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Coupling of Evacuation and Fire Modelling through Soot Level Analysis

5th Fire and Evacuation Modeling Technical Conference (FEMTC)

September 9th - 11th, 2020

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Outline

1. Background
2. Literature review
3. Proposed methodology
4. Comparison of the methodologies
    a. Results
    b. Discussion
5. Conclusion

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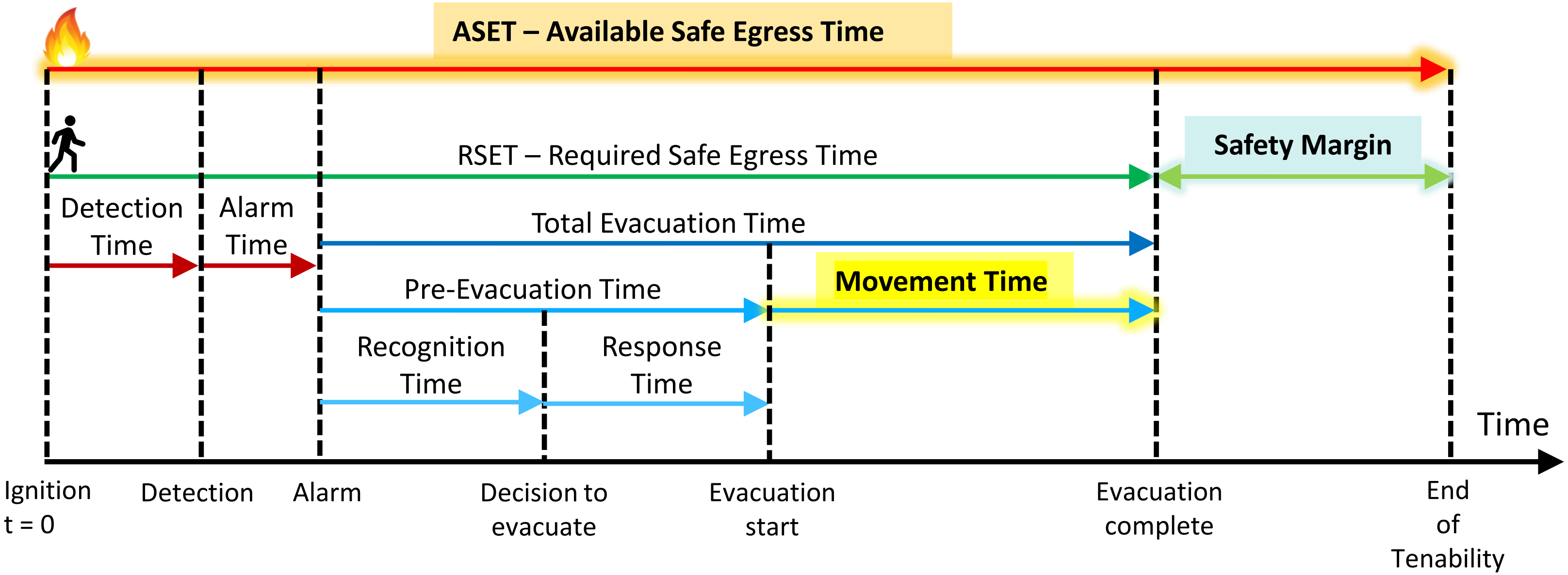
Background

N.B. Scale varies depending on the situation
Image based on Lovreglio (2016)



Source: Lovreglio, R. (2016). Modelling Decision-Making in Fire Evacuation based on Random Utility Theory. PhD Thesis. https://doi.org/10.13140/RG.2.1.1695.5281/1

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Background

Typical tenability conditions:

1. Visibility
2. FED / CO Concentration
3. Temperature
4. Smoke layer temperature

Source:
National Fire Protection Association (2017). NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems. Quincy, MA: National Fire Protection Association, 2017.

Removed for confidential reasons

Background

Previous coupling with commercial software in the industry:

Fire Dynamics Simulator (FDS), *NIST*	**SMARTFIRE, *FSEG, The University of Greenwich***
➢ Pathfinder, *Thunderhead Engineering* ➢ STEPS, *Mott MacDonald* ➢ Evac (FDS+Evac), *NIST*	➢ buildingEXODUS, FSEG, The University of Greenwich

Sources:

- Thunderhead Engineering, 2020. Coupling Pyrosim Fire Results And Pathfinder Movement. [online] Thunderhead Engineering. Available at: <https://support.thunderheadeng.com/tutorials/pathfinder/coupling-pyrosim-pathfinder/> [Accessed 1 August 2020].
- Korhonen, T. (2018). Fire Dynamics Simulator with Evacuation: FDS+Evac Technical Reference and User's Guide (FDS 6.6.0, Evac 2.5.2, DRAFT), VTT Technical Research Centre, Finland.
- Fridolf, K., Ronchi, E., Nilsson, D. & Frantzich, H. (2013) Movement speed and exit choice in smoke-filled rail tunnels. Fire Safety Journal. [Online] 59, 8–21. Available from: doi:10.1016/j.firesaf.2013.03.007.
- Ronchi, E., Gwynne, S.M.V., Purser, D.A. & Colonna, P. (2012) Representation of the Impact of Smoke on Agent Walking Speeds in Evacuation Models. Fire Technology. [Online] 49 (2), 411–431. Available from: doi:10.1007/s10694-012-0280-y.
- Sargant, T., Nightingale S., Disdale-Young, O. & Ganeshalingam, J. (2014). Evacuation Modeling in Road Tunnel Fire Events – CFD Influencing Evacuation Results. FEMTC 2014.
- Rådemar, D., Blixt, D., Debrouwere, B., Melin, B.G. & Purchase, A. (2017). Practicalities and Limitations of Coupling FDS with Evacuation Software. WSP Sweden.
- Galea, E.R., Wang, Z., Veeraswamy, A., Jia, F., Lawrence, P.J. and Ewer, J. (2008). Coupled Fire/Evacuation Analysis of the Station Nightclub Fire. Fire Safety Science 9: 465-476. doi:10.3801/IAFSS.FSS.9-465.

