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Comportamento umano nel progetto di evacuazione durante l'incendio

il *Required Safe Egress Time (RSET)*

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Outline

- The evacuating crowd
- How do we calculate RSET?
  - Design occupant behavioural scenarios
  - Hand calculations
  - Evacuation modelling
- Example of RSET calculation
- Conclusions

The evacuating crowd

What is a Crowd?

A multitude of individuals walking through the same space at a certain moment in time

- Engineers deal with increasingly large, challenging and complex buildings while trying to minimise costs.
- Larger buildings → more people → potential for more severe consequences

The evacuating crowd

QUESTION TIME!

What is the stadium/arena ***able to host 70,000+ people*** *that can be evacuated in 5 minutes?*

The evacuating crowd

- Need for evacuation design known since the Roman Empire
- Colosseum could take up to 73,000 people
- 60 entrances
- It could be evacuated in 5 min

The evacuating crowd

- **Understanding and predicting human behaviour in fire requires the study of several science fields, e.g.:**

- Engineering
- Psychology
- Mathematics/Applied Physics
- Biomechanics

The evacuating crowd

Do people behave rationally or do they panic?

Some definitions of panic

- Panic is a behavioral response that also involves extravagant and injudicious effort (Bryan, 2002).
- An excessive fear reaction which is persistent and unrealistic in terms of the situation (Sime, 1980)
- Breaking of social order, competition unregulated by social forces (Johnson, 1987)

The evacuating crowd

Do people panic in evacuation?

- Competitive behaviours are rare, people behave altruistically
- Panic concept does not match actual behaviour, which in most cases is rational
- Human behaviour in fire models are based on the assumption that **people behave rationally**

The evacuating crowd

A set of core components and relationships should be considered when representing evacuation movement

Factors

- **Pre-evacuation**
- **Movement**
- **Navigation/route choice**
- **Flow conditions/constraints**

Relationships

Occupant load

↓

- **Speed**
- **Flow**
- **Density**

How do we calculate RSET?

How do we know that a building is safe?

Required Safe Escape Time (RSET)

VS
ASET

We need a way to estimate RSET

↓

Hand calcs
Egress models

How do we calculate RSET?

Examples

Prescriptive-based design

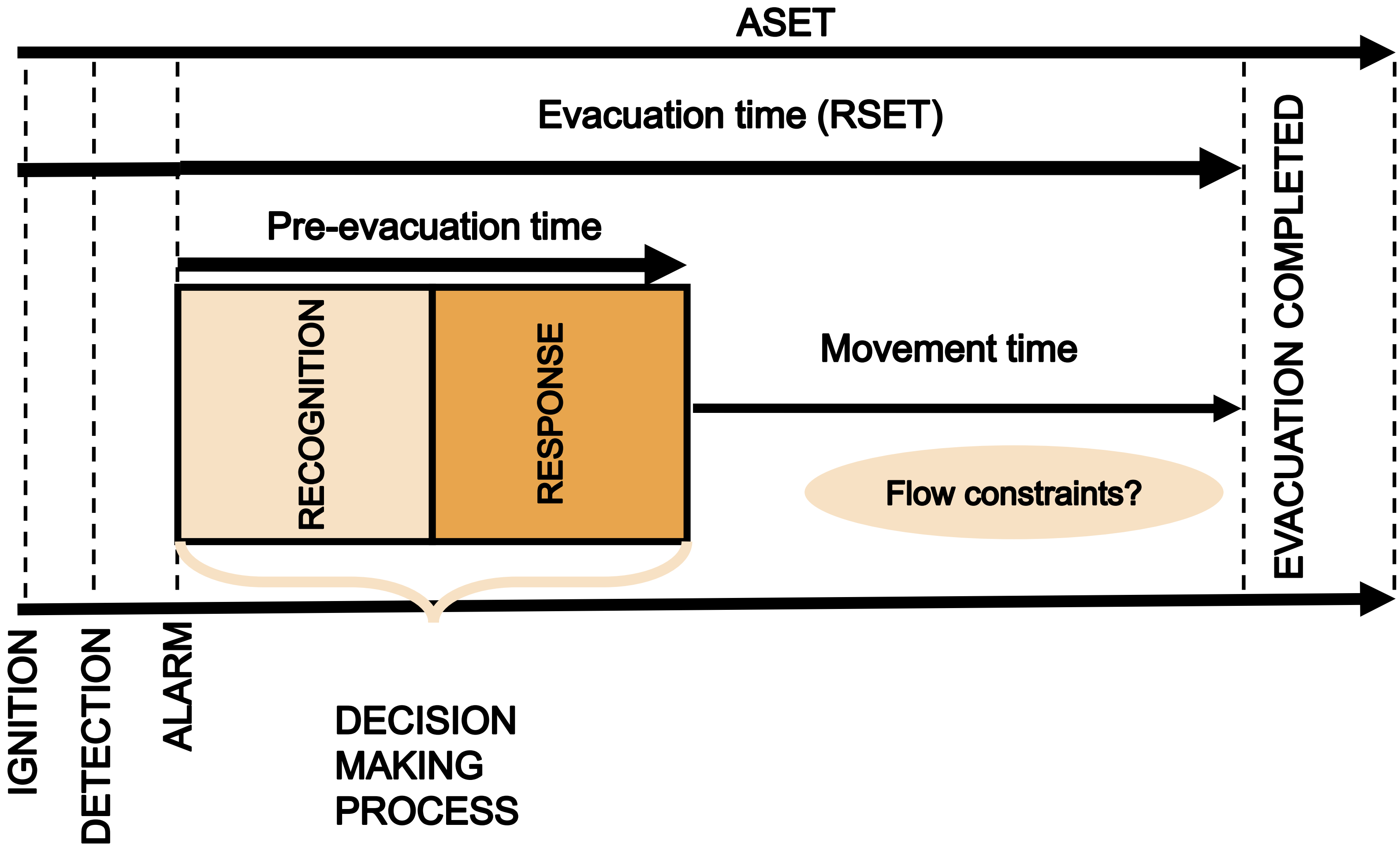
- Prescribed dimensions of egress components (exits, stairs, etc.)
- Prescribed max distance to an exit, max time to reach an exit, etc.

