Fire and Evacuation Modeling Technical Conference

THUNDERHEAD ENGINEERING

EVACUATION MODELLING
Application to an office building using several simulation tools

CONTEXT

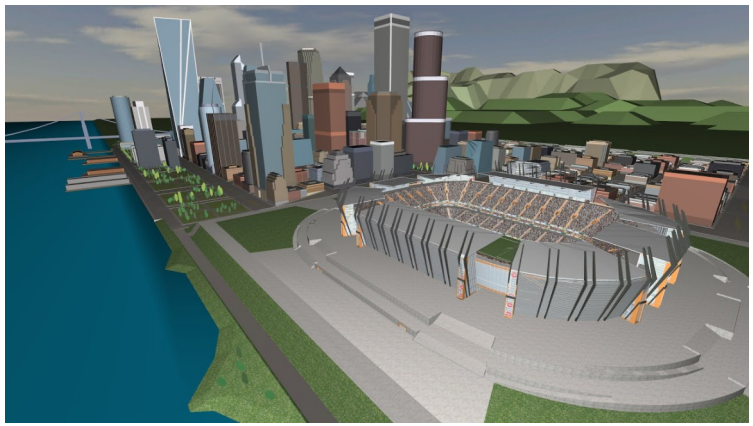
French Fire Regulations
(Prescriptive approach)
Fixed values (Nbr & width) depending on occupancy numbers.

Problem…

RUGBY WORLD CUP™ FRANCE 2023

PARIS 2024

Solution…



A COLLABORATIVE APPROACH

[1]CSTB
84, Avenue Jean Jaurès, Champs-sur-Marne
77447 Marne-la-Vallée cedex 2, France
quentin.iullien@cstb.fr

[2]EFECTIS France
Espace Technologique – Bât. Apollo, Route de l'Orme des Merisiers 91193 Saint Aubin – France
virginie.drean@efectis.com

[3]Movement Strategies
31-35 Kirby St, London, EC1N 8TE, UK,
bkabalan@movemenstrategies.com

[4]Université de Lorraine/LEMTA
LEMTA, Université de Lorraine, CNRS, 2 Avenue de la Forêt de Haye, TSA 60604, 54518, Vandœuvre-lès-Nancy cedex, France
anthony.collin@univ-lorraine.fr

[5]CNPP
Route de la chapelle Réanville, 27950 Saint-Marcel
nicolas.trevisan@cnpp.com, huy-quang.dong@cnpp.com, nicolas.bourlet@cnpp.com,

[6]Université Paris Saclay, CNRS, Laboratoire de Mathématiques d'Orsay, 91405, Orsay, France
sylvain.faure@math.u-psud.fr, bertrand.maury@math.u-psud.fr, etienne.pinsard@math.u-psud.fr

[7]LCPP
39bis Rue de Dantzig, 75015 Paris
jean-luc.paillat@interieur.gouv.fr

[8]STUDIO FAHRENHEIT
128 rue la Boétie, 75008 Paris, France
Romain.Hourqueig@Studio-Fahrenheit.com
Mamoune.Nejjar@Studio-Fahrenheit.com

