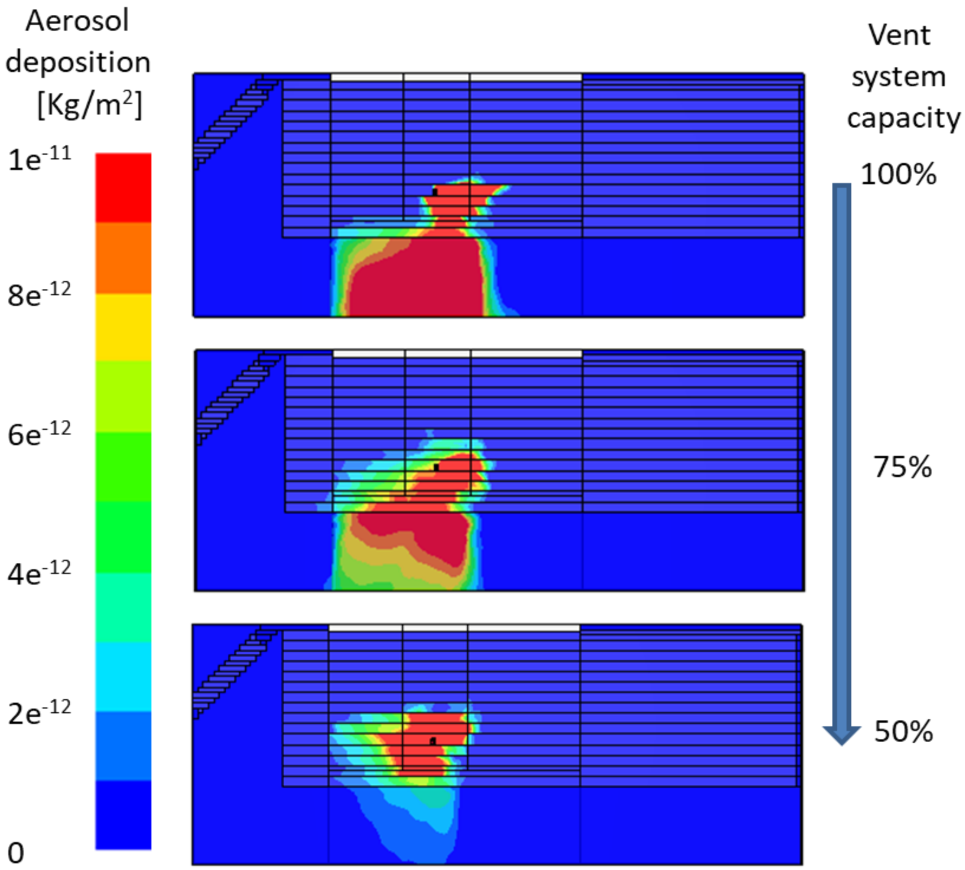
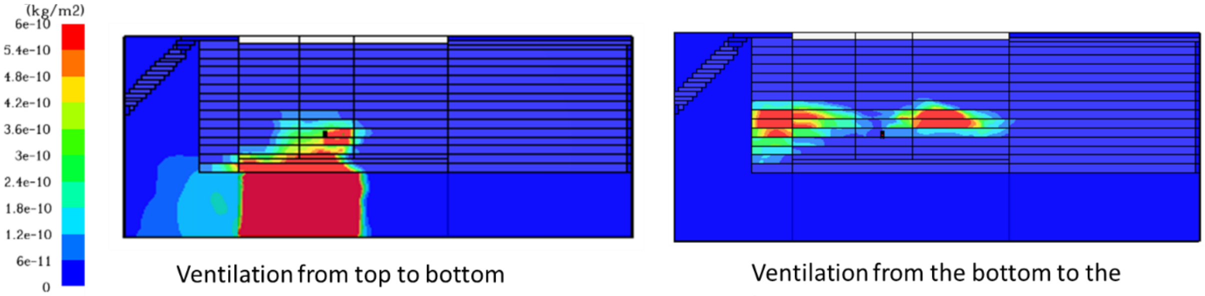


Figure 13 Aerosol deposition as a function of the ventilation system capacity after 5 minutes



Ventilation from top to bottom

Ventilation from the bottom to the top

Figure 14 Inverted ventilation effect in aerosol deposition

Egress scenarios in ordinary condition

At t=0 there are people both in the arena and in the sponsor village:

- in the arena the spectators are in their seats;
- in the sponsor village there is 45% of the expected people for the meeting, whom:
    - 30% are the spectators of the session 2 who have already arrived and wait for the opening of the gates;
    - 15% are citizens without ticket that are hanging out around the village.