Performance-based design

- Egress component dimensions is based on the demonstration of a sufficient safety level for evacuation
- Any max distance to/time to reach an exit can be used as long as the building can be evacuated safely

How do we calculate RSET?

Simplified Time-line engineering model for RSET



Design occupant behavioural scenarios

Similar process to design fire scenarios

Required Safe Escape Time (RSET)

Occupant Scenarios

- »Number of people
- »Location of people
- »Attributes
- »Activities
- »Trained staff?
- »Behaviours
- »Other factors (e.g. environmental conditions)

Occupant variables need to be translated into inputs for calculations/simulations

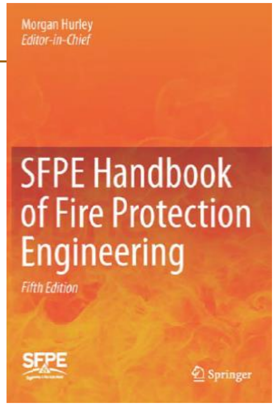
Hand calculations of evacuation

Several methods in the literature to perform hand calculations of evacuation

Predtechinskii and Milinskii, 1978
Pauls, 1980
Gwynne and Rosenbaum, 2016 → example

- **Calculations are made in a deterministic way**
- **Make use of fundamental diagrams (relationship between speed, density and flow)**

Hand calculations of evacuation

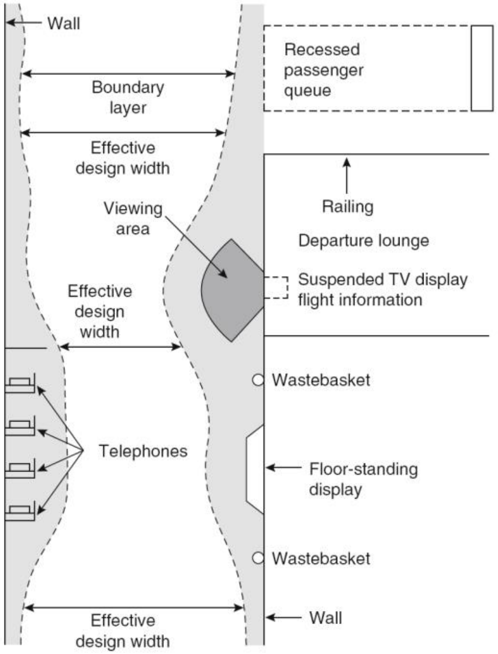


Hydraulic model (Gwynne and Rosenbaum, 2008)

Simple movement equations based on effective width

If the population density is less than approx.0.54 pers/m2, people move at their own pace, independent of the speed of others.

