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SOME EFFECT OF INTERPERSONAL DISTANCE CONSTRAINTS IN MODELING WAYOUT FINDING FROM AN EXHIBITION HALL

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ABSTRACT

The aim of this study is to capture some effect of interpersonal distance constraints in modeling agent based way-out finding. The study was triggered by the all-dramatic experience of the COVID-19 pandemia, where adoption of interpersonal distance limitation is one of the actions used to try to limit the spread of the virus between people. One case study is presented here: an exhibition hall where people may gather in and move around, until an alarm make people realize the need to find their way-out through the exit to a safe place nearby. The hall is a room-like space, with one entrance on one side and two exit doors on the opposite side. Virtual artworks are in place, where people are divided in two main groups: visitors with a leader following some path along the artworks, and curious people wandering about. The model takes into account the presence of some interpersonal distance to be maintained, at least in principle, from people to people, either before and after the alarm heard – and understood – for starting the move out of the hall.
Two Agent Based Modeling (ABM) tools are used: NetLogo and Pathfinder, with some similarities and differences in describing the space and the people, in programming the rules of action and in obtaining the behavioral emergence response. The introduction of the interpersonal distance constraint is one of the clues that are here investigated in order to modeling the interactions and to monitoring possible noise effects on the people's ability to maintain the constraint while moving.
Thus, modeling the interpersonal distance between the agents gives the opportunity of describing and exploring one critical parameter and some of its effects in the way the agents move inside the hall and then get to their safe place out through the exits available.

1. INTRODUCTION

This study is part of a research program meant to explore Crowd and Fire Dynamics in their essence of Complex Systems (Grimm et al. 2005, Erdi et al. 2008). This kind of approach is relatively new in these disciplines. Here we deal with the interactions among people and the built environment. As a matter of fact, crowd dynamics started to be studied with a fluid-particle dynamics approach while nowadays the cybernetic approach, with Agent Based Modelling (ABM) is also applied by the experts in this field as a sort of frontier in evolution still today. This paper deals with some aspects of human behaviour in crowd dynamics, especially those that may be encountered in critical situations where two conditions appear in sequence: from normality to emergency, usually through a sudden transition. Since the aim of this study is to try to capture some essential features in the possible change of people's behaviour under critical conditions by means of ABM, an environment is modelled to highlight patterns of the interactions processed in the associated simulations.
The environment here investigated is a model of an exhibition hall where people move inside and try to maintain some interpersonal distance while enjoying the event, at least until an alarm is suddenly triggered. As usual when dealing with egress studies, all of the occupants are considered entirely inside the environment at the start in normal condition – as when an exhibition is performing and

there is no more admittance inside and the only path to the outside is through two exits doors, 0.90 meters wide each, placed in the end parts along the left wall. Once the alarm sounds, the agents are supposed to immediately understand the necessity of moving out. Since the focus is on the patterns that may emerge from people movement inside the room driven from possible shifts in behaviour, induced not by a physical threat like a fire, there is no need to consider the room height and the environment is modeled as a two-dimensional rectangular room (8 by 16 meters).
In NetLogo is possible to define a more general set of behavioral rules that extend the PathFinder capabilities, which are centered on the egress phase, including also the pre-evacuation activities like in our case the "wandering" of the visitors inside the hall staring at the artifacts. The agents chosen as models of people are in this study subdivided in two basic sets, each one having differing behavioral rules under normal conditions at the start of the simulation: a group of visitors with a leader to follow that move following the artifacts and some other visitors wandering independently of each other inside the exhibition hall. Following a previous work (Ponziani et al. 2018), the introduction of social distancing rules in the agent movement schemes is considered, testing the effective capability of a new version of Pathfinder, introduced in 2020, with specific feature additions. The following ODD (Overview, Design concepts, Details) protocol describes briefly the features of the model in an synthetic manner used in some ABM community (Grimm et al. 2012).

2. OVERVIEW, DESIGN CONCEPTS, DETAILS OF NETLOGO MODEL

2.1 Overview

The ABM approach makes it possible to investigate the people's behaviour shifts as a result of the environmental conditions changing from a normal state to an emergency state via a sudden transition. This means that each agent performs a task ("action") that will tend to be different depending on the state of the environment, on the perception sensitivity, and on the individual response capability, so that each agent could possibly have its own internal different state of performance. Furthermore, some effect of the internal state of the agent could be coupled with the state of the environment. Proper spatial and temporal scales have to be chosen and modelled specific for the process or phenomenon investigated. The model describes the environment as a 2D world with side boundaries that cannot be crossed by the agents ("wrapped off" world, no-torus topology), focuses on the interactions that may arise in each single agent's behavior (hence movements) coming from other agents (hints, constraints) and from the environment (physical and cognitive biases).
In our study, the initial condition is a normal state (pre-evacuation phase), the leader will guide his group of visitors along the artworks following some circulation path ("to visit" action) while autonomous visitors will wander from artwork to artwork following some random path ("to wander" action). At the onset of the alarm (evacuation phase), each agent immediately become aware of the emergency notification and change its behaviour to move out starting the egress directing to its chosen exit ("to move out" action). A visitor belonging to the group will follow the guide while observing the artworks and this link may or may not be maintained during the egress phase.