The simulation ends when the last spectator of the session 1 leaves the safety ring.

During the egress from the arena, it has been considered that 15% of the spectators stop at food corners in the safety ring for 2 to 10 minutes while the remaining 85% go straightly to the exits. In this way it is estimated the maximum time to have the whole site empty (the arena plus the safety ring) before a new session begin.

To force the agents to stop in correspondence of the points where the food corners are provided, the *attractor behavior* has been used.

The egress paths are followed by the agents through the definition of different behaviors and profiles.

Table 5: egress scenarios in ordinary conditions

Scenario	Reserved seats in the arena (session 1)	People in the sponsor village
A1	75%	45%
A2	100%	

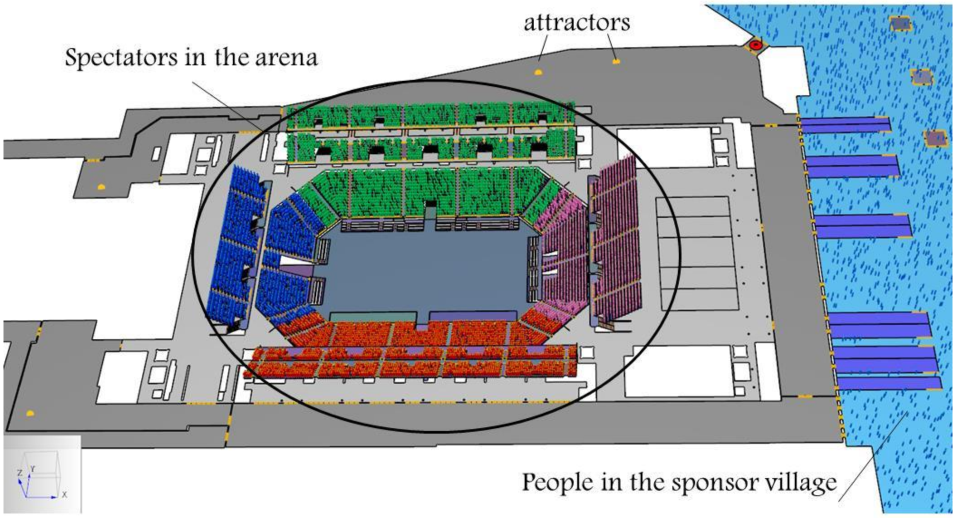


Figure 15: egress scenarios in ordinary condition at t=0

In the simulation the maximum egress time considers the spectators that stop at the food corners. Two time periods can be measured through the simulation:

- t1 = time at which the arena is empty. The spectators are in the safety ring at the food corners or queueing;
- t2 = time at which the last spectator leaves the safety ring.

Table 6: egress time

Scenario	t1 [min]	t2 [min]
A1	40.1	82
A2	63	100

In the following figure a screenshot during the egress is shown (t= 600s). Different colors indicate different starting sector.

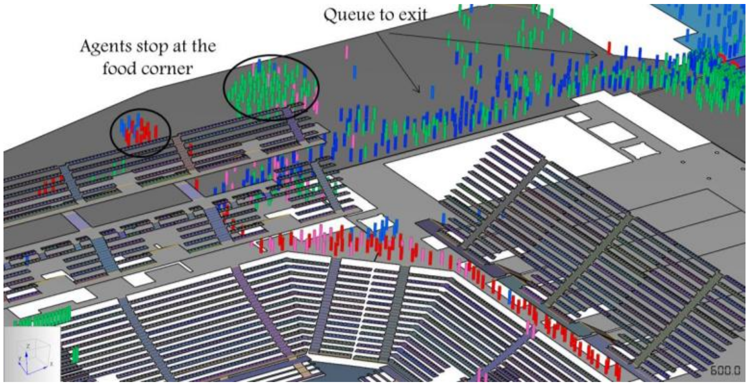


Figure 16: egress in ordinary condition (t=600s)

The exposure time is always lower than 15 minutes (Figure 17). Looking at the social usage results, higher values are registered in correspondence of the food corner. In Figure 18 the plot of social usage is taken at time t1.