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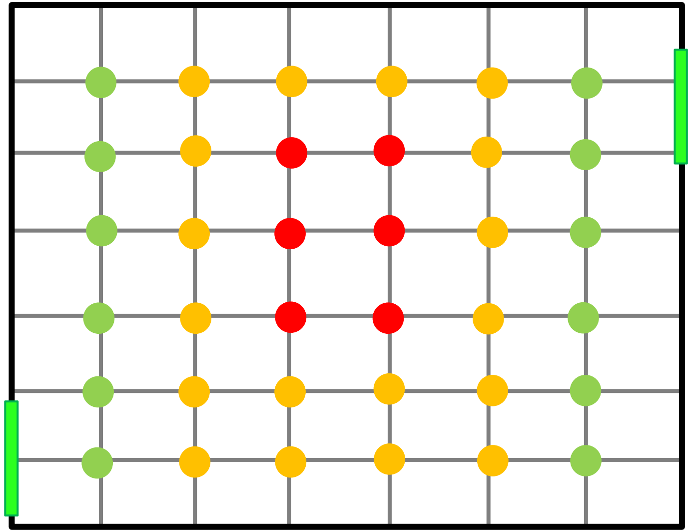
Oasys MassMotion

Software Development Kit (SDK)

(C++, C#, Java, Python)

Current practice in the industry

● Vis = 2 m   ● Vis = 30 m



Plan View at 2.5 m head height, as prescribed in NFPA 502 B.3.

B.3 Geometric Considerations. Some factors that should be considered in establishing a tenable environment in evacuation paths are as follows.

(1) The evacuation path requires a height clear of smoke of at least 2.0 m (6.56 ft). The current precision of modeling methods is within 25 percent. Therefore, in modeling methods a height of at least 2.5 m (8.2 ft) should be maintained

Source:
National Fire Protection Association. (2020) Standard for Road Tunnels, Bridges, and Other Limited Access Highways. NFPA 502. National Fire Protection Association (NFPA). Quincy, MA, USA.

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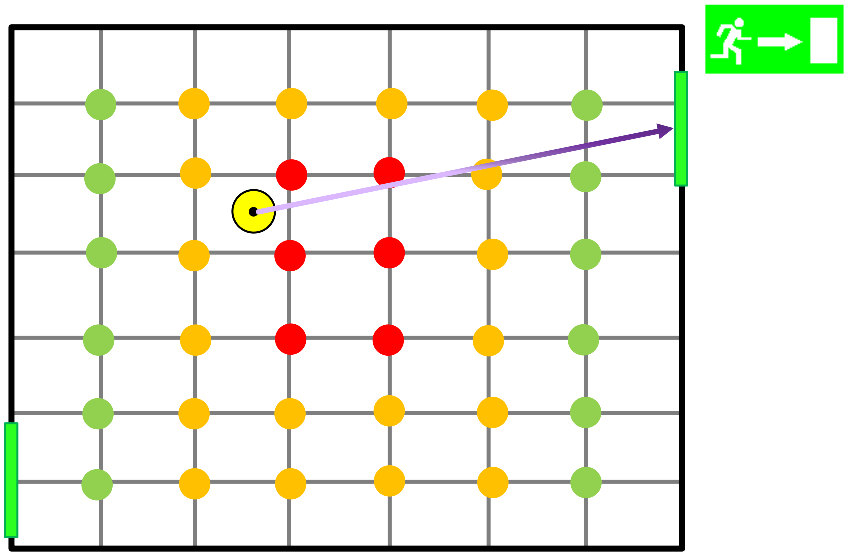
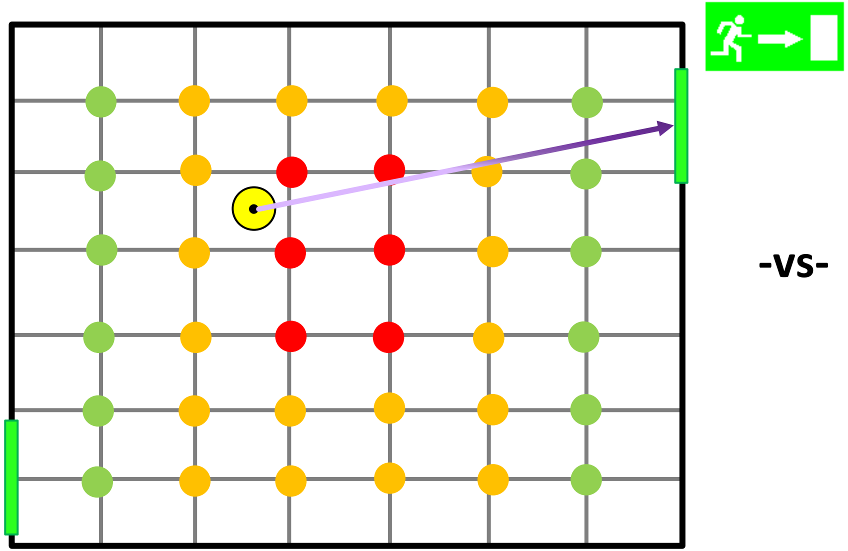
Current practice in the industry