2.2 Design

The state of the agents (internal: physical, cognitive, emotional – at least in principle; external: actions, movements, stops – at least simplified) are programmed and tuned with the aim of letting behavior be free to emerge (i.e. the pathway, the room around the agents) as a consequence of adaptation to a current situation, with spatial and temporal scales that may require some tuning. The model is built using NetLogo, an open source environment designed for research and design in the ABM realm that uses specific entities for modelling purposes: the very basic are the patches, the turtles and the link. The patches are used in this study to describe the environmental space while the turtles model the occupants. Each patch is a square piece of "ground" over which turtles can move. Both patches and agents have coordinates, but patch's coordinates are always integers, while turtle's coordinates can have decimals allowing that a turtle can be positioned at any point within its patch. The patches and the turtles represent the world (Wilensky 2015). By varying the scales of the model, it is possible to adopt discrete or continuous schemes. In this study the world - i.e. the exhibition hall – is wrapped off (need boundaries for people), with continuous space and discrete time that elapses in steps called "ticks",that marks the advancement of the simulation when all of the rules of all of the agents are executed in the current step. NetLogo is particularly suited for simulating complex system and their properties: e.g. connectivity, nonlinearity, self-organisation, co-evolution (Rzevski 2016).

2.3 Details

The model is initialised by designing the environment and the agents. The input data of the environment deal with the geometry (plan area, walls, doors, artworks) and the effects (solid boundaries, unavailable doors, exits to way out, alarm set). The input data of the agents are the position (number, spatial distribution) and the characteristics (physical and cognitive). The actions of the turtles, modeling the occupants, deal with positioning (interpersonal distances), movement (visit, wander, dodge, move out, stop) and decisions (reactive, adaptive). The effects of the environment deal with signalling (alarm triggering, doors blocking, exits availability) and attraction to way out (random, not random based on criteria like familiarity or shortest path). At setup, the number of agents to be accounted for inside the exhibition hall can vary in such a way as to span a range of occupancy thresholds, from lower to higher, and so do the interpersonal distances assigned to each agent. A lower value for the number of agents may be useful to help visualize more easily emerging patterns of behavior, a lower value for the interpersonal distance may be useful in modeling contact versus proximity, with some preferred value representing some critical condition.

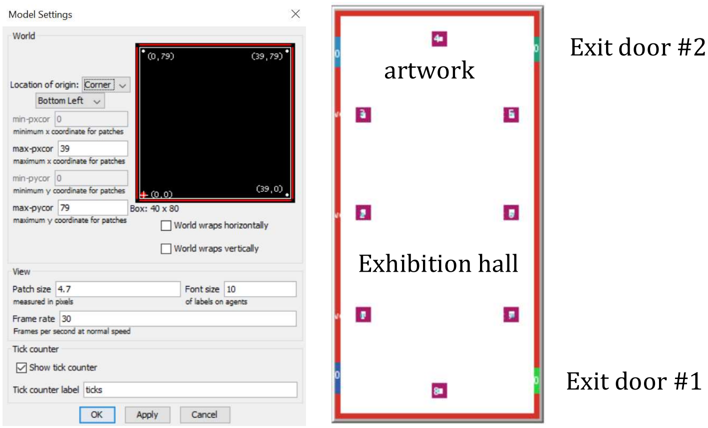


Figure 1: NetLogo model settings and "world" (exhibition hall).

2.3.1 Behavioral rules and constrains

The links are used in NetLogo to model some characteristic that is useful to be associated with the turtles. While the turtles and the links associated with the turtles are mobile agents, the patches are fixed agents that cannot move; anyway, all of these three kinds of entities may have qualities and properties that dynamically translate into rules of behavior and proper interactions for all of them. The basic idea of this study is to use a relatively few rules internal to the agents, in such a way to let the system evolve to some state with not too strong a forcing from the outside. The rules depend on the nature of the entities: the rules for the patches deal with the properties of the environment (walkable space or not, pre-alarm and post-alarm sounding, employing a color-based picturing for a quick visualization); the rules for the turtles deal with the breed (leader, visitor, wanderer) and the actions (leading or following while moving, moving independently, checking for sufficiently available

room around oneself, checking for obstacles, pointing some target); the rules for the links deal with the characteristic (room around oneself).
Several constraints need to be implemented in the model for the agents: internal and external to their own state. Internal constraints describe programmed or derived biases, such as avoiding obstacles or pointing one target; external constraints describe the effect of the world, such as solid barriers or responding to the alarm. While, in general, different sets of rules are assigned to each group of agents depending on their breed, same constraints are assigned to the agents as such. This is necessary in order to model the actions of the agents, with their dos and don'ts, so they tend to achieve the final goal of their decisions, step by step. These actions, in turn, may be reactive to something happened in previous steps of simulation or adaptive to find a better achievement in the following steps. Typically, placement and speed of the agents may show these characteristics. The interpersonal distance constraint, usually associated with the room freely available for each agent, may span from contact (practically in touch) to proximity (near vicinity), up to assuming a rank of metrics or an expression of noise effects. With the use of the links, the room constraint around each turtle is visualised as a halo that moves together with the turtle itself. The distance of the leader with its nearest visitors, dynamically variable during the movements, is adopted here as reference metric, but alternative metrics could refer to each occupant or to any other specific occupant.
The heading of each agent (the direction the agent points to) is set in the code programming as dynamically variable and it serves to orientate the agent towards the selected target.