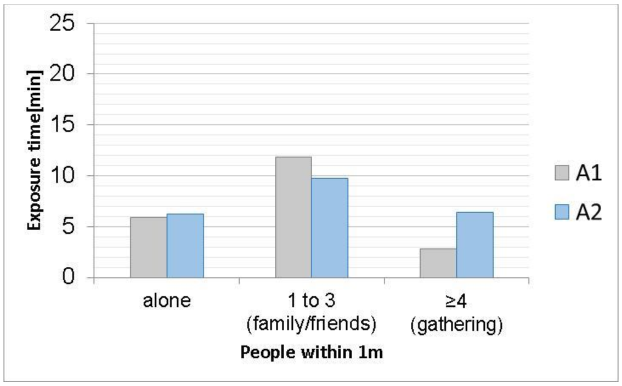


Figure 17: egress in ordinary condition - exposure time

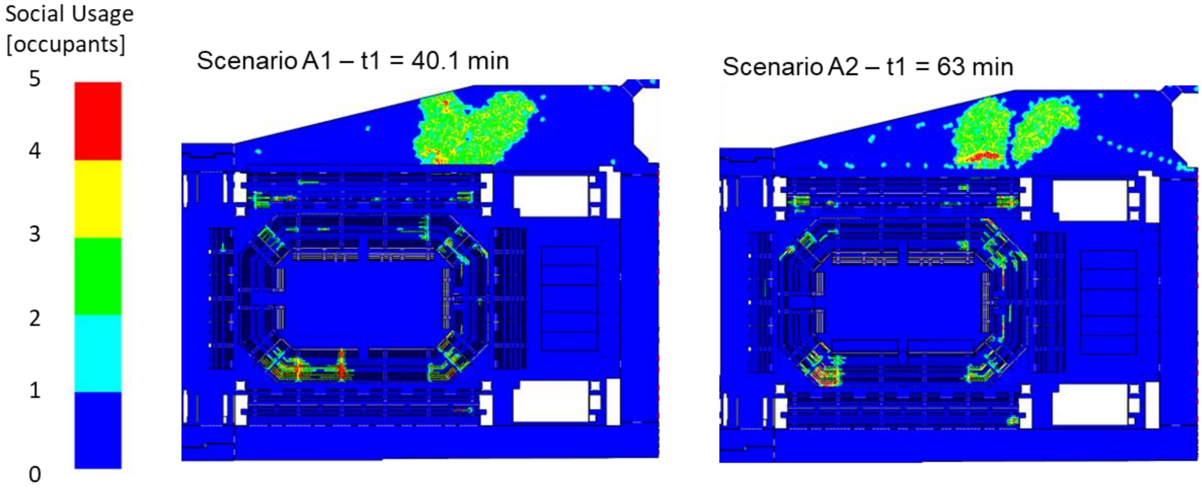


Figure 18: egress in ordinary condition - social usage

Evacuation scenarios:

As in the egress in ordinary condition, at t=0 there is people in both the arena and in the sponsors village.

During an emergency, the evacuation affects the individuals in both the arena and the sponsors village, so the simulation ends when both areas are empty.

Also in these cases, the emergency paths are followed by the agents through the definition of different behaviors and profiles.

Table 7: egress scenarios in emergency conditions

Scenario	Reserved seats in the arena (session 1)	People in the sponsor village
E1	75%	45%
E2	100%	

The evacuation time is determined:

- at t1 = when the arena is empty, i.e. when the last spectators enters in the safety ring;
- at t2 = when the whole site is empty, i.e. when the last spectator leaves the sponsor village.

The time t1 is always within the threshold value of 8 minute suggested by the Green Guide[10].

Table 8: egress time

Scenario	t1 [min]	t2 [min]
E1	7.2	13.3
E2	8	15

The queue time is always lower than 10 minutes. In scenario E2 (arena capacity 100%) the percentage of spectators that stay in the queue between 5 and 10 minutes is about 40%, respect 18% registered in scenario E1.

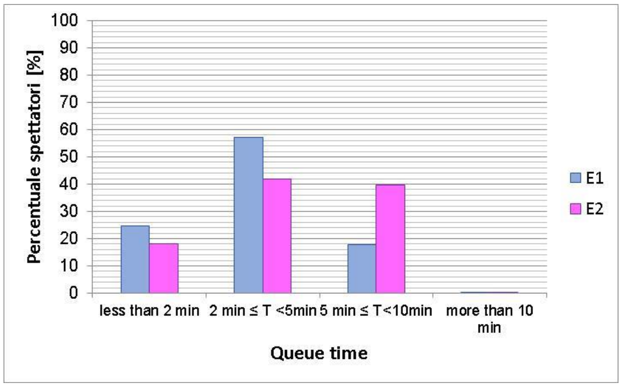


Figure 19: egress in emergency - queue time

Figure 20 shows a plot during the moment when the maximum value of density is registered. Density is lower than 3.5 spectators/m^2 in most of the domain, except in correspondence of some exits of the safety ring (red circle in Figure 20).