● Vis = 2 m ● Vis = 30 m ○ Agent

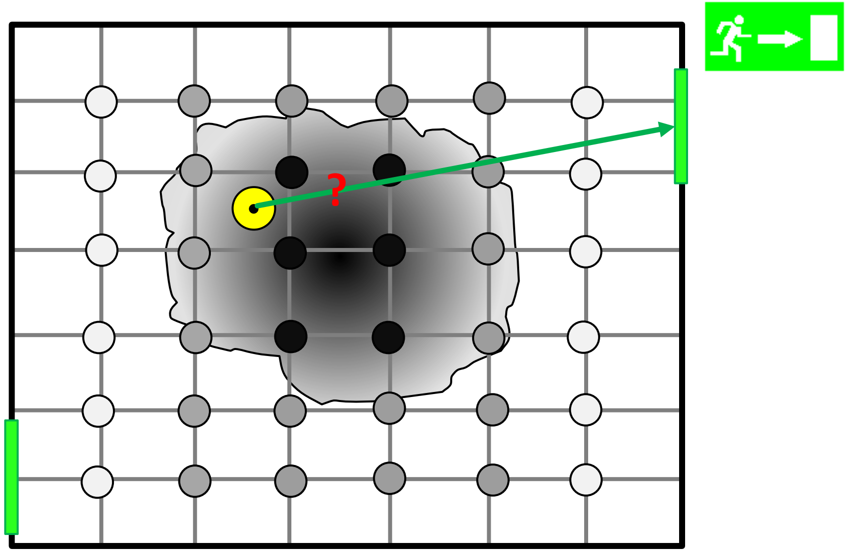


Our assumption

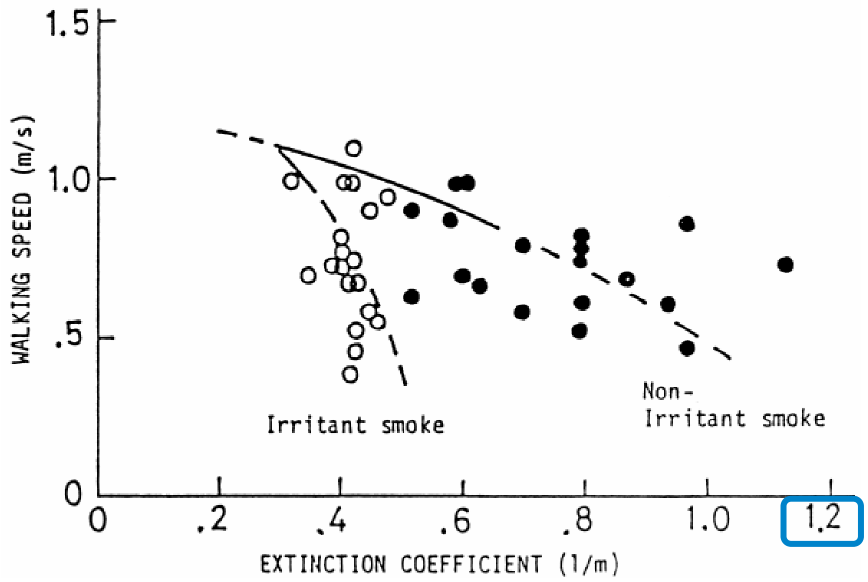
● Vis = 2 m ● Vis = 30 m ● Agent ● Soot level



-vs-



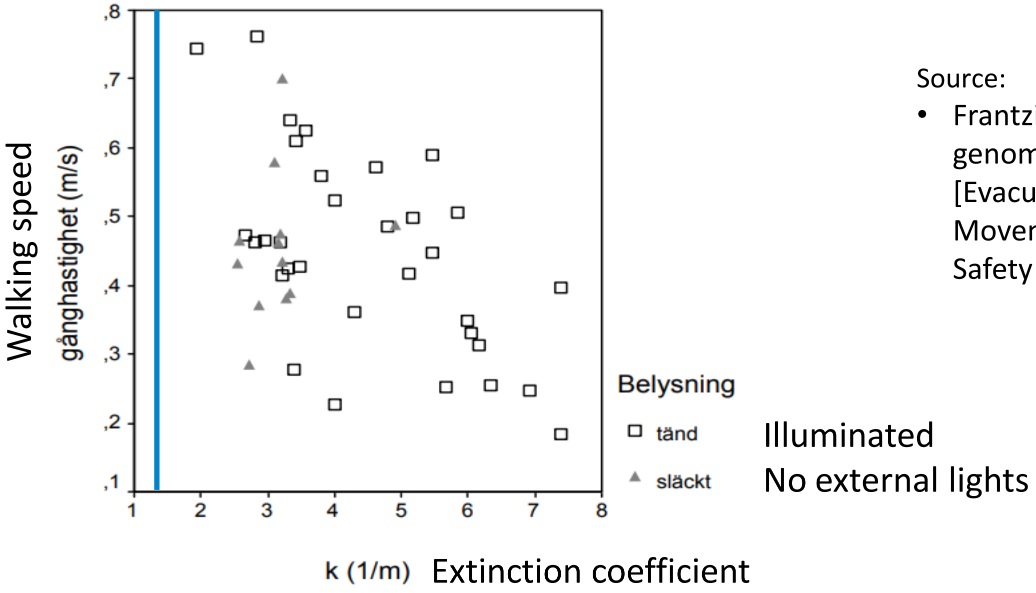
Walking speed vs extinction coefficient (Jin, 1970)



$$Visibility = \frac{Constant}{extinction\ coefficient}$$

Source:
- Jin, T. (1970) Visibility through Fire Smoke, Bull. of Japanese Assoc. of Fire Science & Eng., 19, 2, (pp. 1–8).

Walking speed vs extinction coefficient (Frantzich and Nilsson, 2003)



Source:

- Frantzich, H., and Nilsson, D. (2003) Utrymning genom tät rök: beteende och förflyttning, [Evacuation in dense smoke: Behaviour and Movement] 75 p., Report 3126, Department of Fire Safety Engineering, Lund University, Sweden

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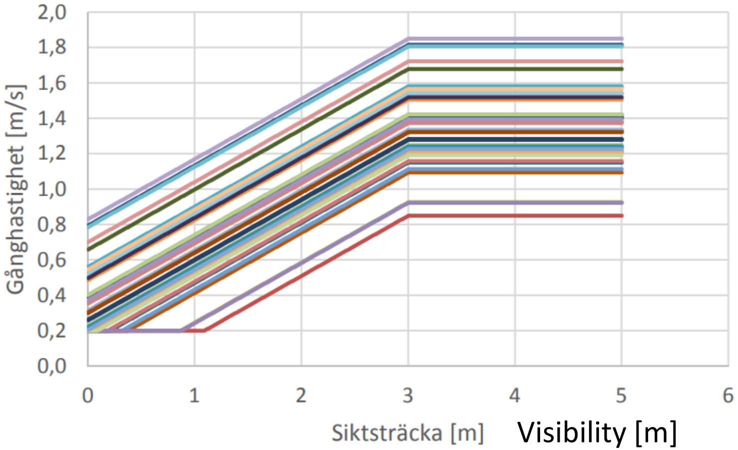
Walking speed vs visibility (Fridolf et al, 2016/2018)

$$v = \min(v_{smoke-free}; \max(0.2, v_{smoke-free} - 0.34 \times (3 - Visibility))$$

Walking speed [m/s]