3. NETLOGO RESULTS

The simulations performed for this study extend a previous work (Ponziani et al. 2018) reporting some results concerning the egress phase that will be briefly recalled later when dealing with PathFinder simulations. The focus is here on the leader with its group of visitors during the visiting time (pre-evacuation phase) and the capabilities of the model to capture the interactions in the group moving under an interpersonal distance constraint. For the sake of clarity and without losing in generality, no autonomous visitor is included in this analysis. The initial position of the leader is set at random near one artwork while the initial position of the seven visitors is set in chosen points automatically placed taking into account the relative distance to be maintained between the agents; the initial heading of the leader is set to face west, the initial heading of the visitors is set at random. The agents are instructed to direct towards their target only if it is in their vision cones, otherwise they start a random walk till the target is detected. Two social distancing schemes are applied. In the first set of simulations - visit type - the basic ideas under the behavioral rules assigned to the leader and the visitors of the group are (as seen by the agent):

- "If I am the leader, if I see in my cone of vision an artwork I'll move toward it, but If I don't see any artwork I'll move at random until I see one artwork; I'll keep trace of the distance from me to the near visitors".
- "If I am the visitor, if I see the leader in my cone of vision, if there is no other agent inside my interpersonal distance constraint I'll follow the leader, otherwise I'll move at random a little; if I don't see the leader in my cone of vision, I'll move at random until I catch sight of the leader".

With these rules, a noise effect in the moving constraints may appear due to some overlapping.
In the second set of simulations - maneuver type - the basic ideas under the behavioral rules assigned to the leader and the visitors of the group are (as seen by the agent):

- "If I am the leader, if I see in my cone of vision an artwork I'll move toward it, but If I don't see any artwork I'll move at random until I see one artwork; I'll try to maintain the interpersonal distance constraint; I'll keep trace of the distance from me to the near visitors".
- "If I am the visitor, if there is no other agent inside my interpersonal distance constraint, if I see the leader in my cone of vision I'll follow the leader, otherwise I'll manage to know where the leader is and move a little toward his direction".

Some tuning may be needed to match the relative speeds of movement. For instance, the leader applies a 0.35 factor to the advancement (move-ahead-visit command) for good smoothing move along with the visitors. With these rules, a better achievement over the moving constraints is reached. In the sequence hereafter, Figures 2 and 3, snapshots coming from a series of runs exemplify the results obtained applying the two set of behavioural rules. The specified social distancing is expressed in patch units (setpoint: 5 patch units corresponding to 1 m). The snapshots show the initial setup and the status after 60 ticks at the alarm onset. Colours are used to differentiate the agents and highlight the patterns: the leader has a white arrow while the group visitors are grey. The yellow markers in the final state track the initial positions. The interpersonal distancing is more strictly respected by the Maneuver type scheme. Implementing more advanced strategies adapted combining those employed in process control and in cognitive sciences, could improve the respect of the distancing between agents, having in mind that the scope is to mimic the human capabilities.

