Egress Simulation Models and Their Application

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Rome

Outline

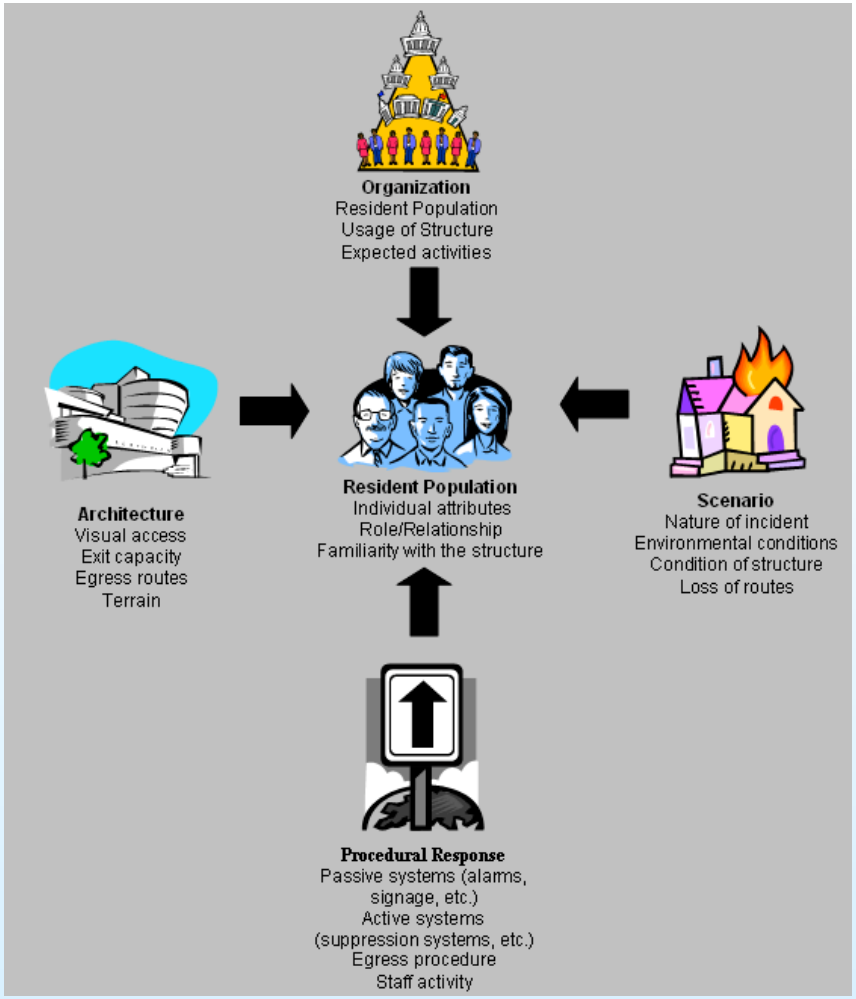
- The importance of understanding human egress performance.
- Examples of incidents and associated investigations, including 9/11.
- Available models of egress performance.
- Tall buildings and the lessons learned
- What is gained through the use of egress models?
- Conclusions

Evacuation Movement

Why is important to understand human behavior?

- It determines the time taken to reach a place of safety
- It determines the effectiveness of measures taken to assist the egress process
- It needs to be considered both when assessing the time to evacuate and when designing the emergency plan.
- If not considered, we may be underestimating the egress time.
- It is critical when responding to the incident to have an understanding of where people will be and the conditions present, especially as population densities increase.
- *What methods are open to us?*