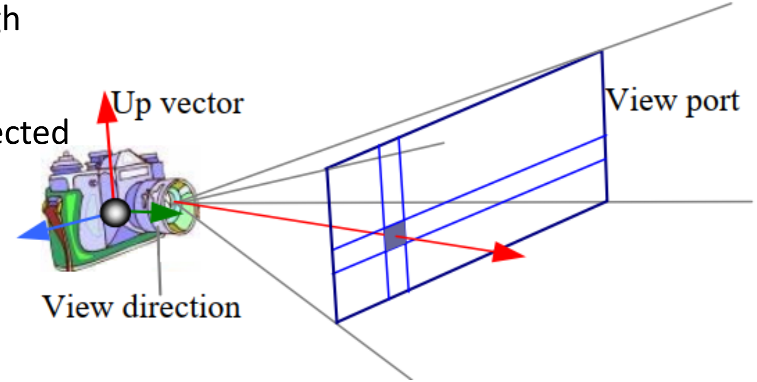
Visibility [m]

Source:
Fridolf, K., Nilsson, D., Frantzich, H., Ronchi, E. & Arias, S. (2016). Människors gånghastighet i rök: Förslag tillrepresentation vid brandteknisk projektering.
Fridolf, K., Nilsson, D., Frantzich, H., Ronchi, E. & Arias, S. (2018). Walking Speed in Smoke: Representation in Life Safety Verifications.

Ray tracing method (Kang, 2005)

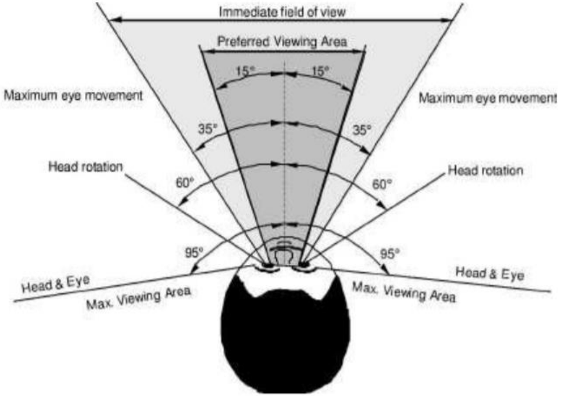
- Kang (2005) proposed having a camera is set up at a given location to cast rays and simulate how it propagates through space.
- A raster image is created with dimmed pixels for waves affected by smoke.
- Visibility is deduced based obscurity levels using Bouguer-Lambert-Beer Law,

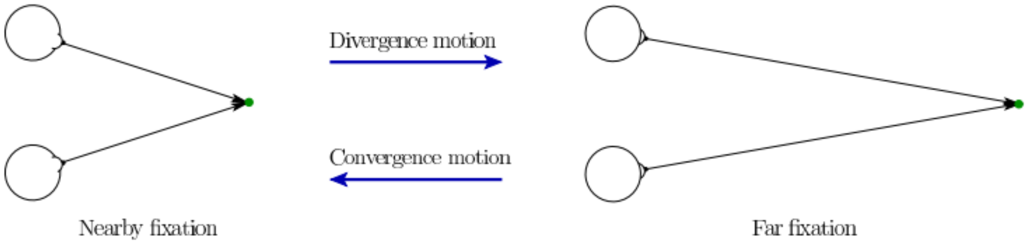
$$I = I_0 exp(-s\alpha_m \sum_{i=1}^{n} \rho_i \omega_{s,i}) \le I_t$$



Source: Kang, K (2005) Modeling Smoke Visibility in CFD. Fire Safety Science 8: 1265-1276. doi:10.3801/IAFSS.FSS.8-1265

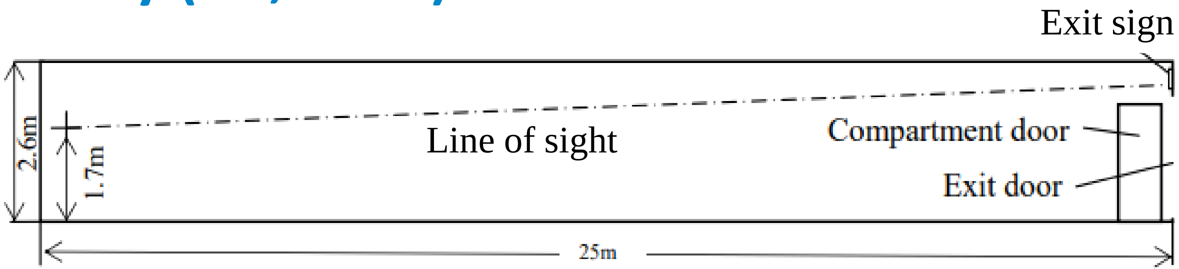
Physiology of human vision (Lavelle, 2019)





Source: Lavelle, S. (2019) The Physiology of Human Vision. Virtual Reality. University of Oulu. Cambridge University Press.

Virtual visibility (He, 2009)



- He (2009) evaluates tenability (not the impact on the walking speed) based on the **average** extinction coefficient along the line of sight
- Virtual visibility, S_{aL}

$$S_{aL} = \frac{Constant}{average\ extinction\ coefficient, K_{aL}}$$

$$K_{aL} = \frac{1}{d}\int_0^d K(s)ds$$

Source: He, Y. (2009) Evaluating visibility using FDS modelling result [online]. In: FSE09: Fire Safety Engineering International Conference: Charting the Course. Melbourne, Vic.: Engineers Australia Society of Fire Safety: [77]-[88]. Availability: <https://search.informit.com.au/documentSummary;dn=932351910776036;res=IELENG> ISBN: 9780977559640. [cited 28 Aug 20].