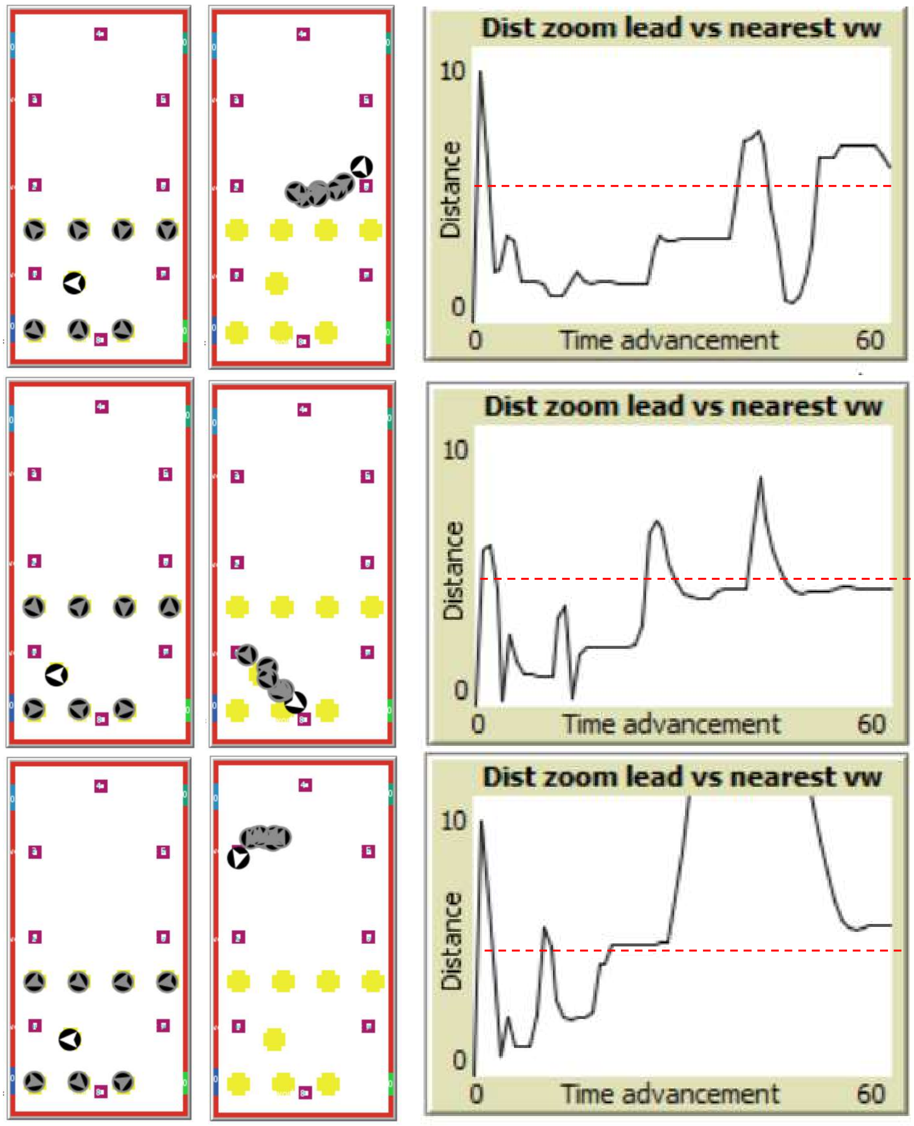


Figure 2: Visit type scheme. Initial setup (tick 0) and final state (tick 60) with distancing metrics of the leader vs nearest visitor obtained in three runs. Social distancing set to 1 m. (distance in patch units, 1 patch = 0.20 m; time advancement in ticks).
Population of 8 occupants formed by a group of 7 visitors and a guide.