If the population density exceeds approx. 3.8 pers/m2, no movement will take place until enough of the crowd has passed



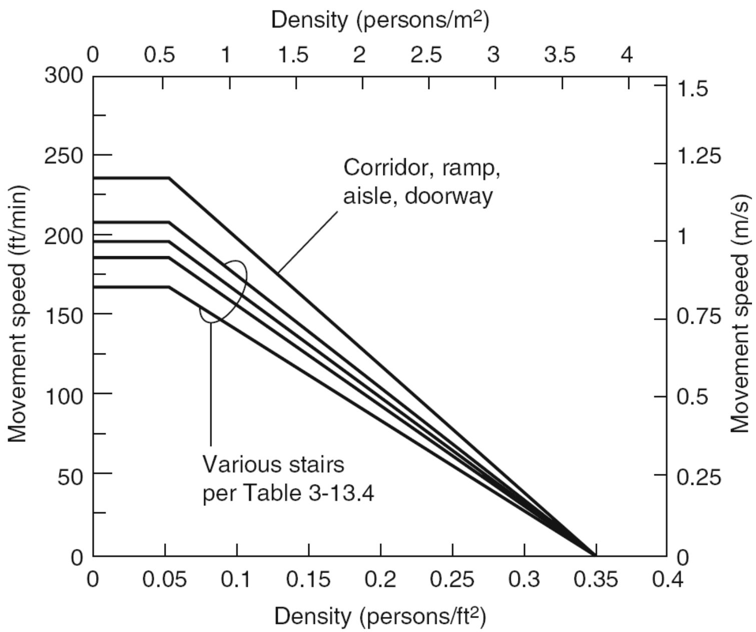
Hand calculations of evacuation

Hydraulic model (Gwynne and Rosenbaum)

IF 0.54>D>3.8

S = k-akD

S is the speed along the line of travel (m/s)
a is a factor which changes if in m/s or ft/min
D is the Population density (pers/m2)
k is a constant (value from a table)



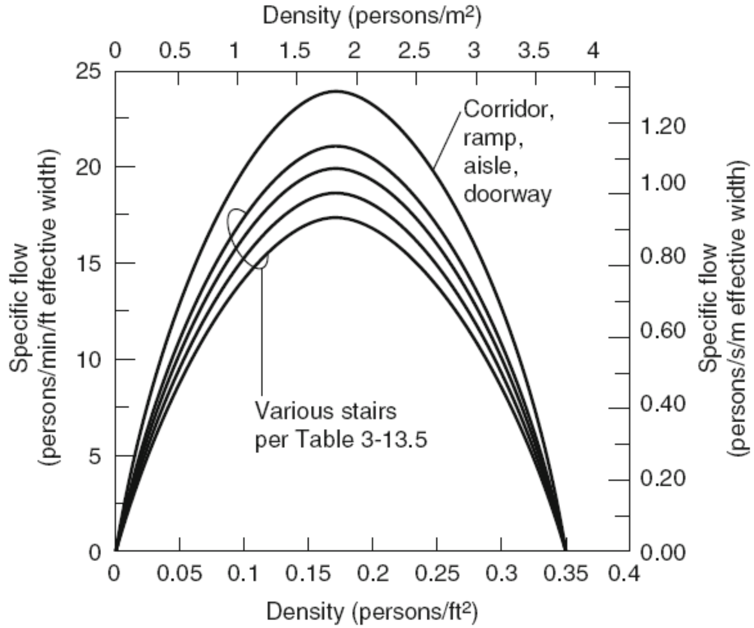
Exit route element		k_1	k_2
Corridor, aisle, ramp, doorway		275	1.40
Stairs			
Riser (in.)	Tread (in.)		
7.5	10	196	1.00
7.0	11	212	1.08
6.5	12	229	1.16
6.5	13	242	1.23

1 in. = 25.4 mm

Hand calculations of evacuation

Hydraulic model (Gwynne and Rosenbaum)

You can then calculate the Specific flow (Fs) of evacuating people past a point in the exit route per unit of time per unit of effective width



Fs = SD=(1-aD)kD

Fs is the specific flow (pers/m/sec)
S is the movement speed (m/s)
D is the Population density (pers/m2)

Hand calculations of evacuation

Hydraulic model (Gwynne and Rosenbaum)

$$Fc = FsWe$$

Fc is the calculated flow (pers/s)
Fs is the specific flow (pers/m/sec)
We is the effective width (m)