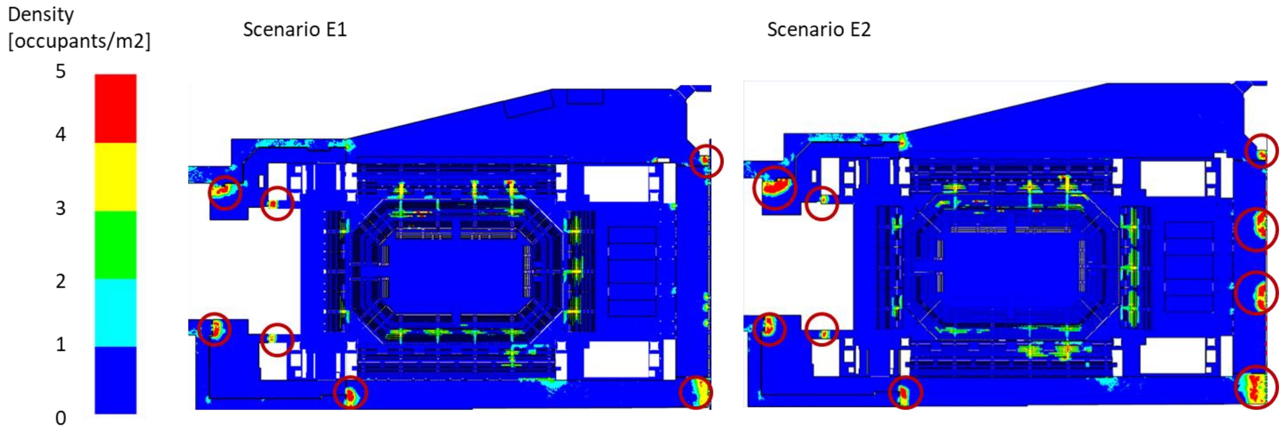


Figure 20: egress in emergency - density

FUTURE RESEARCH

Evacuation models and fluid dynamic models are a great source of data capable of aiding the design of the management of mass gatherings and similar kinds of events. The COVID-19 pandemic has introduced new needs in the users of these type of software as tools to manage crowds considering health safety regarding the propagation of diseases. With this in mind, the research of the mechanisms of propagation of diseases and methods to accurately simulate them is a field that could be explored both by the academia and the private sector, to ensure safer events and bigger revenues for the organizers.

CONCLUSION

Through the agent-based evacuation simulations (in Pathfinder) and computational fluid dynamic calculations (in FDS) it was possible to assess the safety of the event through its 3 phases: before (ingress), during (aerosol propagation) and after (egress); including emergency scenarios. The load factor (LF) was one of the main variables of the study, evaluating the scenarios, before and after the event, with spectators equal to the 75% (LF-75) and 100% (LF-100) of the arena capacity. The results obtained through the different phases are:
During the ingress:

- the total ingress time for LF-75 is close to 20% less than for LF-100;
- the queue time is less than 10 minutes for the 80% of the spectators in both LF-75 and LF-100;
- the exposure time threshold is respected only for LF-75, staying under 15 minutes of exposure for the spectators;
- the social usage, in both LF-75 and LF-100, is low with small concentrations of people only in the queues and narrow passages in the arena;

During the event:

- in the case of a diseased individual without a protective mask, the concentration of contaminants in the air around this individual falls sharply, arriving to a 50% concentration in only 1 meter, making it difficult for the disease to propagate to the other spectators.

During the Egress:

- the total egress time for LF-75 is close to 20% less than for LF-100;
- the exposure time in both LF-75 and LF-100 respects the limit of 15 minutes of exposure for the spectators.

- the social usage: in both LF-75 and LF-100, is low with small concentrations of people in the queues and around the food corners;

During Evacuation:

- the evacuation time, for both LF-75 and LF-100, respects the threshold for the evacuation time of 8 or less minutes to empty the arena.
- the queue time, in both LF-75 and LF-100, is below 10 minutes for all the spectators.

Considering these outputs, the load factor of 75% of capacity was recommended as it ensures the safety conditions linked to both the COVID-19 pandemic and the crowd management in a sports event.

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