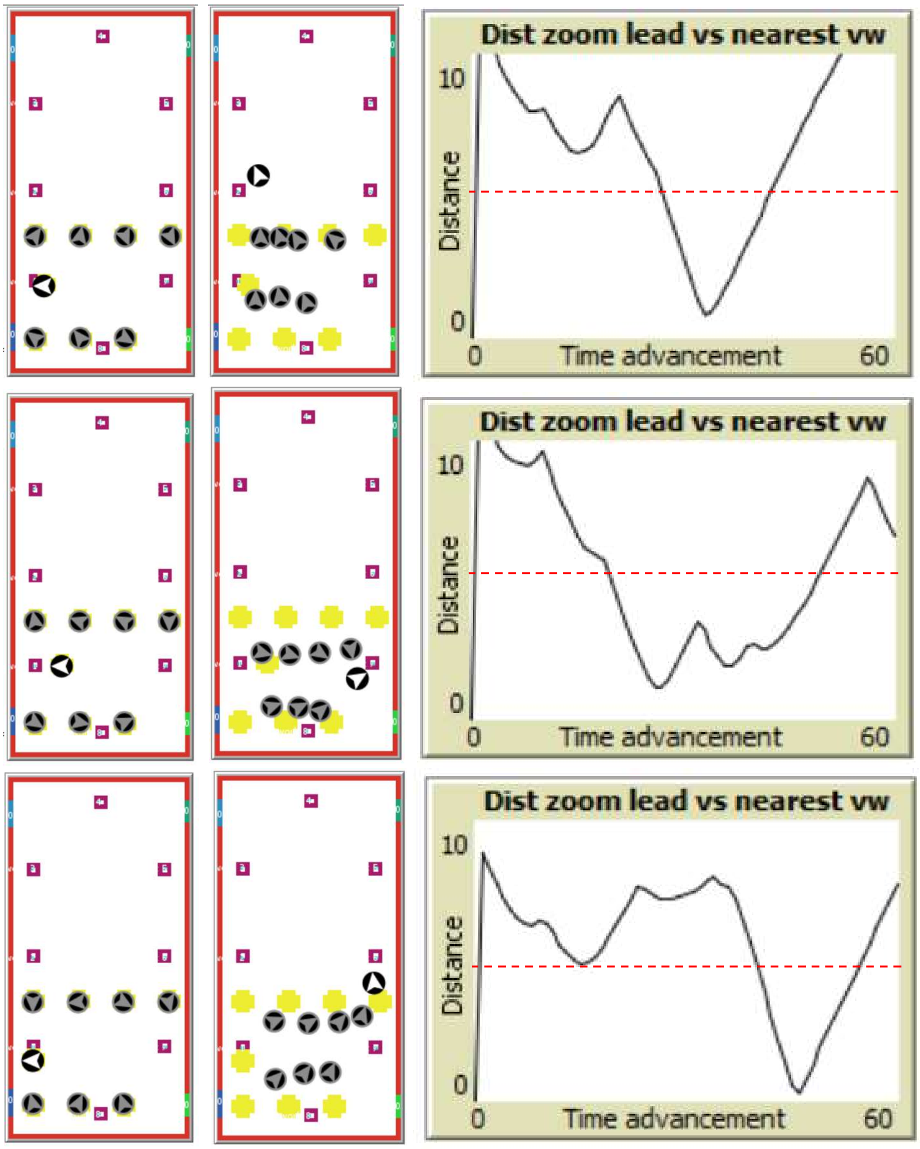


Figure 3: Maneuver type scheme. Initial setup (tick 0) and final state (tick 60) with distancing metrics of the leader vs nearest visitor obtained in three runs. Social distancing set to 1 m. (distance in patch units, 1 patch = 0.20 m; time advancement in ticks). Population of 8 occupants formed by a group of 7 visitors and a guide.

4. PATHFINDER MODELING AND RESULTS

4.1 Simulation model

General details concerning PathFinder are here omitted and can be consulted in the technical documentation and online resources. Pathfinder uses Profiles to assign parameters to occupants, typically to define walking speeds and other agent characteristics, like social distancing. Profiles here considered are the guide, acting as the leader of a group of visitors, and the visitors, being autonomous or group members. PathFinder default profile is selected as a common basis for all the agents, given the objective of this study to investigate how behavioural and movement schemes determine the system evolution, in a framework not influenced by the individual agent capabilities.

In PathFinder there is little built-in capability to model the pre-evacuation activities (mainly by setting a time delay before the agent activation). To reproduce the scenario simulated in NetLogo, all the agents are initially positioned at random inside the exhibition hall. The pre-evacuation phase allows the guide and visitors group to form correctly before the egress process starts Two basic behaviors are applied: in the first 10 s the guide and the group are ruled to direct to a waypoint, simulating an artwork, while the autonomous visitors stay passive in their initial positions. At the scheduled time (10 s), corresponding to the onset of the emergency state, the action "Exit (any)" is applied to all agents. The only exit door choice strategy available in PathFinder model, "Exit (any)", is equivalent to the "Less distant exit at the alarm onset" implemented in NetLogo model (Ponziani et al. 2018). The Advanced "Current Door Preference" field in the Door Choice tab of the Edit Profiles dialogue is set equal to 100% for all the Profiles, to freeze the initial door choice.
Three primary movement schemes, defined in the agents Pofiles, are investigated:

1. Free flow, i.e. the agents could possibly come into contact with other agents (shoulder-shoulder distance governed by the parameter "Personal Distance ").
2. Social distancing partially constrained flow, i.e. the specified minimum distance (set by the parameter "Social Distancing ") is applied with the exception of group members among themselves (but not by other occupants) by the use of a specific box in the Movements Group.
3. Social distancing constrained flow, i.e. all the agents shall respect a minimum distance equal to 1.0 m among themselves (measured center-to-cent), governed by the "Social Distancing" selection box in the Advanced tab of the Edit Profiles dialogue.

The alternative option to increase occupant/occupant collision diameter should be avoided as the algorithm unduly slow down the flow through the exit door in case of queueing.
The Free flow scheme implemented in our PathFinder model is equivalent to the "Buffer zone is contact" pattern, while the Social distancing constrained flow is equivalent to the "Buffer zone is proximity" pattern in our NetLogo model (Ponziani et al. 2018). Because it is not possible to vary at random the waypoint coordinates, for each primary movement scheme three fixed positions for the group waypoint, respectively in the upper, central, and lower section of the exhibition hall are considered, giving a set of nine basic input files. At least forty replicates for each of the nine basic input files have been carried out using a set of scripts to automatically generate variations for testing the sensitivity to the input parameters (occupant positions). The nine simulations results batch have then been reviewed and regrouped back into the three primary movement schemes (each one consisting therefore of a set of at least 123 runs). The pre-evacuation phase ensures also the correct group formation at the egress process starting.

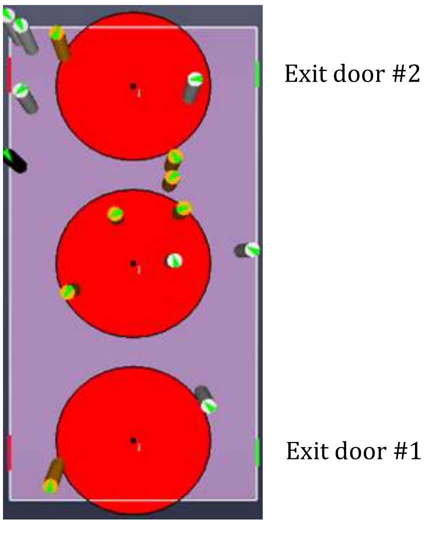


Figure 4: PathFinder model with the initial agents positions and the location of the group waypoint.