		Maximum specific flow	
Exit route element		Persons/min/ft of effective width	Persons/s/m of effective width
Corridor, aisle, ramp, doorway		24.0	1.3
Stairs			
Riser	Tread		
(in.)	(in.)		
7.5	10	17.1	0.94
7.0	11	18.5	1.01
6.5	12	20.0	1.09
6.5	13	21.2	1.16

$$Fc = (1\text{-}aD)kDWe$$

$$tp = P/Fc$$

tp is the time for passage (sec)
P is the population size (pers)

$$tp = P/[(1\text{-}aD)kDWe]$$

Hand calculations of evacuation

Hydraulic model (Gwynne and Rosenbaum)

Transitions (e.g., character or dimension change in the route)

Example. One flow into and flow out of a transition point

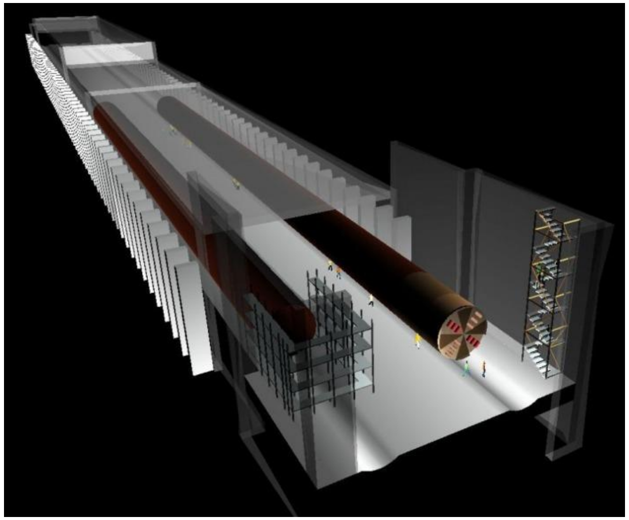
Fs(out) = [Fs(in)We(in)]/We(out)

Fs(out) is the Specific flow departing from transition point (pers/m/s)
Fs(in) is the Specific flow arriving at transition point (pers/m/s)
We(in) is the effective width prior to transition point (m)
We(out) is the effective width after passing transition point (m)

Evacuation modelling

What are evacuation models?

Computer models (research and commercial) for the representation of human behaviour and people movement during emergencies



Movement (equation-based/agent-based)

- Hydraulic model in the SFPE handbook,
- Social force model
- Steering model, etc.

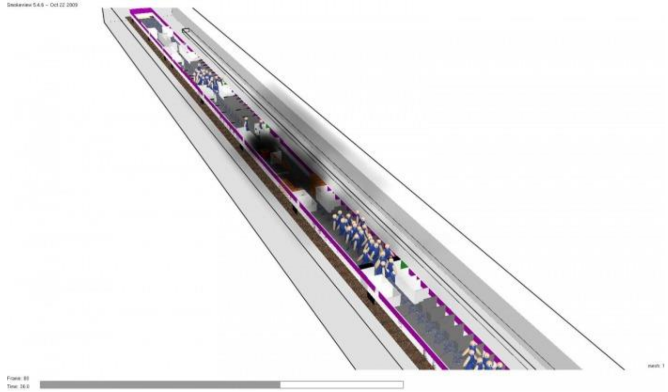
Behaviours (generally agent-based)

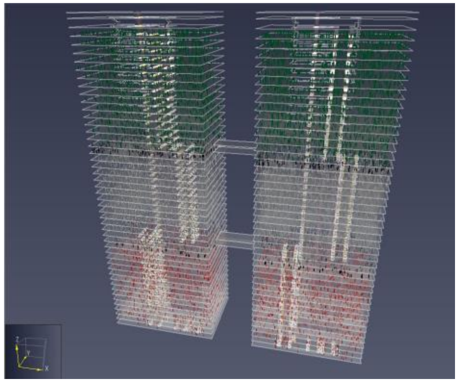
- Time-line model (sequence of actions)
- Decision making

Evacuation modelling

What results can we get from evacuation models?