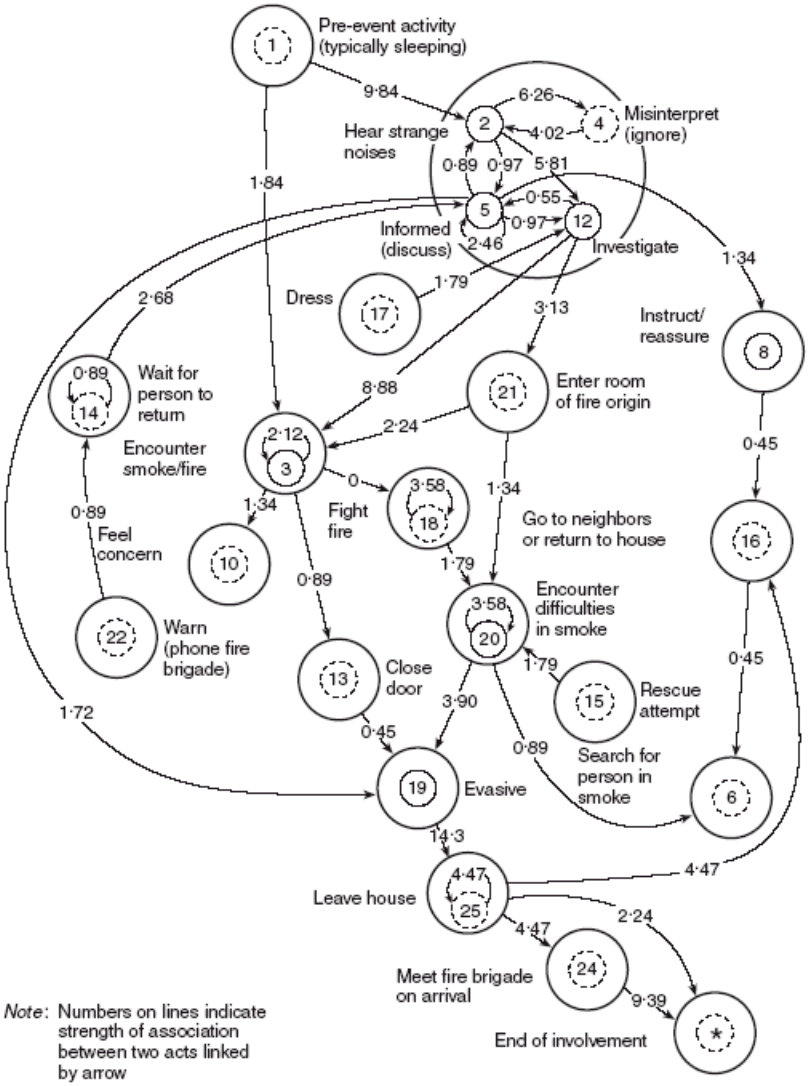
Aspects of the Evacuation Process



- Large number of factors that influence the outcome of an evacuation

Aspects of the Evacuation Process

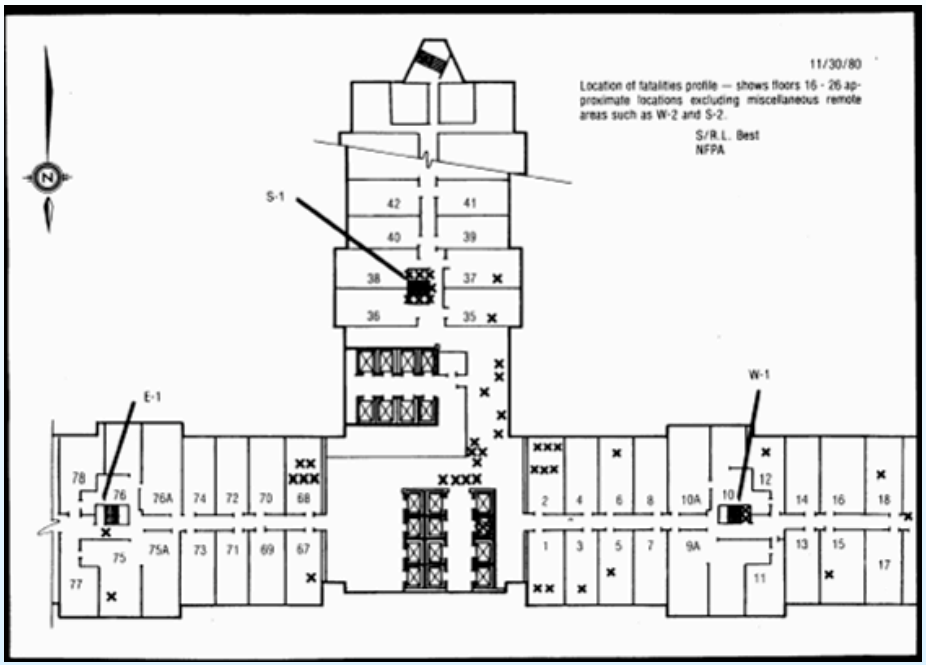
- Assessment of Evacuee Response Performed by Canter, Breaux and Sime.
- Complexity of behaviour immediately apparent.
- Simplifications have to be made - still value in the assessment made.



What incident analysis has been done before?

MGM Grand, Las Vegas, 21/11/80.

- Operators forced from switchboards just after announcement made
  - Guests in rooms not alerted
- Construction workers aided evacuation
- Guests alerted early, able to escape
- Guests alerted later remained in their rooms or moved to other rooms
- The fire resulted in 85 fatalities
- Existence of convergence clusters



SFPE Handbook

Detailed analysis

Beverly Hills Supper Club, 28/5/77

2400-2800 patrons.

- 164 fatalities; 162 situated in one room
  - Estimated 1200 - 1300 patrons in room
- Fatalities at two overloaded exits
- Many overcome by rapid arrival of smoke
- Complex enclosure affected communication
  - Contributed to death toll
- Dispersion of population and visual separation from incident delayed information
- More horrific tragedy avoided by actions of employees.

Detailed analysis and later computer analysis. Decision rather than simulation.

Gothenburg Disco, Sweden, 29/10/98

- Approx. 400 people. Approved occupancy = 150.
- Upper floor of industrial two-story building, two staircases.
- 63 fatalities, 180 injured.
- Fatalities located at internal exit/in side room, where they had sought refuge.
- Verdict (NFPA):
  - Overcrowding,
  - Lack of fire alarm,
  - Loss of an exit stairwell