4.2 PathFinder results

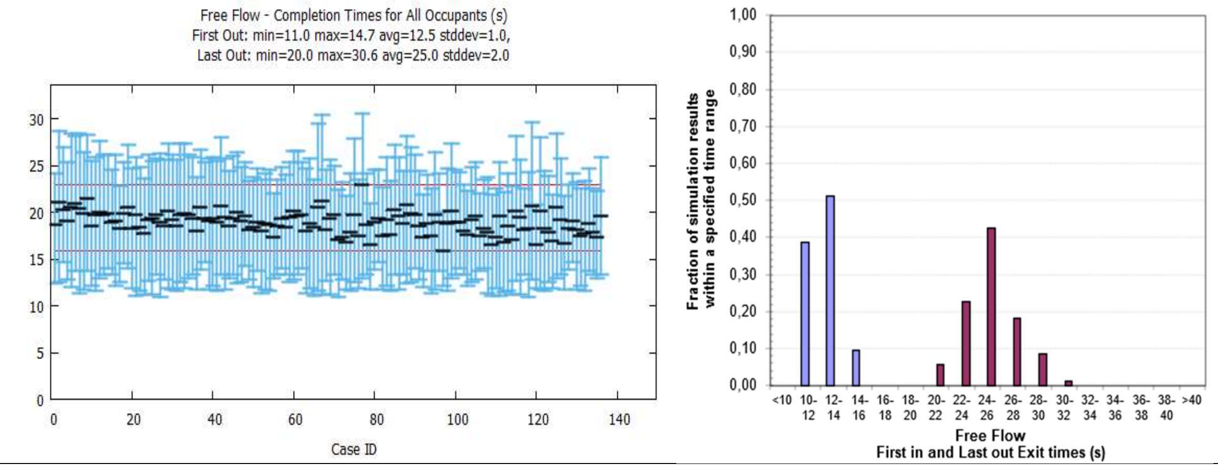
The Monte Carlo simulations for each of the nine primary files were run using the latest PathFinder version available (release 2020.3.0729). With this recent development PathFinder effectively maintains the specified distance among the occupants, when the social distancing is enabled, and produces, if required, two data files reporting the transient data about occupant separation and exposure time. This new option can be applied also to the Free flow movement scheme, in order to establish a baseline useful in assessing the effect of the social distancing schemes.
The calculated exit times for each of the three primary movement schemes, i.e. the time the first and the last occupant required to complete the evacuation, has been analyzed in order to obtain the statistics shown in Table 1 and Figure 5. A similar trend applies to the egress time, subtracting to the last out occupant data the initial pre-movement phase with a constant duration of 10 s.

Table 1: Statistics of the exit times in PathFinder simulations

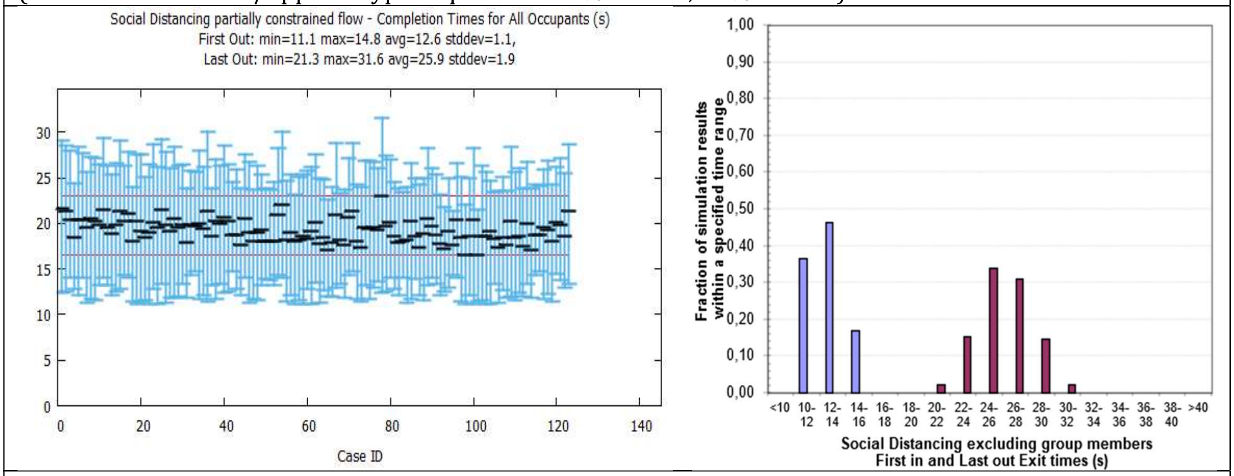
Exit times (s)	1. Free Flow		2.Social distancing partially constrained flow		3. Social distancing constrained flow	
	First out	Last out	First out	Last out	First out	Last out
Dev. std	0.99	2.03	1.07	1.95	1.04	1.83
Min	11.0	20.0	11.1	21.3	11.1	22.4
Max	14.7	30.6	14.8	31.6	15.1	32.1
Average	12.5	25.0	12.6	25.9	12.7	27.2