- **Total evacuation time (RSET)**
- Occupant-evacuation time curves
- Prediction of congestion levels (comfort and safety) and other emergent behaviours
- Toxicity assessment in case of fire-people interaction (Purser’s FED model)





Evacuation modelling

Hierarchy of behaviours

(Reynolds, 1999)

1	Action Selection	Strategy, Goals, Planning
2	Movement (Steering)	Path determination
3	Locomotion	Animation, articulation

Most models represent first two levels only

examples

Evacuation modelling

Social force model **(Helbing and Molnar, 1995)**

Used in many continuous evacuation models

It is a multi-particle self-driven model used to model emergent behaviours of pedestrians

Self-driven particles (Vicsek et al, 1995): A swarm is modelled by a collection of particles that move with a constant speed but respond to a random perturbation. Each particle is an autonomous agent, but the direction of each particle is updated using local rules (caused by the behaviour of the other particles)

Motion of pedestrians are described as subject to “social forces”, measure for the motivations of individuals to acts

Evacuation modelling

Social force model

$$\mathbf{f}_i(t) = m_i \frac{\mathrm{d}\mathbf{v}_i}{\mathrm{d}t} = m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \mathbf{f}_{ij} + \sum_{W} \mathbf{f}_{iW}$$

Acceleration term

Desired velocity
at the desired direction

Relaxation time:
strength of the motive force

Actual velocity

Interaction with
other pedestrians

Repulsive (private sphere)
Or
Attractive (e.g. family, friends, etc.)

Interaction with
walls

Evacuation modelling

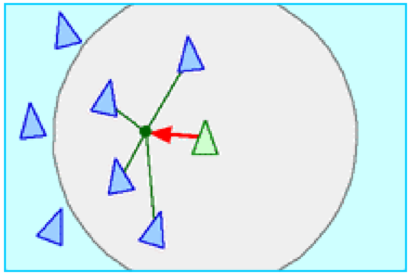
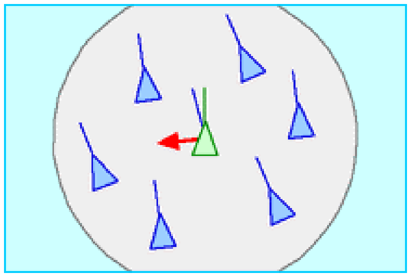
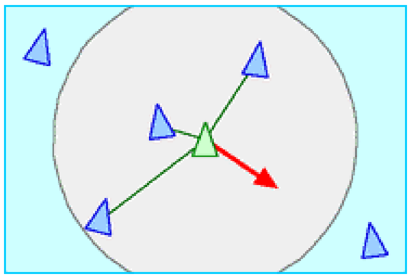
Steering model

- Used in computer animation and in evac models (e.g. Pathfinder)
- Developed by Reynolds (1987)
- Born as a model called BOIDS
- What are BOIDS?

Flock of birds (from Wikipedia)

Screenshot from
Tim Burton's Batman Returns (1992)
using Reynolds' model

Evacuation modelling

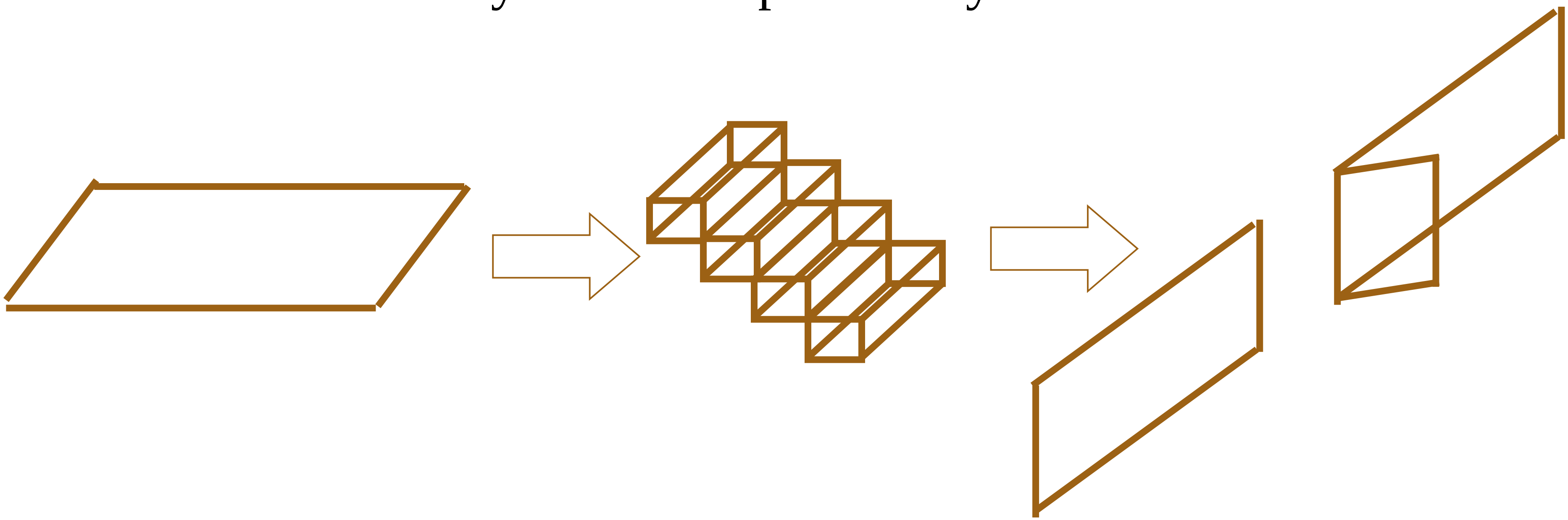
	**Cohesion**	The attraction of the boids to each other.
	**Alignment**	The adjustment of each individual boid's velocity to match up with the rest of the flock's velocity.
	**Separation**	The avoidance of any direct collisions with any other boids