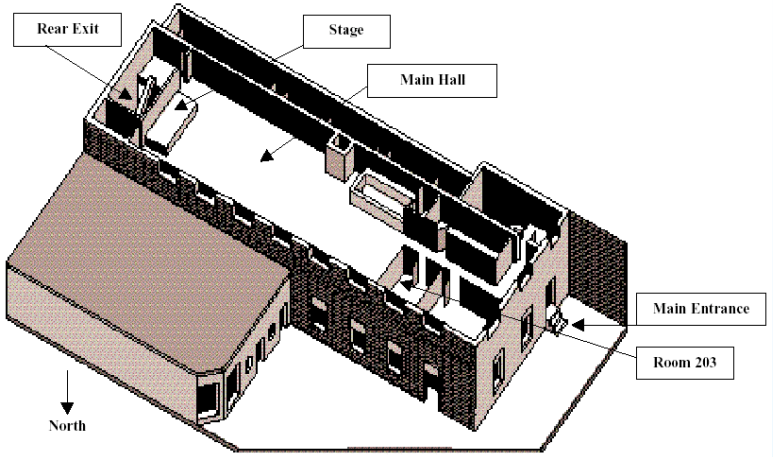
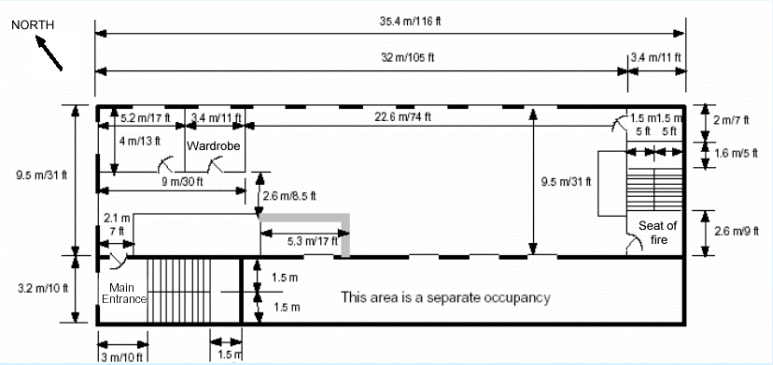