While the first out exit times are independent from the flow scheme implemented, representing for the scenario examined the result of the undisturbed flow of the occupant nearest to the exit doors, the exit times for the last occupant depends on the primary movement scheme adopted. Even if the free unimpeded walking speed is the same for all the agents, the differences in the primary movement schemes here considered generates an appreciable differentiation in the results that is unveiled by randomizing the initial occupant positions (including the guided group). As expected, the Free flow scheme resulted to be the fastest, followed by the Social Distancing constrained flow schemes that increase the calculated average value for the small population of occupants here considered of about 3.5% in the case of partial distancing (excluding group members) and 8.8% for integral distancing (including group members). The observed differences arise mainly in the exit doors approach, with a queueing formation process enhanced by the social distancing schemes. Increasing the number of occupants (initial density) and/or group movements will increase substantially the differences in the calculated exit times when social distancing schemes are applied.
The capability of the PathFinder algorithm to effectively track the interpersonal distance specified in the input file has also been analysed for the social distancing constrained flow scheme, being the most severe test as the distancing is applied to all the agents. Assuming as reference the leader, the time series representing the calculated closest occupant distance and the number of occupants within the 1 m radius have been extracted by all the simulations and analyzed in order to obtain the plots exemplified in Figure 6. For each one of the 132 time series, discarding the first 3 seconds where the random positioning at the starting could initially put the agents too close each other, the minimum and average of the closest occupant distance have been calculated and again averaged to obtain the overall values. The minimum distance overall is equal to 0.33 m, same as the reduction in the agent size by default implemented by PathFinder, while the average overall of the closest occupant distance is 0,86 m, lower than the specified value of 1.0 m, with peaks of 4 occupants within the 1 m radius.
In the engineering practice it is therefore recommended to increase the input value specified for the social distancing in order to demonstrate the compliance with code requirements and include in the assessment the sensitivity to group movements.

1. Free Flow exit times
(136 runs with lower/upper waypoint position: 49% of runs; 51% central)



2. Social distancing partially constrained flow exit times
(123 runs with lower/upper waypoint position: 45% of runs; 55% central)



3. Social distancing constrained flow exit times
(132 runs with lower/upper waypoint position: 41% of runs; 59% central)

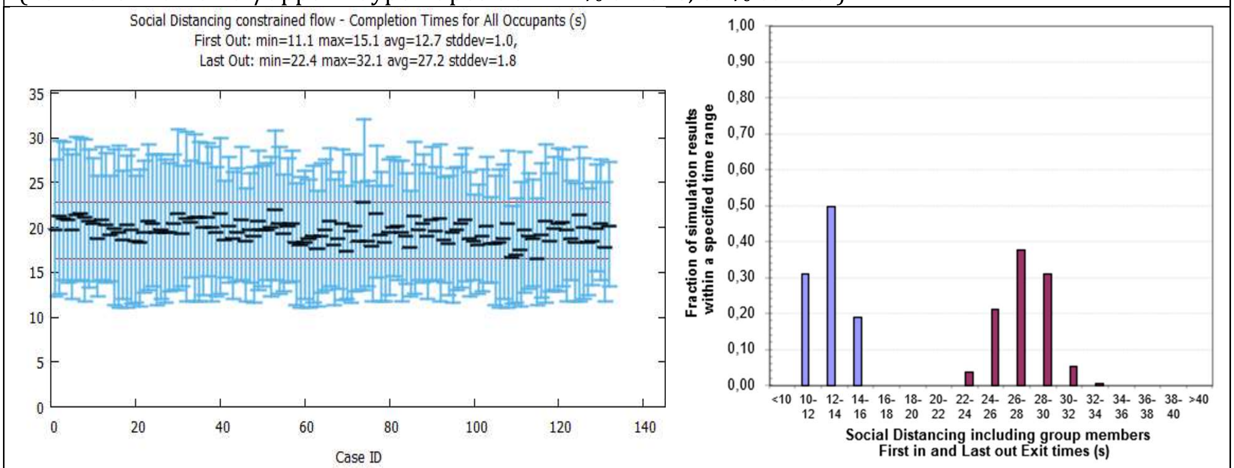
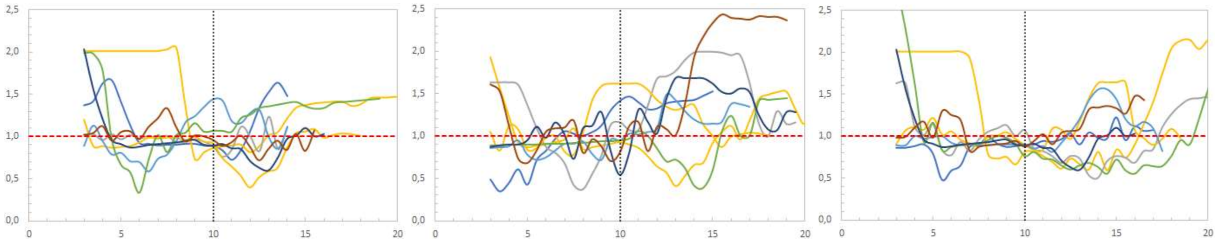
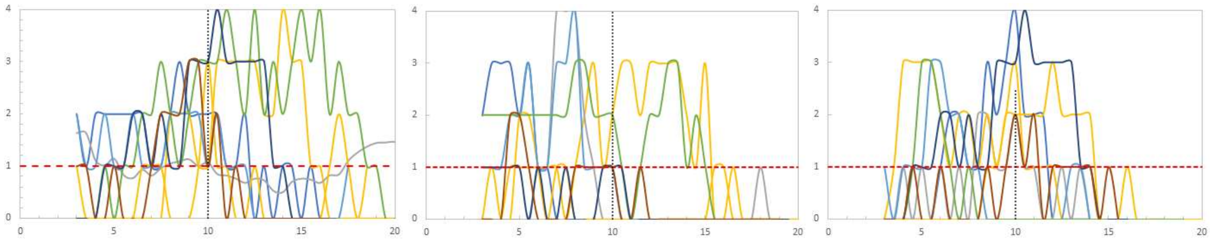