Example of RSET calculation

Application of the hydraulic model (Gwynne and Rosenbaum, 2016)

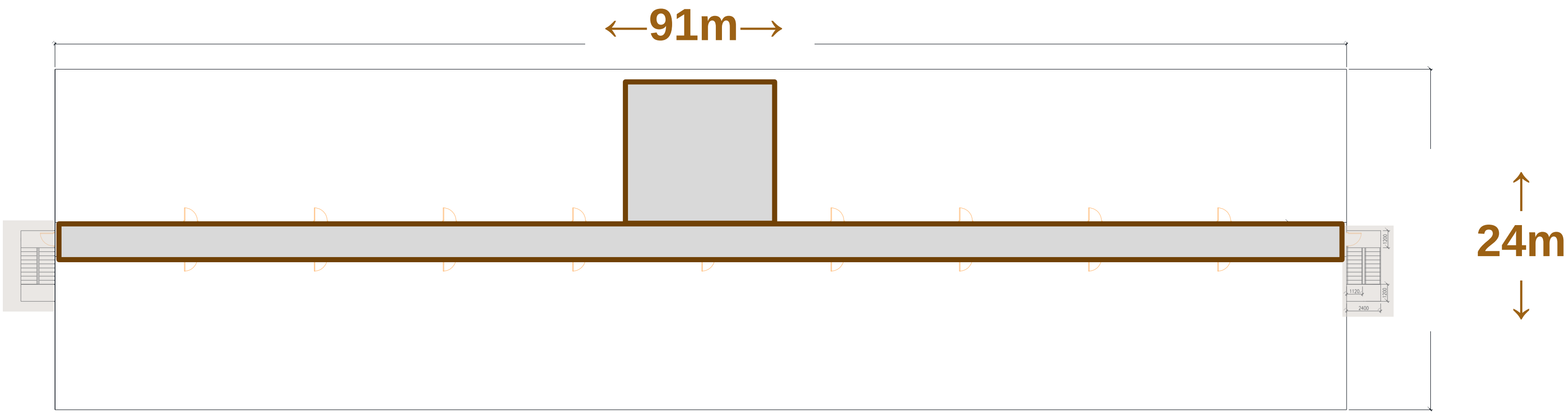
Two approaches

- First order analysis → Focus on the critical component
- Second order analysis → Complete analysis