BRIGADE DE SAPEURS-POMPIERS DE PARIS

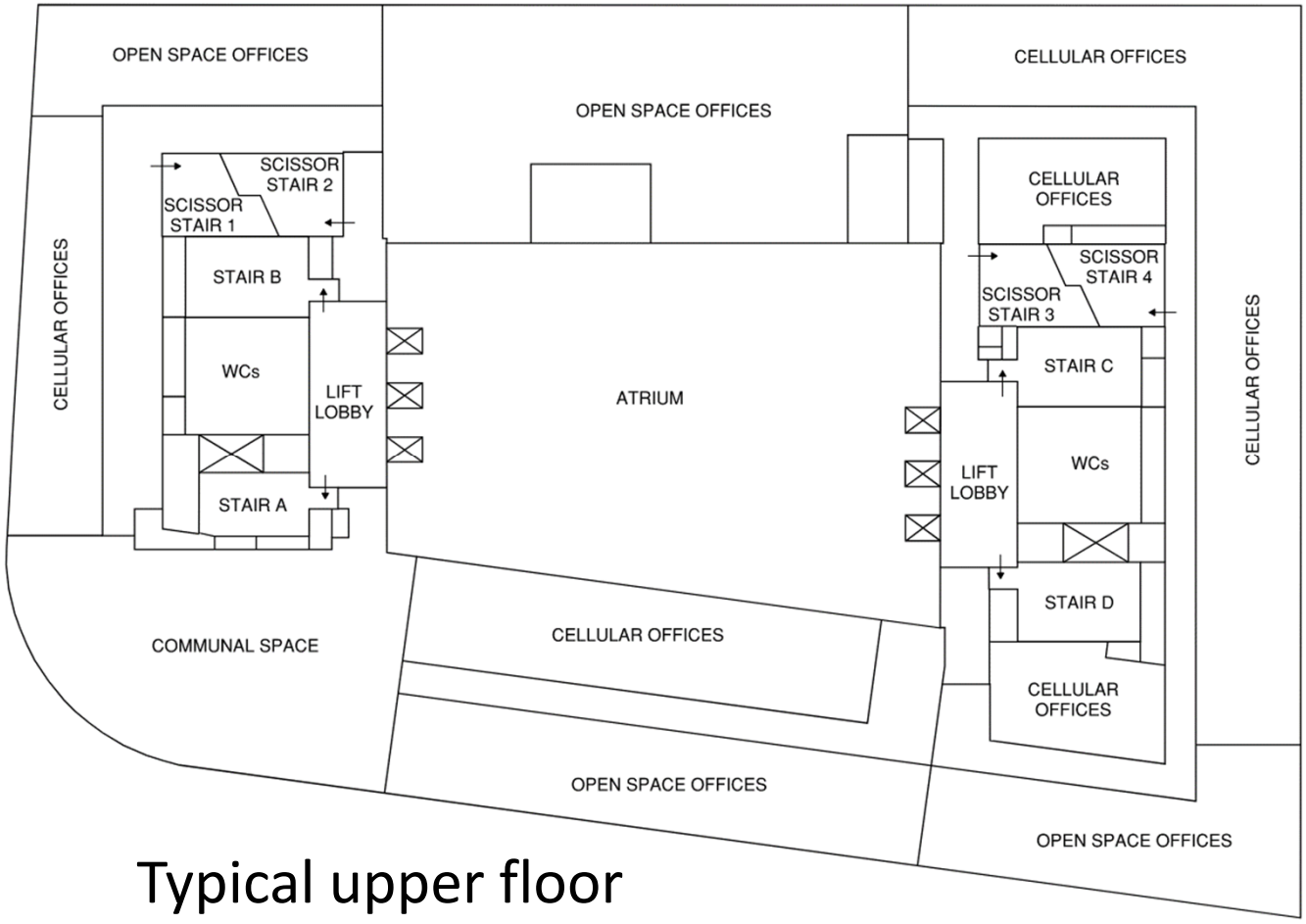
Jura SAPEURS-POMPIERS

CASE STUDY

10-storey office building
Compliant with French code
61m long x 44m wide
20,600m² in total area
8 egress stairs (2 scissor)
Occupancy during drill:

- L8: 133p L7: 169p
- L6: 139p L5: 249p
- L4: 218p L3: 146p
- L2: 0p L1: 137p
- GF: 65p Bst: 39p