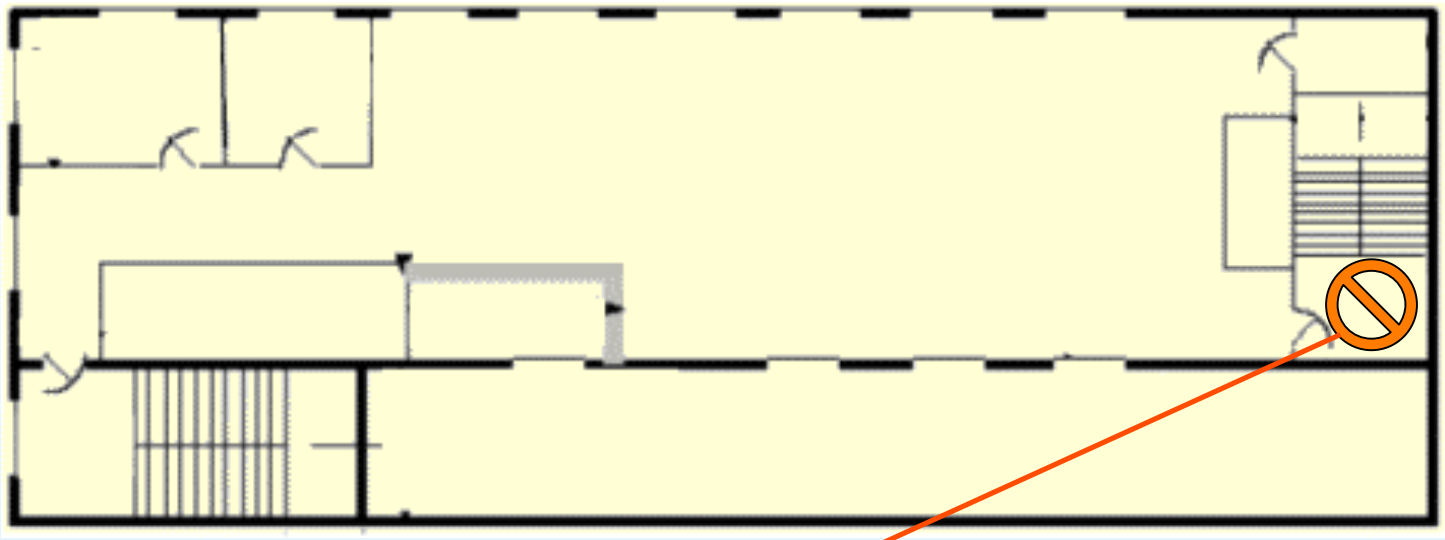
Figure No. 2 – Detailed Site Plan



Comeau and Duval, NFPA

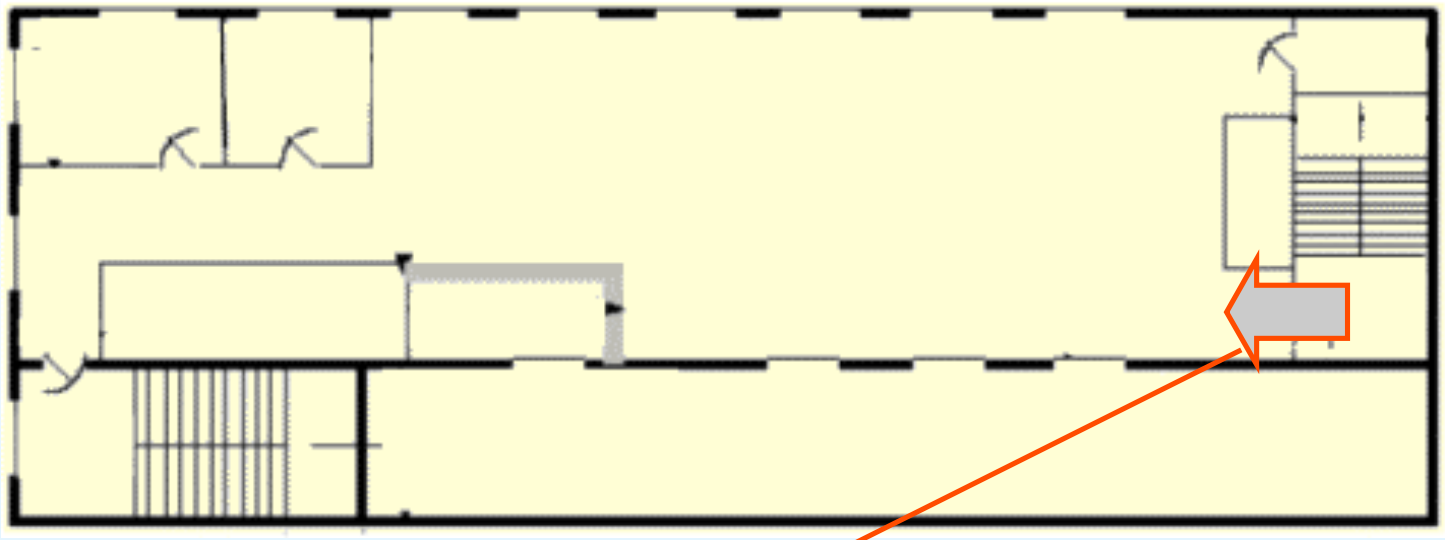
Detailed analysis and later computer analysis.

Gothenburg - Event Evolution



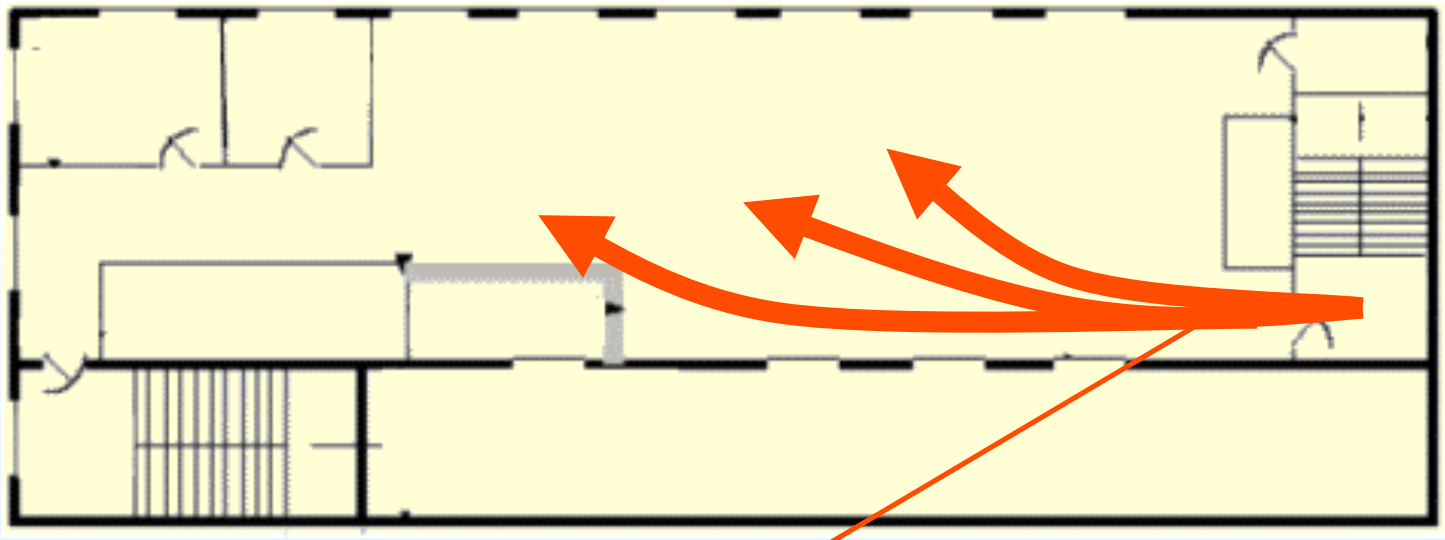
Fire develops unnoticed, blocking potential egress route