Figure 5: Summary plots with PathFinder calculated minimum, average and maximum exit time and First out and Last occupant exit times histograms

Population of 15 occupants formed by a group of 7 visitors and a guide and 7 autonomous visitors



(Closest occupant to the leader distance in m; time advancement in s).



(Count of occupants; time advancement in s)

Figure 6: Distancing metrics of the leader vs nearest visitor (above) and number of occupants within 1 m of the leader (below) (each graph shows eight runs). Social distancing set to 1 m. Population of 15 occupants formed by a group of 7 visitors and a guide and 7 autonomous visitors

The social distancing scheme applied to the group produce the emergence of patterns shown in Figure 7 like the V-shaped flock formation in the egress phase or the circle around the leader in the pre-evacuation phase.

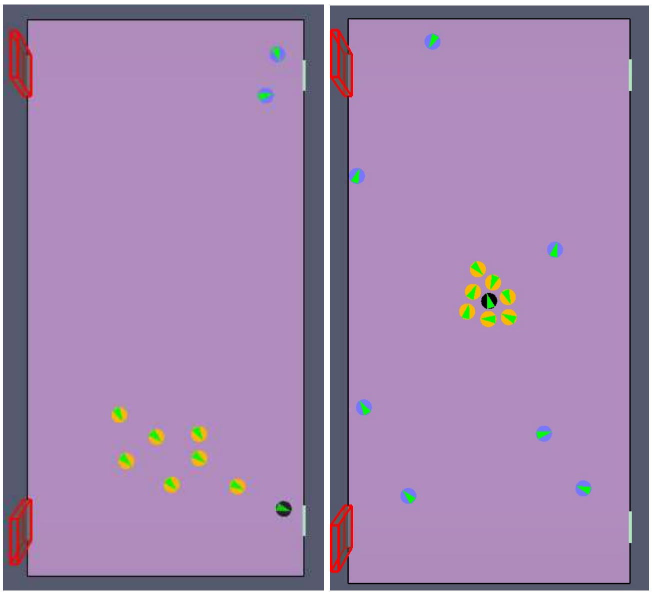


Figure 7: Emergent pattern for group movement when social distancing is applied

5. FUTURE RESEARCH

The design of a proper behavioural space deepen the understanding of the system. In the next step of the research program, the agents will be considered with different characteristics, physical and cognitive, introducing some statistical distribution and variability (gender, age, health), varying also the initial density and the number of groups. This will have impact, for example, to the movement and to the reaction times or the fatigue resistance. Different way out finding strategies can be considered, from gradient following to field attractors which could be of interest when investigating the effect of a design fire on the egress. Furthermore, the rules of behaviour of the agents could evolve from reactive to adaptive, and learning from experience will hopefully expand the potential of the agents. For the rules of the agents considered, a check will be made to try to grade their effect on the overall dynamic of the system, ranging from a forcing term (the system evolution is forced by the rules) to a boundary term (the system evolution is only started by the rules). In addition, it might be useful testing extreme conditions, with higher crowd densities, which in turn require checking some measurable quantity not obscured by the high crowd density itself.

REFERENCES

Erdi, P. (2008), "Complexity explained", Springer.

Grimm, V. and Railsback, S.F. (2005), "Individual-based modeling and ecology", Princeton University Press.

Grimm, V. and Railsback, S.F. (2012), "Agent-based and individual-based modeling", Princeton University Press.

NetLogo, available at: https://ccl.northwestern.edu/netlogo/.

Ponziani, F. A., Tinaburri, A. and V. Ricci (2018)," Multi Agent Approach To Analyse Shift In People Behaviour Under Critical Conditions", Int. J. of Safety and Security Eng., **8**(1), 1-9.

Rzevski, G. (2016), "Harnessing the power of self-organisation", *Int. J. of Design & Nature and Ecodynamics*, **11**(4), 483–494.

Thunderhead Engineering (2020), "Pathfinder – Technical reference".

Thunderhead Engineering (2020), "Pathfinder Monte Carlo User Manual".

Wilensky, U. and Rand, W. (2015), "An Introduction to Agent Based Modeling", MIT Press.