TOTAL = 1350 people



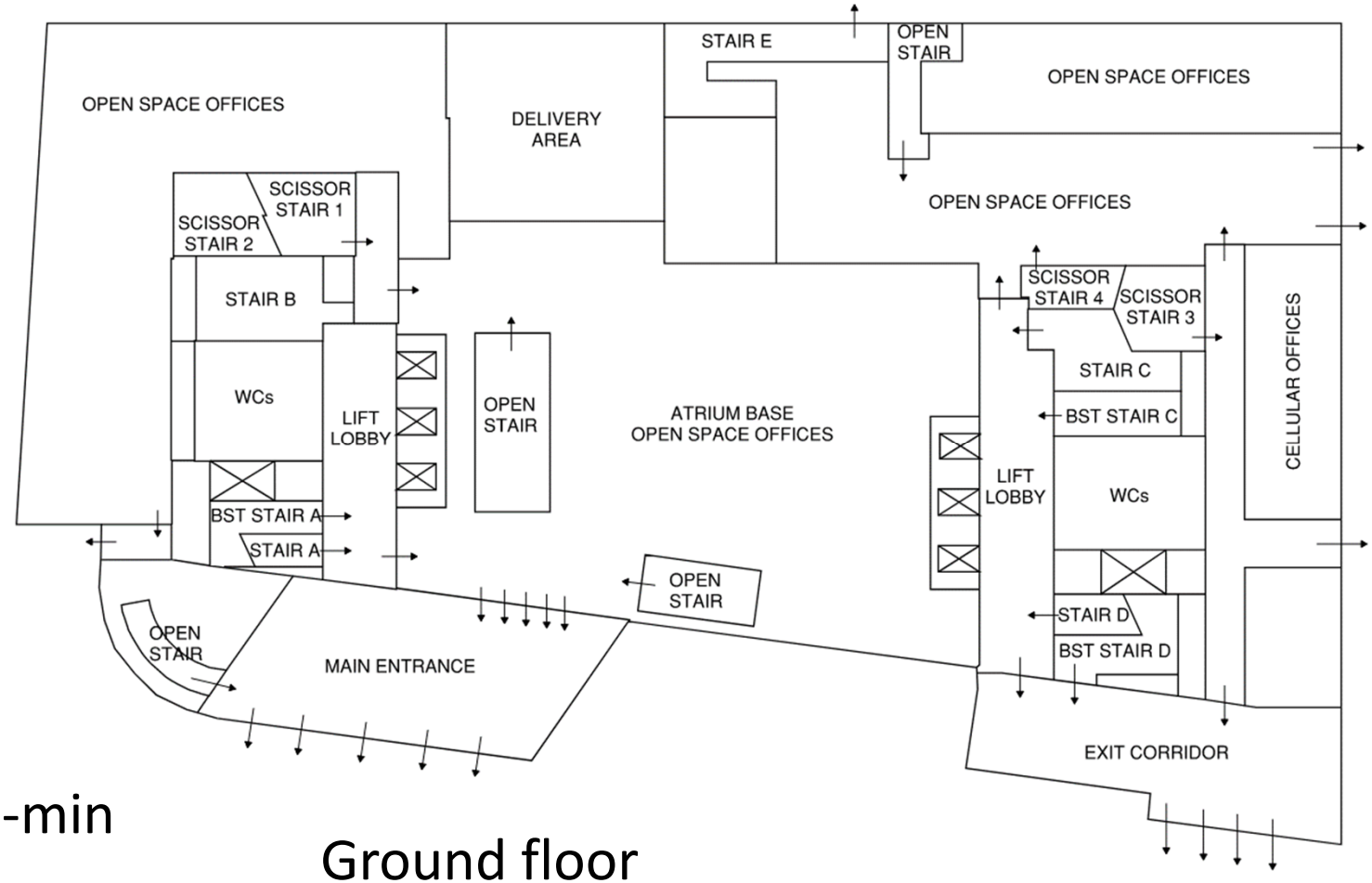
Typical upper floor

CASE STUDY

20 members on site
3 cameras installed in stair C.
CCTV throughout (except in stairs).
Very large single assembly point at rear.

Evacuation times:

- To outside: 7-min
- To assembly point: 8,5-min



Ground floor

EVACUATION MODELLING

A range of computer models used to simulate evacuation phenomena:

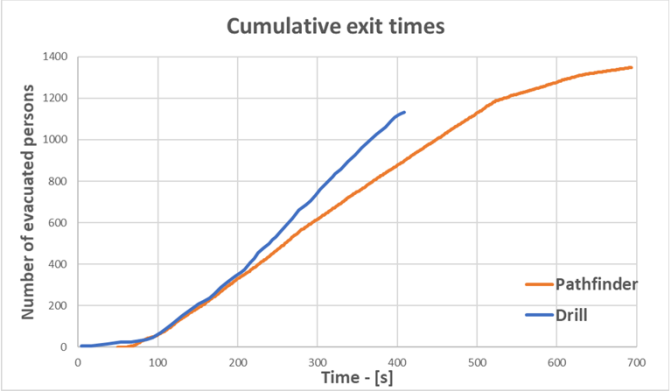
- Pathfinder (2 users)
- FDS+EVAC
- buildingEXODUS
- CROMOSIM (Compartment Model)
- CROMOSIM (Granular Model)

An a code compliant analytical approach:

- French code type GA premises – GA23 hand calculations

PATHFINDER – USER 1

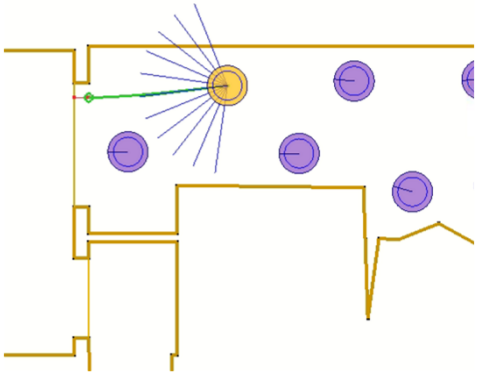
- Commercial software edited by ThunderHead Engineering;
- Microscopic Model :
  - 3D geometry model and 2D navigation mesh (triangulated);
  - Pathfinding : SFPE egress model (flow-based) or steering mode (collision handling);
  - Agents choose the exit that minimize their travel time ;
  - Walking speed is a function of terrain (e.g. slope, stairs, escalator…) and density.