Gothenburg - Event Evolution



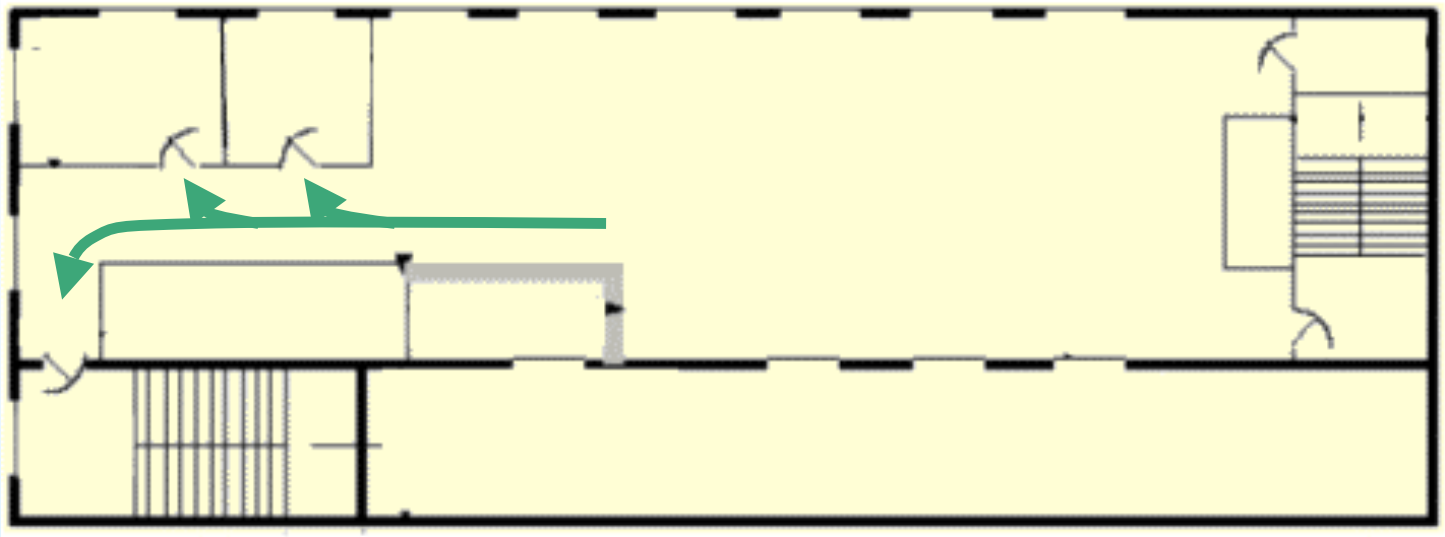
Door opens, fire bursts into main room.

Gothenburg - Event Evolution



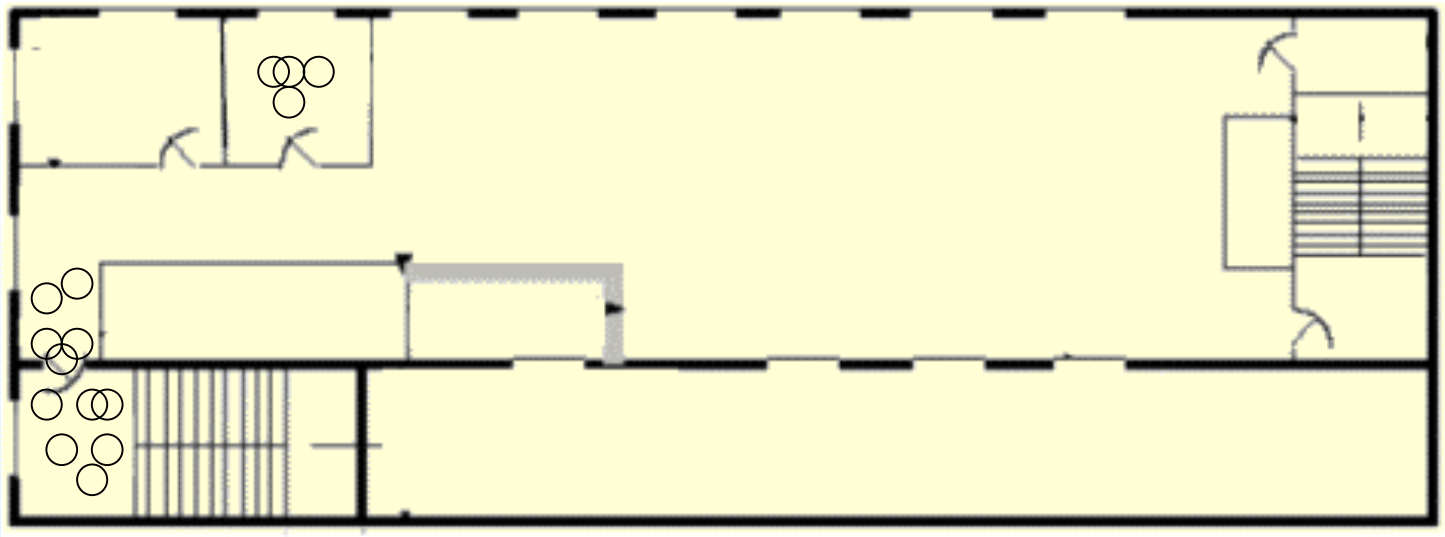
Fire spreads into room, forcing people to evacuate.