Example of RSET calculation

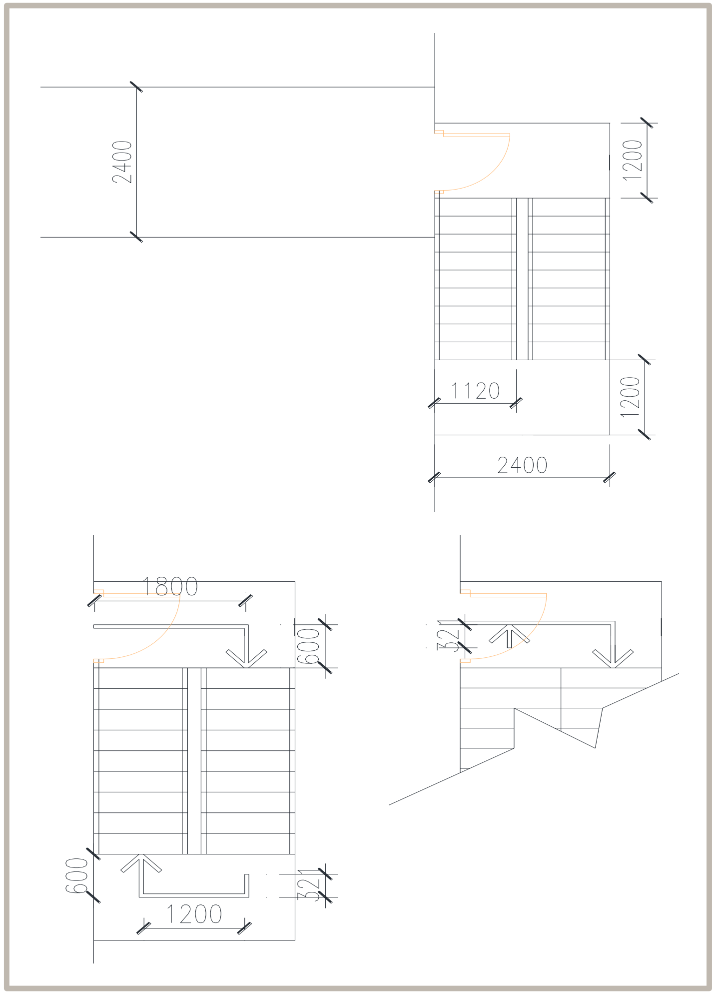
Fictitious building, office building or similar



- Nine floors: 91 m by 24 m (see above).
- Two stairways are located at the ends of the building.
- Each stair is 1.12 m wide (tread width) with handrails protruding 0.063 m.
- There are two 1.2 m by 2.4 m landings per floor of stairway travel.
- There is one 0.91m clear width door at each stairway entrance and exit.
- The first floor population does not exit through stairways.
- Each floor has a single 2.4m wide corridor extending the full length of each floor.

Example of RSET calculation

- 20 risers floor to floor: riser = 178 mm Tread = 279mm
- Vertical distance floor to floor = 3.56m
- 10 risers landing to landing so rise landing to landing = 1.78 m
- Total tread from the top nosing to the landing would equal to ten treads = 2.79m
- Using Pythagoras calculate travel distance per flight and add on horizontal travel on landings.
- 1.8m (landing)+ 0.6 m (landing)+ 3.31 m (down stair flight) + 0.32 m (half landing) + 1.2 m (half landing) + 0.6 m (half landing) + 3.31 m (down stair flight) + 0.32 m (lower landing to join flow) = 11.46 m



Example of RSET calculation

First order analysis

1. Assumption and occupant behavioural scenario

- Assumed occupant load = 150+150=300 people per floor
- Time to reach controlling component corresponds to:

  Time for population to traverse the controlling component

  Time for last person to leave the controlling component

  Time for last person to reach safety

- Controlling factor: either stairs or door discharging from them.
- Assume queuing will occur, use maximum specific flow and optimal density (1.9 p/m^2)
- All occupants will start evacuating at the same time and will use both stairs evenly.

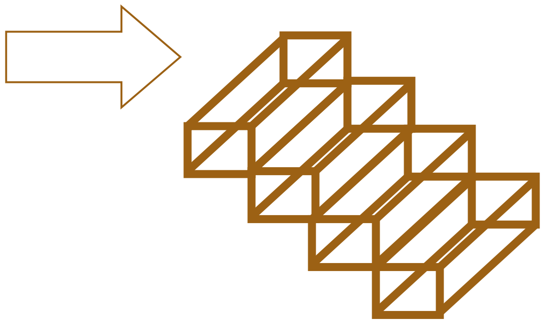
Example of RSET calculation

First order analysis

Table D.1 — Constants for equation (A.1) (effects of density on travel speed), maximum unimpeded travel speeds (m/s) and flow rates (persons/s/m of effective width) for horizontal and stair travel

Exit route element mm		k	speed	flow
Corridor, aisle, ramp, doorway		1.40	1.19	1.3
Riser mm	Tread mm			
191	254	1.00	0.85	[illegible]
178	279	1.08	0.95	1.01
165	305	1.16	1.00	[illegible]
165	330	1.23	1.05	1.16

2. Estimate Flow Capacity of Stair.



- Nominal stair width = 1.12m,
- Effective width
  - *We= 1.12- (2 x 0.15) = 0.82m*
- Maximum specific flow
  - *Fsm = 1.01 p/s/m*
- Maximum calculated flow in a stair would be
  - *Fc = Fsm x We= 1.01 x 0.82 = 0.83 p/s*