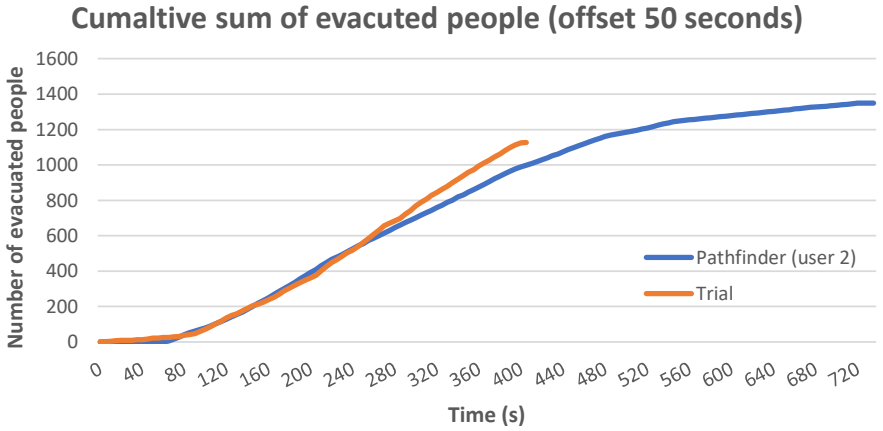
- Main results :
  - 10 simulations performed (with various occupants' initial distribution within each room);
  - Total egress time ~ 695 seconds (with 50 s offset)
    - Slopes are similar until ~200 s; After, evacuation is slower in simulation;
    - The first 1127 agents exit after 500 s (with 50 s offset) while the evacuation time of the drill is 410 s;
  - Can be explained by:
    - Congestion are observed at some staircases (entry and/or exit).
    - The default SFPE speed-density profile was used in the simulations ;
    - The free walking speeds (flat level or in stairs) used in the simulations are slower than speeds observed during the drill

PATHFINDER – USER 2

- Commercial pedestrian microscopic model edited by ThunderHead Engineering;
  - 3D geometry model and 2D navigation mesh (triangulated);
  - Pathfinding : SFPE egress model (flow-based) or steering mode (collision handling);
  - Agents choose the exit that minimize their travel time ;
  - Walking speed is a function of terrain (e.g. slope, stairs, escalator…) and density
- Main results :
  - Total egress time ~ 720 seconds (with 50 s offset)
    - Results start diverging after ~ 250 seconds.
    - This is due to the impact of congestion at bottlenecks (mainly stairs and doors)
  - Can be explained an overestimated drop in flow rates due to input assumptions:
    - The default SFPE speed-density profile was used in the simulations ;
    - The free walking speeds (flat level or in stairs) used in the simulations are slower than speeds observed during the drill

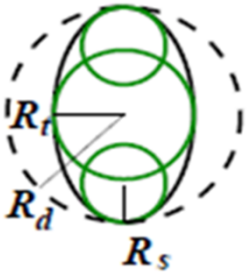


Pathfinder Steering mode

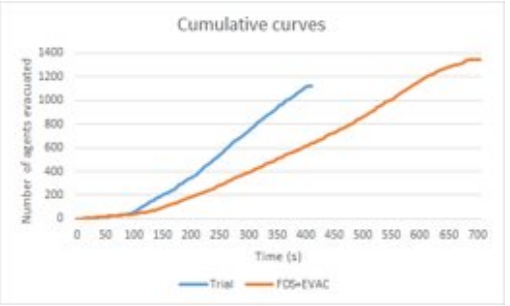


FDS+EVAC

- Evacuation module EVAC of the CFD code FDS (Fire Dynamics Simulator)
- Model of Helbing - Treats each evacuee as a separate entity (“agent”)
  - Own escape strategies
    - Equation of motion for each agent in a continuous 2D space (e.g., a horizontal xy-plane) and time,
    - Observes the actions of others - selects the target exit with evacuation estimated to be the fastest
  - Own personal properties
    - Agent characteristics mainly consist in body size and main walking velocity
    - Body shape made of 3 circles approximating the elliptical cross-sectional shape of the human body

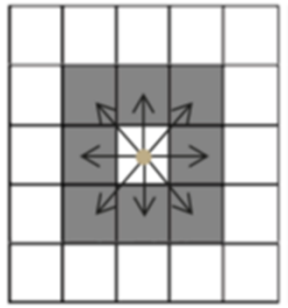


- Main results
  - 20 simulations performed
  - Total egress time ~ 705 seconds
    - Seems to be slower than during the real drill
    - The first 1127 agents exit after 585 s while the evacuation time of the drill is 410 s
  - Can be explained by:
    - Agents do not use the full width of the stairs due to the wall agent repulsive force.
    - Agents force the passage towards the interior of the stairs, which has the effect of reducing their speed and increasing congestion phenomena
    - Speeds used correspond to those recorded during the drill, already taking into account congestion phenomena.