Gothenburg - Event Evolution



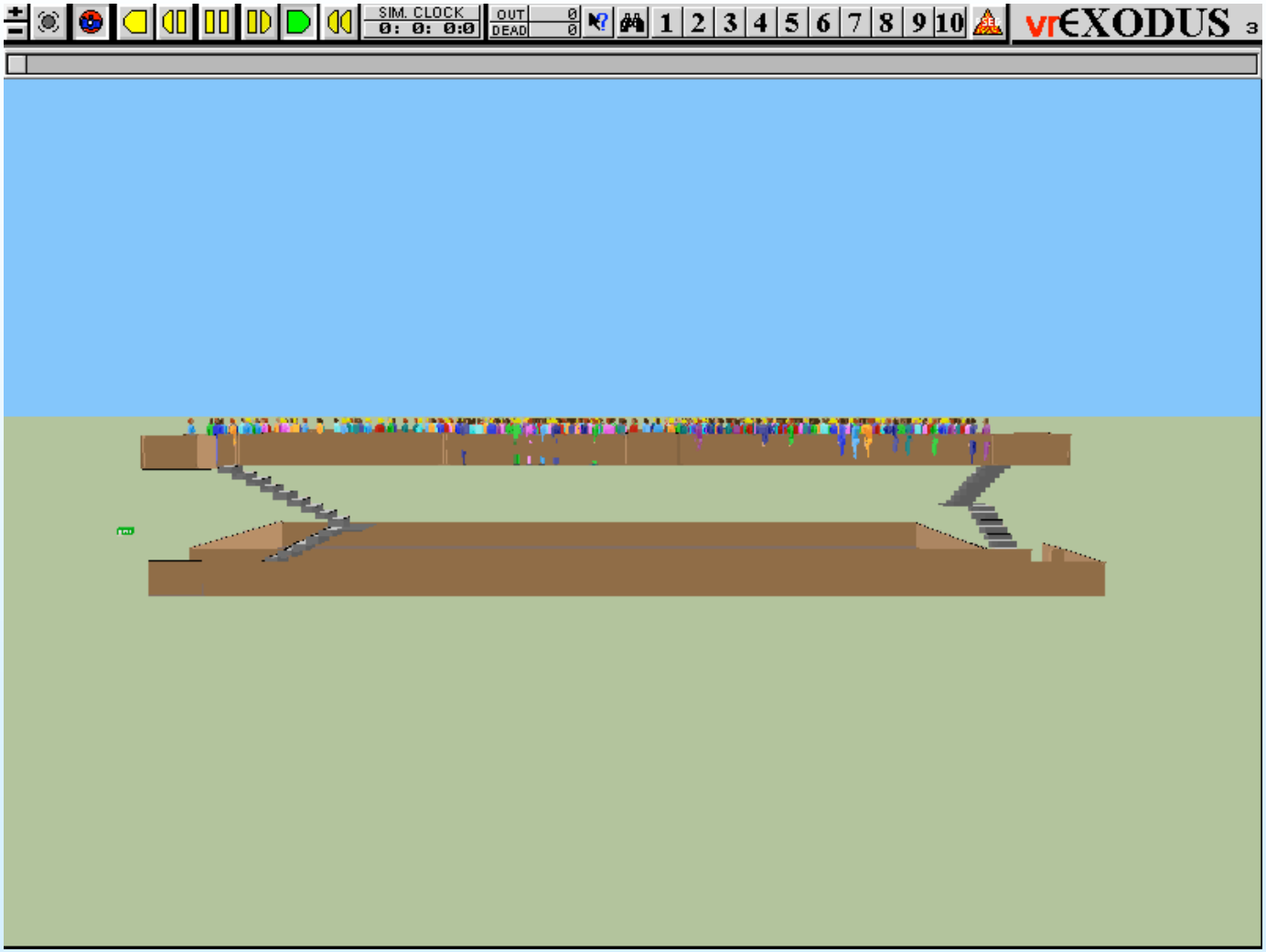
People evacuate via the only staircase, now available, shelter in side rooms and leap out of windows

Gothenburg - Event Evolution



Numerous bodies found at and around the entrance to the available staircase

Impact of Crowding on Outcome



Station Nightclub Fire, RI (2003)

- **~440 in venue, ~100 fatalities, 180 injured.**
- Some killed by fire and smoke, others are “believed” to have been trampled.
- *"The flame... just went up the ceiling and people stood and watched it. Some people were already trying to leave and others were just sitting there going 'Yeah that's great!'"*
- "People were new to the club. As is human nature, they tried to get back out the way they came in," said. Fire Chief Charles Hall.
- Detailed analysis conducted by NIST involving behavioural analysis and egress simulation.