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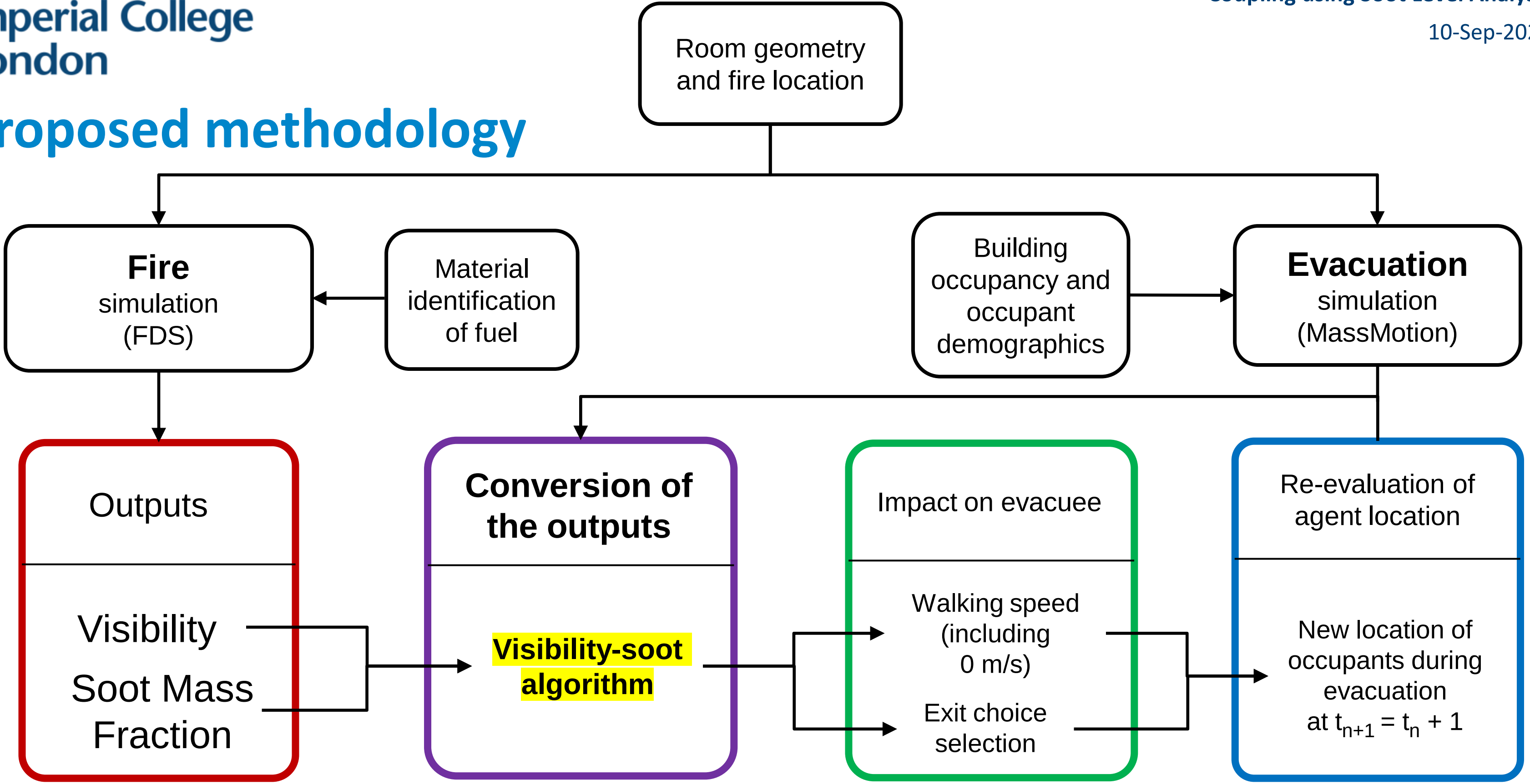
Proposed methodology



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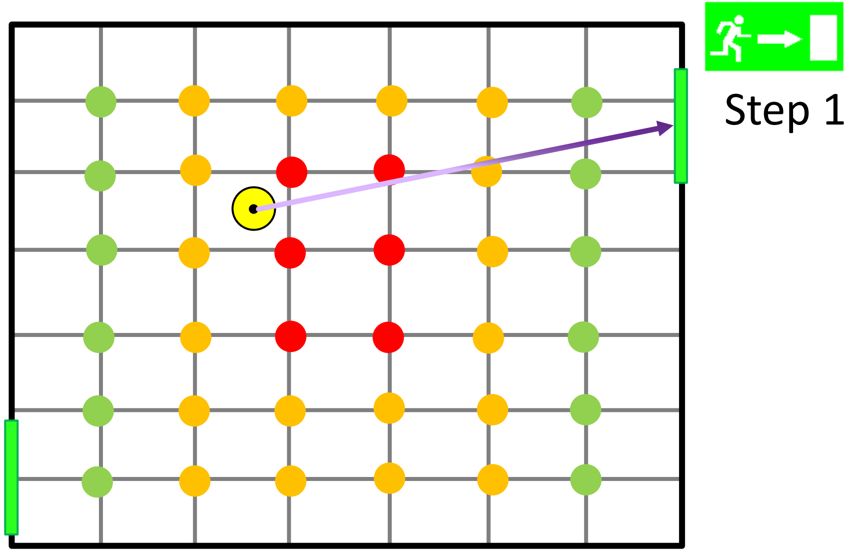
Visibility-SOOT algorithm

Agent Vis = 2 m Vis = 30 m Walked route and speed



Step 1. **Visibility** impacts the walking speed (Fridolf et al, 2016/2018)

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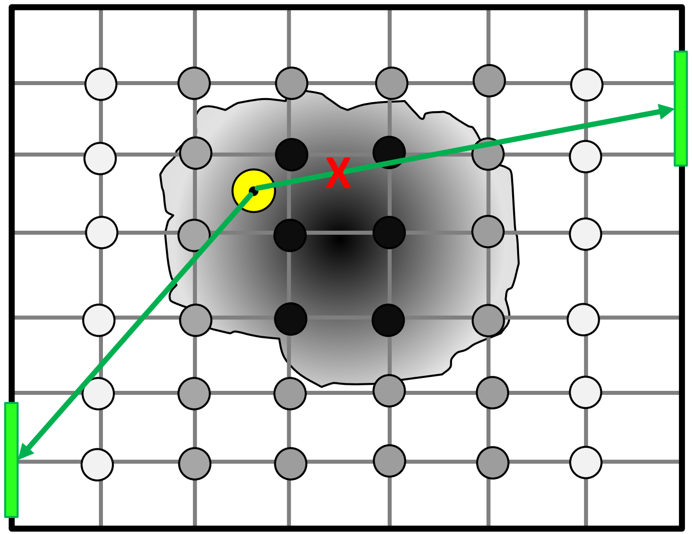
Visibility-SOOT algorithm