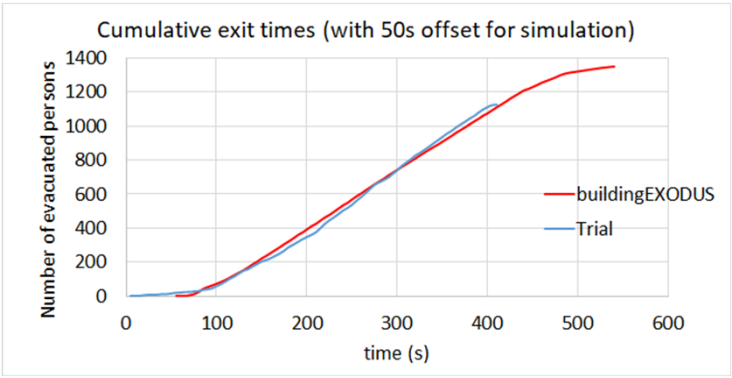
buildingEXODUS

- Microscopic model – each occupant has its own characteristics
  - A building is represented as a collection of levels linked together
    - Occupants move in a discretized 2D space made of nodes interconnected with arcs
    - Connecting network is according Moore's model
  - Default egress strategy
    - Calculation of a potential map (distance linking each node to the closest exit)
    - Each agent tries to minimize their travel time by optimizing their trajectories



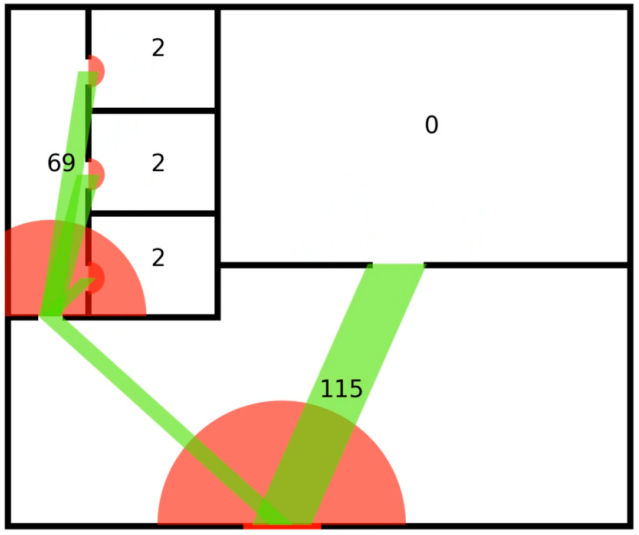
The Moore neighbourhood

- Main results
  - 10 simulations performed
  - Total egress time for 1349 persons ~ 490 seconds (without response time: RT)
    - Seems to be close to the real drill
    - The first 1127 agents exit after 365 s (without mean RT evaluated around 50 s)
    - evacuation time of the drill is 410 s
  - Can be explained by:
    - User decision to convert egress width of the staircases into a number of lane for stairs and width of landing door into one connection
    - Generate congestion on landing but in stairs occupants are staggered leading to an optimal use of the full stair widths



CROMOSIM – COMPARTMENT MODEL

- Macroscopic model
  - A building is represented as a graph of rooms connected together
    - Each node represents a door with maximum capacity
    - An arc represents the path between two doors with a determined travel time
  - Default egress strategy
    - Each time interval, if people are waiting in a door, a quantity is injected into the path
    - Quantity is controled by maximum capacity of doors
    - This Quantity is added to the arrival node's stack when travel time is complete
- Main results
  - 1 simulation performed, with a 391 nodes graph
  - Total egress time for 1349 persons ~ 432 seconds (without pre-movement time: PM)
    - Seems to be close to the real drill
    - evacuation time of the drill is 410 s

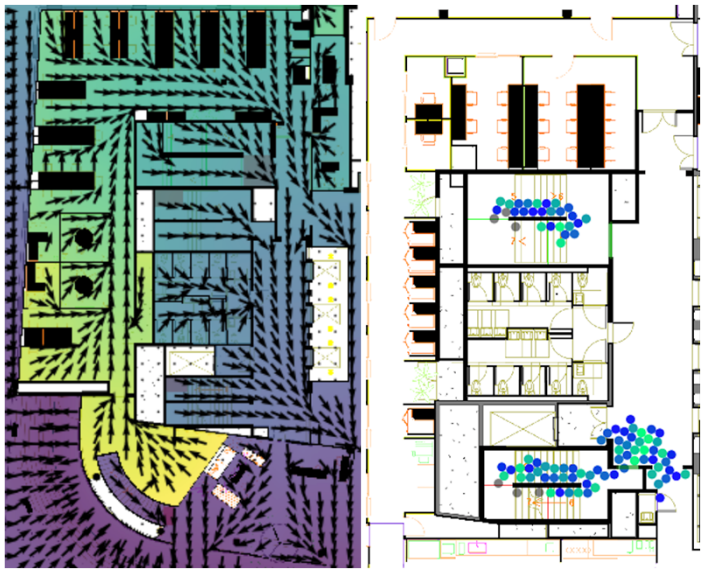


CROMOSIM – GRANULAR MODEL

- Microscopic model –
  - A building is represented as a collection of interconnected maps (floors and stairs)
  - Default egress strategy : Computation of the velocity field associated to shortest path
  - Actual velocity defined as the closest to the desired velocity among admissible motions (which avoid overlapping)
  - The congestion is handled in a **hard way** : approach especially adapted to represent highly crowded situations