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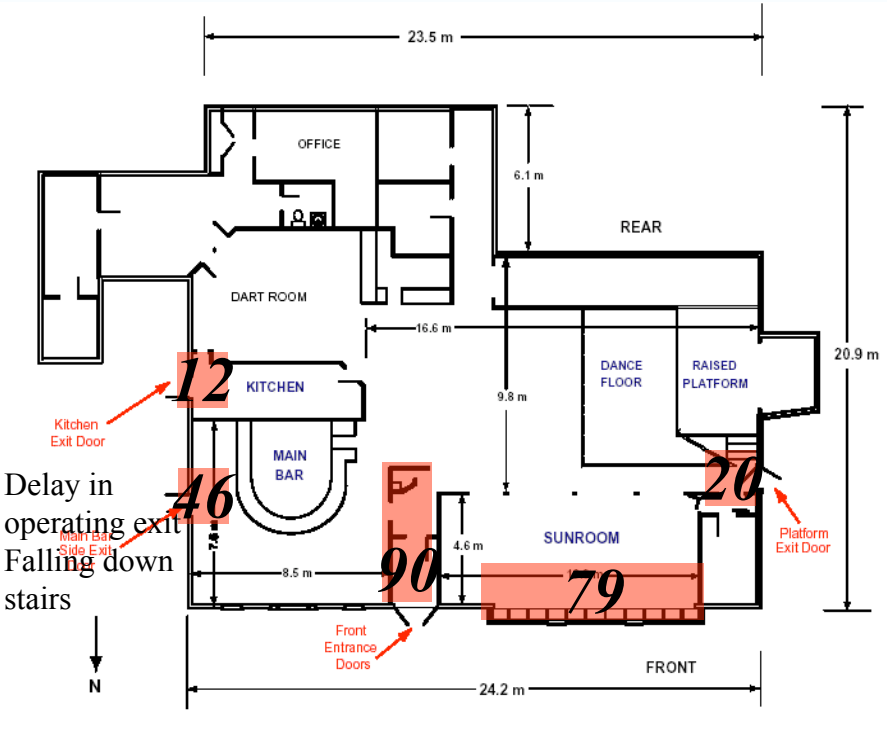
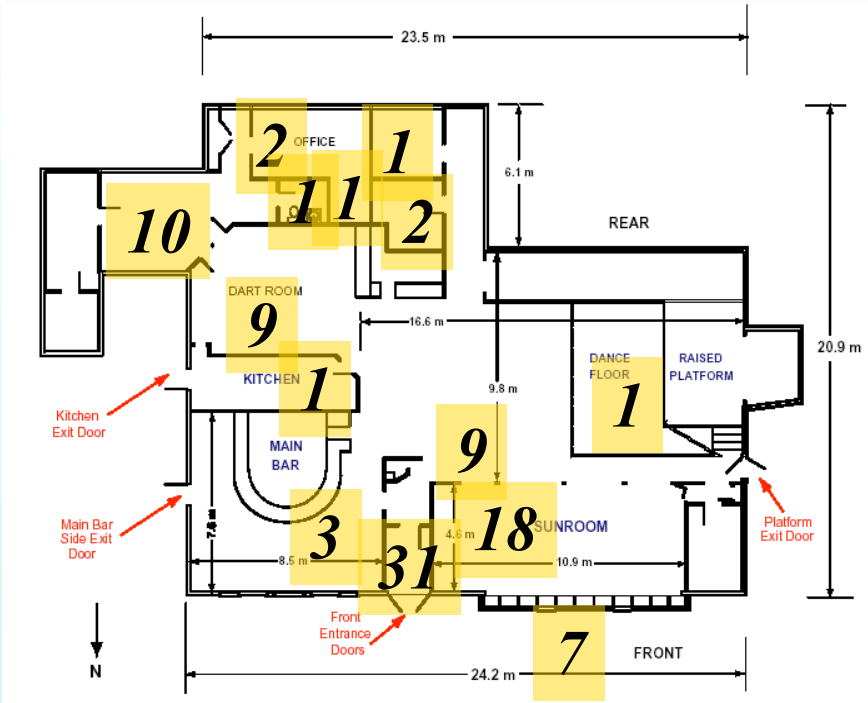
Detailed analysis and computer analysis using several egress models.