Agent   Soot level   Line of sight at head height



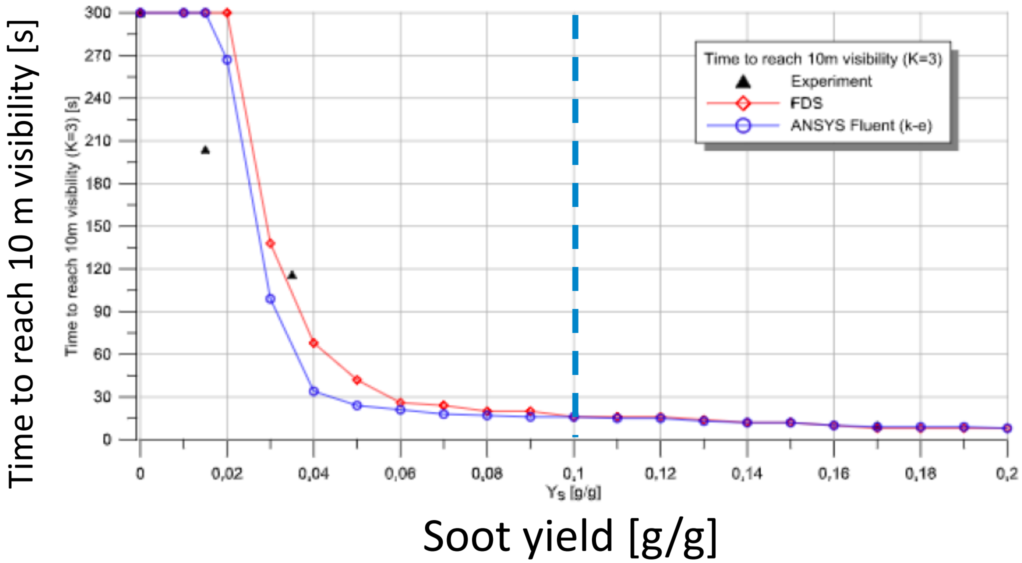
Step 1. **Visibility** impacts the walking speed (Fridolf et al, 2016/2018)

Step 2. **Soot level** impacts the exit choice

a. Shoot a single ray at head height to all the exits in a line of sight
b. Compare the maximum soot mass fraction to a threshold to select the exit

Visibility-SOOT algorithm – soot yield threshold

Wegrzynski, W. & Vigne, G. (2017)



"[…] the value of soot yield below approximately 0.10 g/g should be used with extremely cautiousness when performing an ASET/RSET exercise."

Source:
Wegrzynski, W. & Vigne, G. (2017) Experimental and Numerical Evaluation of the Influence of the Soot Yield on the Visibility in Smoke in CFD Analysis. Fire Safety Journal. 91 389-398. Available from: https://doi.org/10.1016/j.firesaf.2017.03.053.

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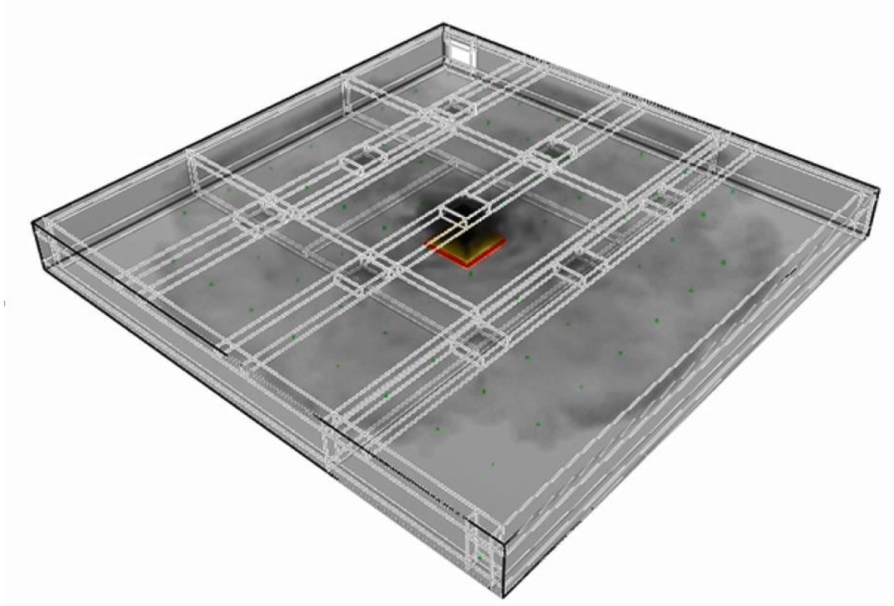
Geometry

- 50m x 50m open plan room
- 2 exits – 2m and 4m wide
- Ventilation system
- Fire source: Sofa with HRR of 3MW

- 30 agents
- 300 second pre-evacuation time
- 7 entry portals



Similar to the geometry from Fang et al. (2010)

Sources:
HM Government of United Kingdom. The Building Regulations 2010. Approved Document B. Fire Safety. Volume 1: Dwellings. 2019 edition – for use in England. United Kingdom; 2019.
Fang, Z.-M., Song, W.-G., Zhang, J. & Wu, H. (2010) A Multi-Grid Model for Evacuation Coupling with the Effects of Fire Products. Fire Technology. [Online] 48 (1), 91–104. Available from: doi:10.1007/s10694-010-0173-x.