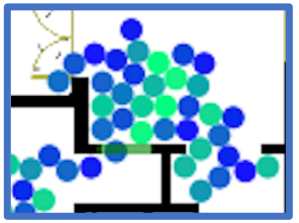
Main results

- 2 simulations performed
- Total egress time for 1349 persons :
  415 seconds (without response time: RT)
  - Smaller that the time computed by most other tools
  - evacuation time of the drill is 410 s
- Can be explained by:
  - Size of individuals has been reduced to avoid static jams
  - Social tendencies have been added to reduce clogging



Desired velocity field

Congestion near a stair



Zoom to see people in contact

ANALYTIC APPROACH

Code compliant approach defined in French fire regulations (prescriptive).

Approach prescribed to design egress routes from railways stations (GA23).

Flow rate data (corridors, doors, escalators, etc.) taken from real evacuation events.

Methodology:

- For each floor, take the further point and calculate horizontal travel time to exit access.
- Based on floor occupancy, calculate flow time through floor exit access.
- Calculate the vertical travel time to ground floor and then horizontal travel time to outside.
- Add all times together to determine the total evacuation time.
- Run similar calculations floor by floor and select the longest egress time.

Calculated evacuation time = (177s) **3-min** (without pre-movement time).

INPUT & OUTPUT DATA

Input or Output – all depends on the computer model!

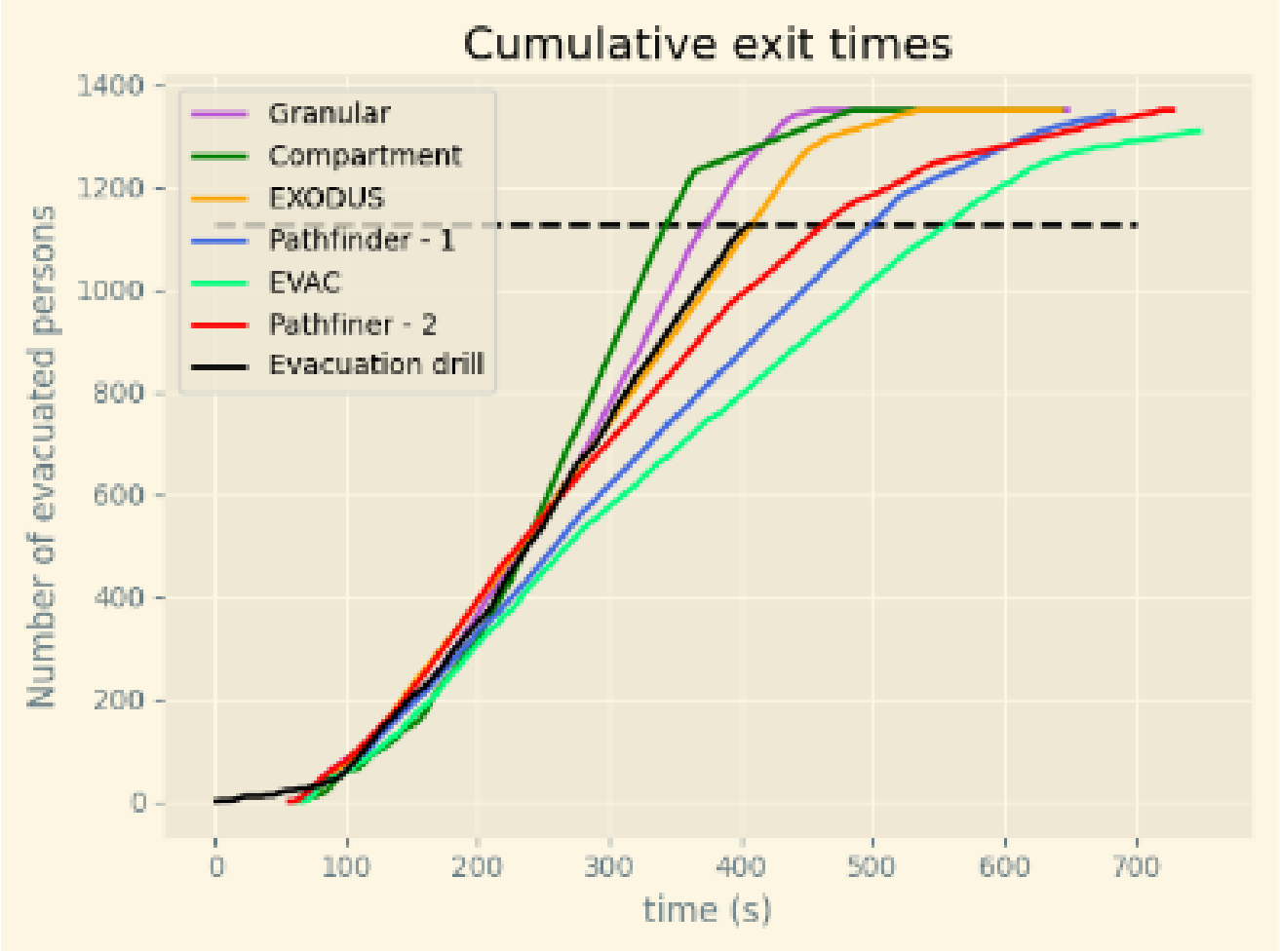
	Pathfinder* User 1 and 2	FDS+EVAC	building EXODUS	Cromosim Granular	Cromosim Compartment	Analytic GA 23
Walking velocity (m/s)	0,9	0,9	0,9	0.9	0.9	1
Walking velocity in stairs (m/s)	0,6	0,6	0,6	0.6	0.6	0.4
Maximum density (pers/m^2)	4	4	4	no	no	no
Maximum flow rate at doors (pers/m/s)	1,33	no	1,33	no	1,66	0,92
Initial agent location Y/N How	Randomized per room	Randomized per room	Randomized per room	Randomised per room	Uniform per room	Per floor with a horizontal and vertical distance to do
Agent diameter(m)	2xRd*** = 0.45	2xRd*** = 0.51±0.07	0.5 x 0.5 m^{2**}	0.40±0.01	NA	NA
Space meshing	Triangulated navigation mesh	Cartesian mesh	Space grid mesh	Cartesian mesh	NA	NA