Example of RSET calculation

First order analysis

Table D.1 — Constants for equation (A.1) (effects of density on travel speed), maximum unimpeded travel speeds (m/s) and flow rates (persons/s/m of effective width) for horizontal and stair travel

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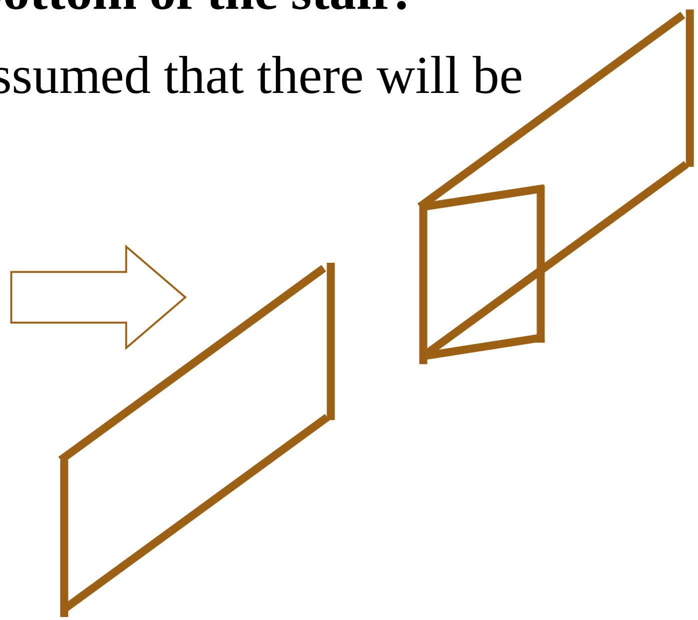
165	330	1.23	1.05	1.16

3. Estimate flow capacity through exit door at bottom of the stair.

- Again use the maximum specific flow as it is assumed that there will be queuing
  - $F_s = F_{sm} = 1.3\ p/s/m$
- The effective width
  - $W_e = 0.91 - (2 \times 0.15) = 0.61\ m$
- Calculated flow
  - $F_c = F_s \times W_e = 1.3 \times 0.61 = 0.79\ p/s.$



- Controlling factor is the **final exit door** as 0.79p/s is lower than 0.83p/s.

Example of RSET calculation

First order analysis

4. Estimate the speed of movement for the stairway flow

- Max density=1.9 p/m^2 → *speed S = 1.08 – (0.266 * 1.08 * 1.9) = 0.53 m/s* < tabulated maximum

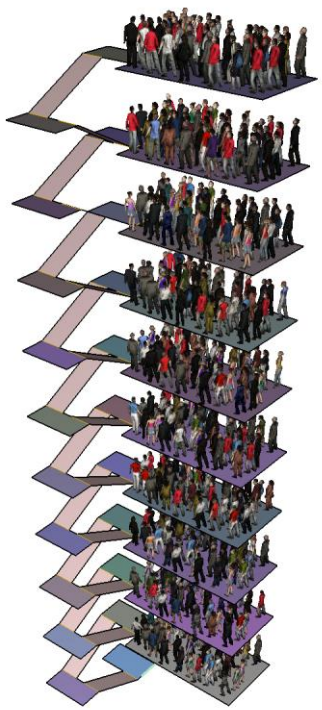
5. Estimate building evacuation time

- Time to traverse floor to floor is therefore obtained by the distance
  - *11.46 m / 0.53 m/s = 21.62 s* , this is the time for the first person on the first floor to travel to the ground floor exit.
- Final exit door is the controlling factor, assume 50% population goes down each stair
- Total numbers using one stair are *150 * 8 = 1200 people.*
- The max calculated flow is 0.79 p/s so the flow through the door would take 1519 s .
- Add this to the time it took the first person from the first floor to reach the exit door
  - *1519 + 21 = 25 min 40 s.*

Example of RSET calculation

The use of an evacuation model would not only permit to estimate the movement time through the building, but also to explicitly consider **behavioural factors →**
Pre-evacuation times, uneven route/exit choices, impact of variation in population, etc.

Hand calculations give the opportunity to rapidly obtain a rough estimate of evacuation time of a building



Conclusions

- The estimation of RSET allows to perform an **actual evaluation** of the **safety** level of a building

- There are different tools to perform the estimation of RSET, including **hand calculations** and **evacuation models**

- Simple hand calculations allow an **estimation** of evacuation time under given assumptions

- Evacuation models include advanced sub-models which allow prediction of movement and **human behaviour**

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References

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THANK YOU!

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