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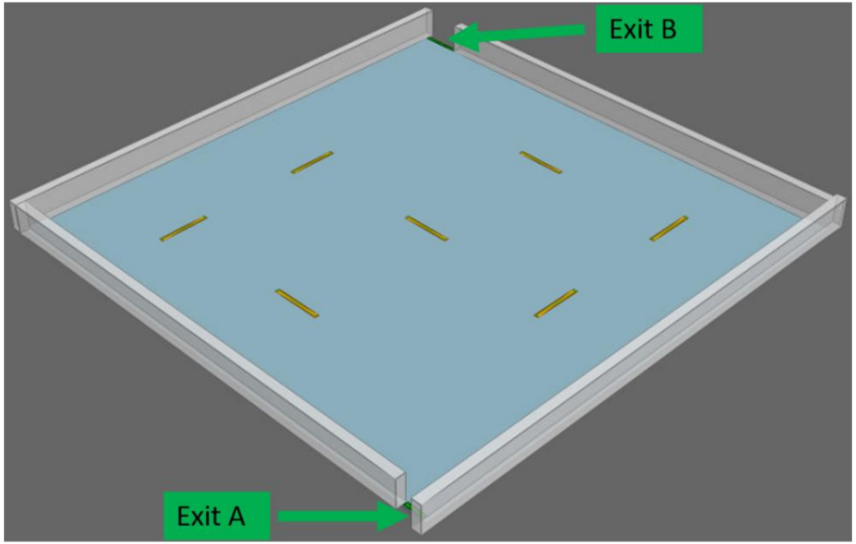

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HM Government of United Kingdom. The Building Regulations 2010. Approved Document B. Fire Safety. Volume 1: Dwellings. 2019 edition – for use in England. United Kingdom; 2019.
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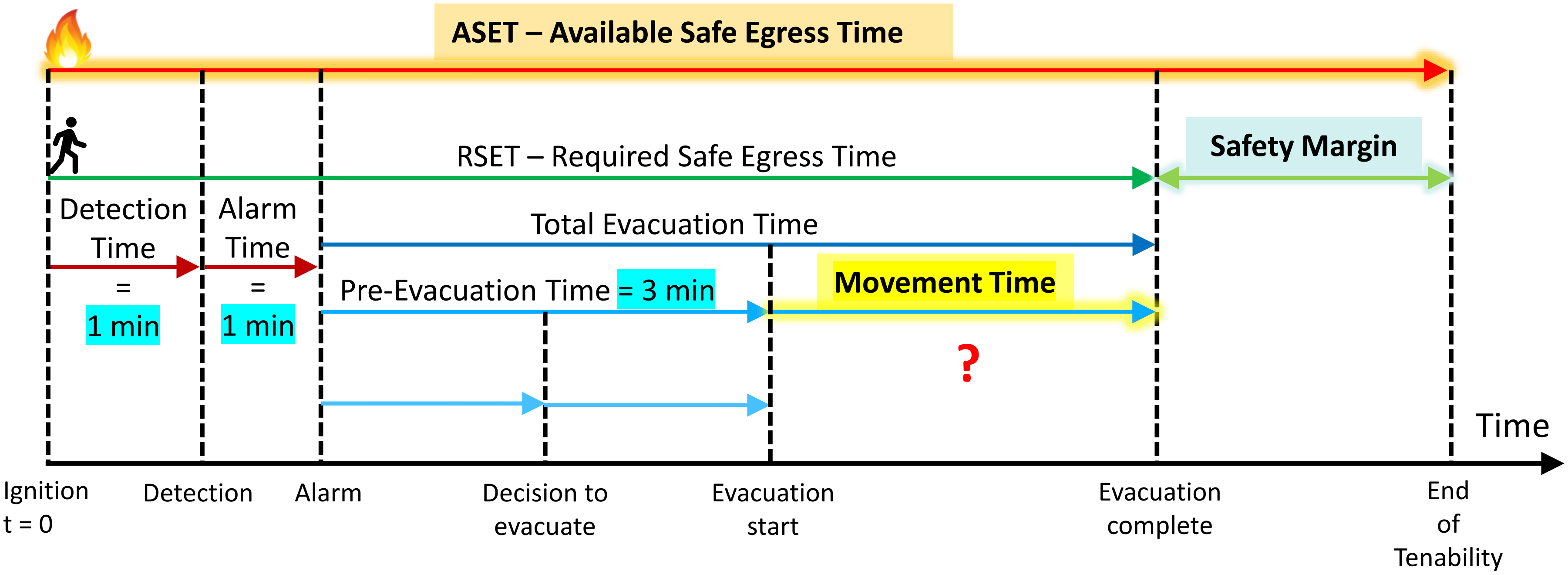
Demographics



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Coupling using Soot Level Analysis

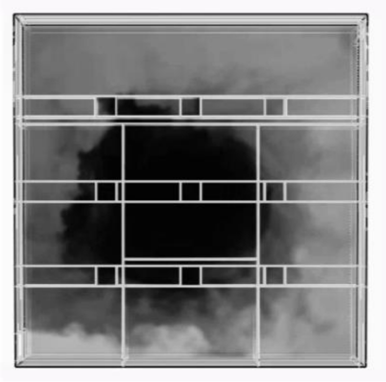
10-Sep-2020

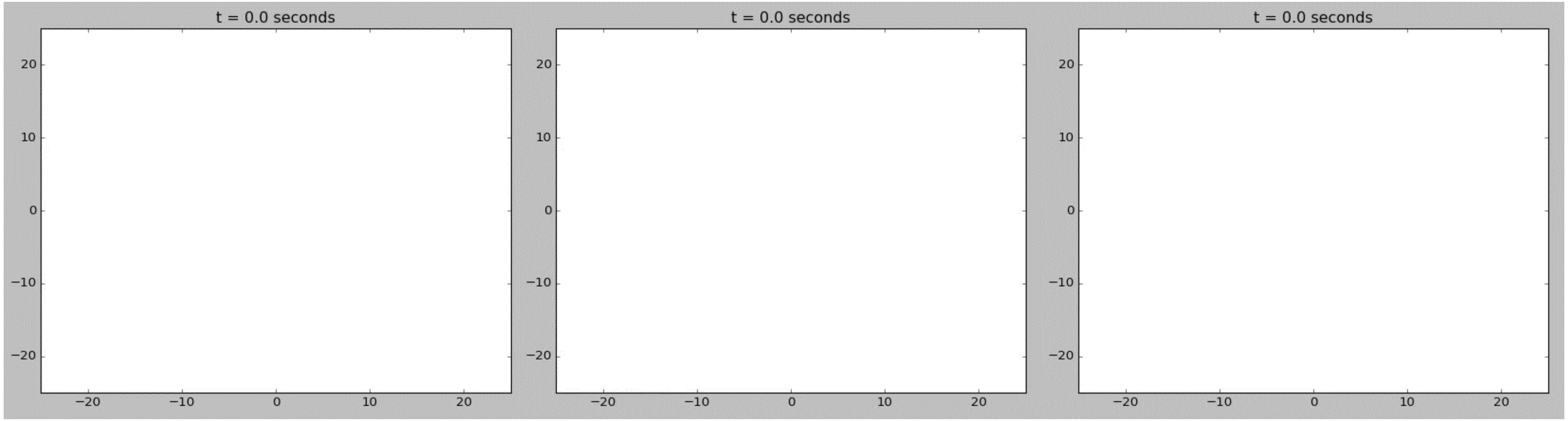
Results

Agent movement

Plan view of the room

(t starts after pre-evacuation period)