*: modelling software Pathfinder was used by 2 entities

**: relative to cell size

***: shoulder radius of an agent

RESULTS

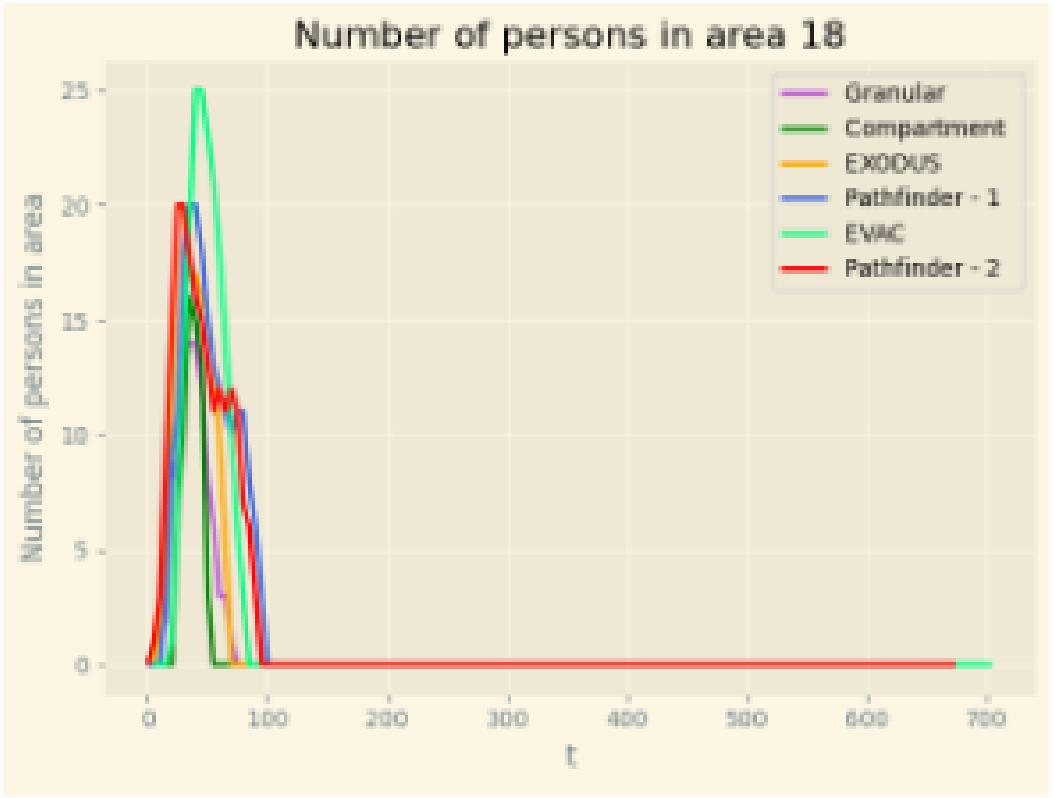


Similar results up to 4-min.