Only evacuation | Visibility only | Visibility-Soot

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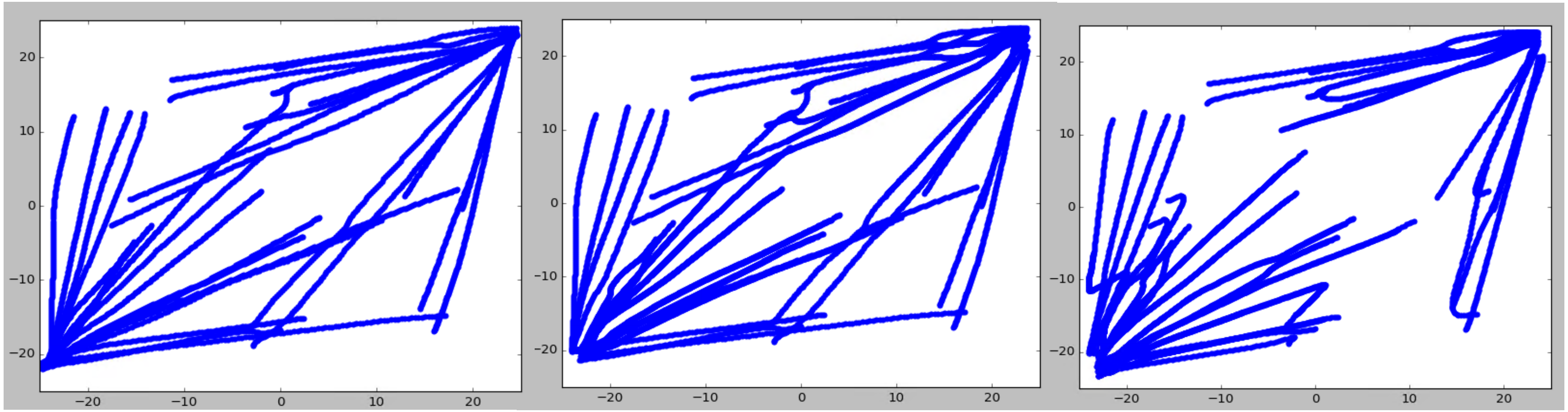
Results

Agent paths

Plan view of the room



Only evacuation | Visibility only | Visibility-Soot

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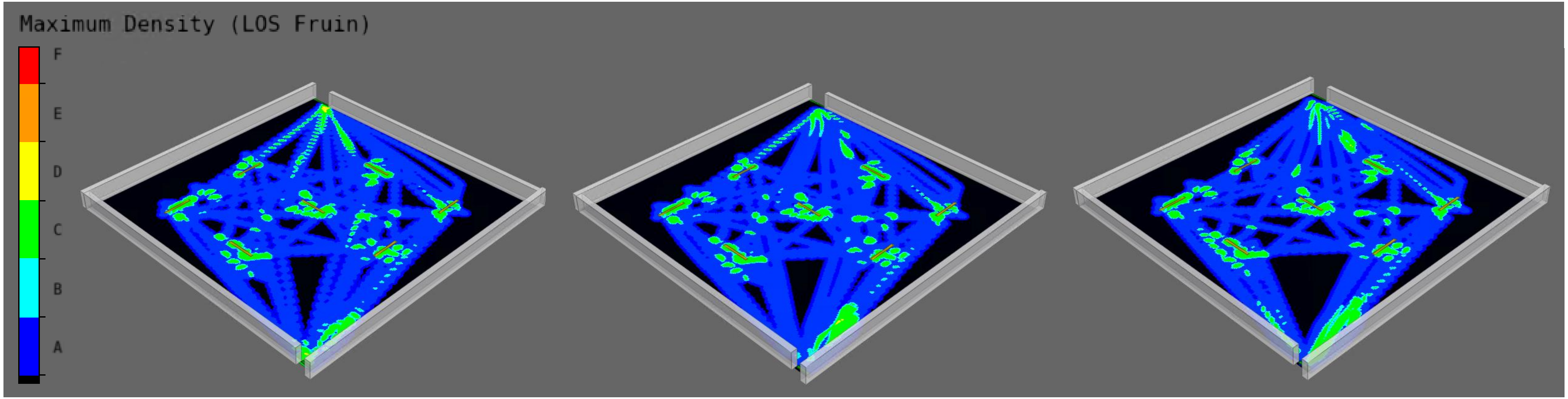
Results

Fruin Density

Plan view of the room



Only evacuation | Visibility only | Visibility-Soot

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Results

Key areas	Base model	Visibility only	Visibility-Soot Method
Computational runtime	2.574 seconds	111.863 seconds	166.549 seconds
Total movement time	46.6 seconds	176.7 seconds	137.0 seconds
Exit selection	47% choose exit A 53% choose exit B	47% choose exit A 53% choose exit B	43% choose exit A 57% choose exit B
Density analysis	Smaller high-density areas at the exits with higher densities experienced on the paths	Larger high-density areas at the exits.	Largest high-density areas at the exits.

Discussion

- Incorporating soot level analysis provides a different evacuation dynamic
- The increase in runtime justifies the analysis

Next steps

- Verification and validation
- Soot level threshold evaluation
- Use of different geometry
- Stochastic analysis

Summary

- Soot level analysis was incorporated for evacuation modelling.
- One-way coupling of fire (FDS) and evacuation (MassMotion) has been applied.
- Results show there is a different evacuation dynamic when evacuees consider the soot level along the line of sight to the exit rather than just the local values.
- Soot level threshold needs to be investigated further.

Acknowledgments

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Thank you.

Q&A

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