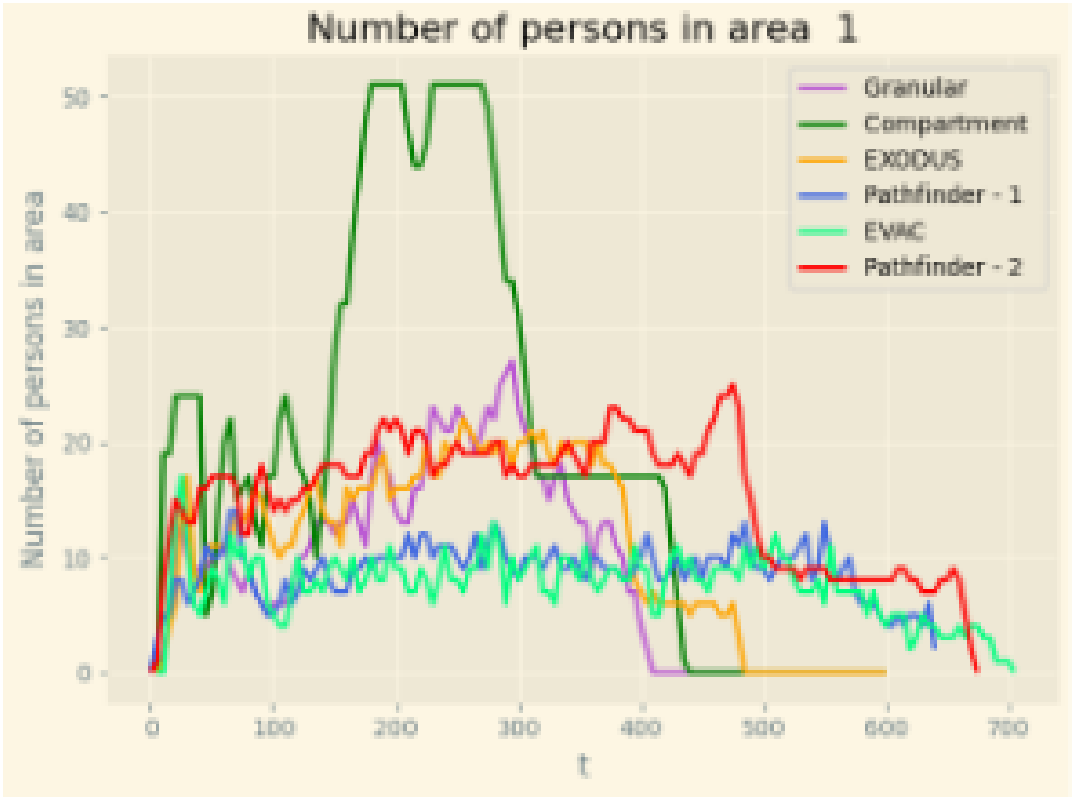
Then curves move apart.

Congestion and merging flows treated differently.

RESULTS



Occupancy in area 18



Occupancy in area 1

RESULTS

Table 3: Egress time for the last occupant to reach the bottom of the stairs for different tools Note: this table does not include the pre-movement time in the simulation results

	Egress time of the last occupant (s) to reach the bottom of the stairs						
	Pathfinder User 1	Pathfinder User 2	FDS+EVAC	building EXODUS	Cromosim Granular	Cromosim Compartment	Drill
Staircase A	483	405	680	413	343	283	385
Staircase B	614	630	560	459	311	389	335
Staircase C	379	304	440	315	298	249	340
Staircase D	442	418	560	410	353	265	355
Scissor stair 3	147	140	165	124	136	192	175
Scissor stair 4	150	148	185	121	146	199	-

Analytical approach not compared with other results as merging flows are not considered.

SYNTHESIS

1st set of drill and evacuation modelling carried out.

Objective was not to validate the tools (too early).

50s pre-movement time added to all results above (obtained from drill) as a fixed value. This is not 100% as the PM time during the drill ranged from 10s to 80s.

Input of walking velocities in stairs & corridors taken from drill, so already include congestion effect (counted twice!).

CONCLUSION & NEXT STEPS

Code compliant analytic approach (GA23) not applicable to multi-storey buildings.

Future drills' attendance to confirm/obtain additional test/input data for models.

To equip more stairs with video equipment to better understand merging flows.

To continue modelling to better apprehend simulation of merging flows.

Attempt to validate the computer models.

THANK YOU!!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