Station Disco Fire Analysis





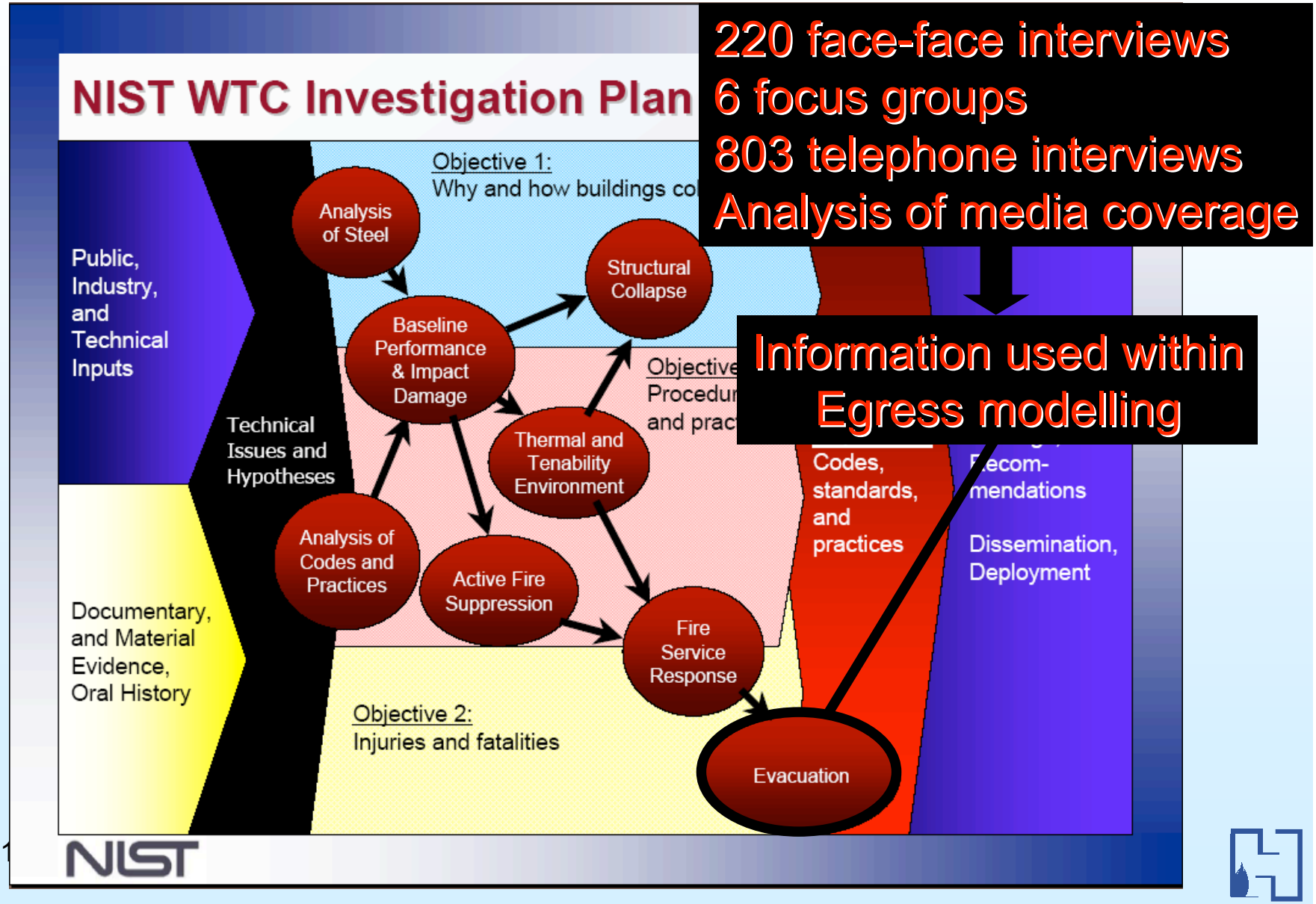
Exit Usage

Fatalities

WTC

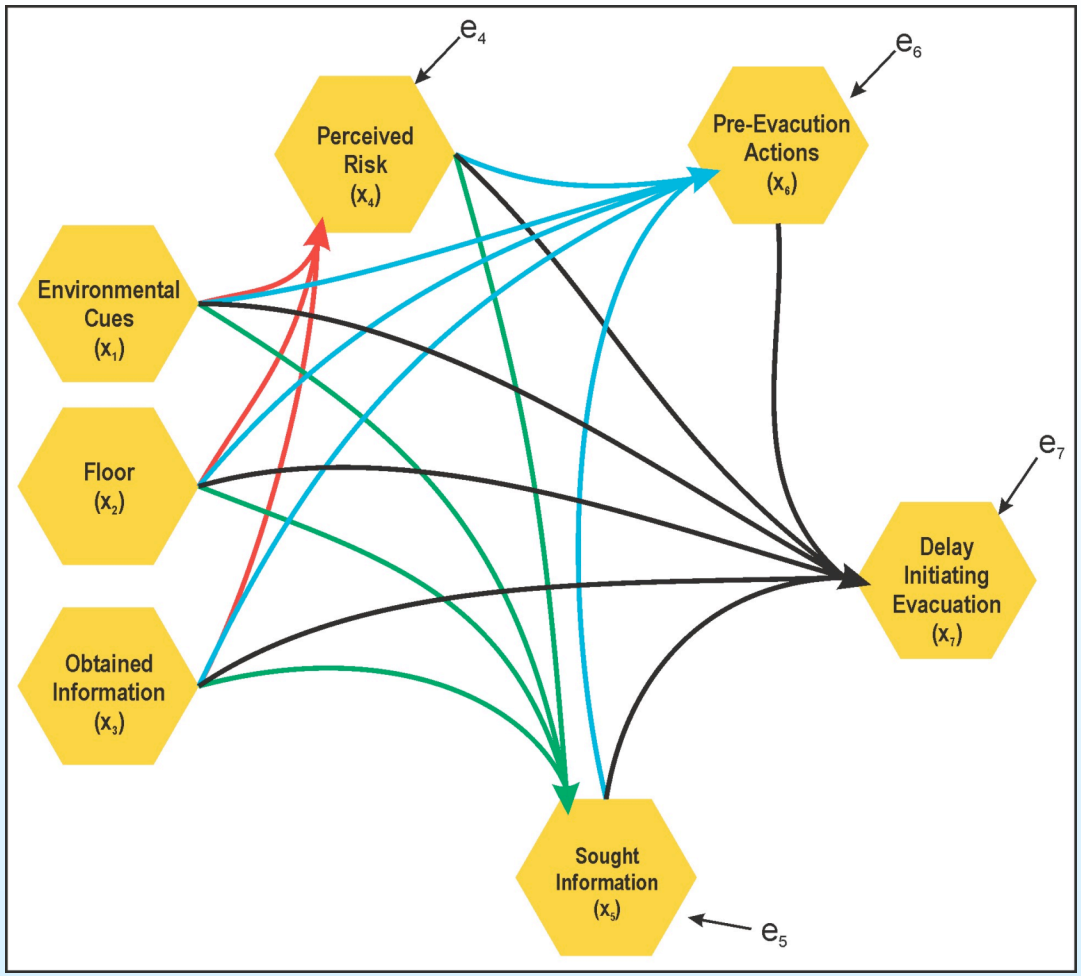
- Efforts made to understand the egress performance
- Establish influential factors
- Analysis performed to improve
  - Our understanding of the event
  - Our understanding of human egress behaviour
- Conducted in US and Europe during several projects; e.g. NIST, BDAG, HEED.
- Computational Egress Models used to better understand incidents.

NIST Approach to the WTC Incident



From NIST

NIST - Behavioural Analysis

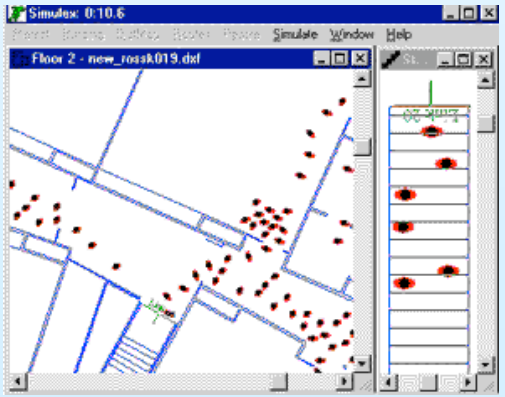


WTC: Averill et al. 2005

NIST Egress Modeling

- Adopted a ‘triangulation’ approach to modeling

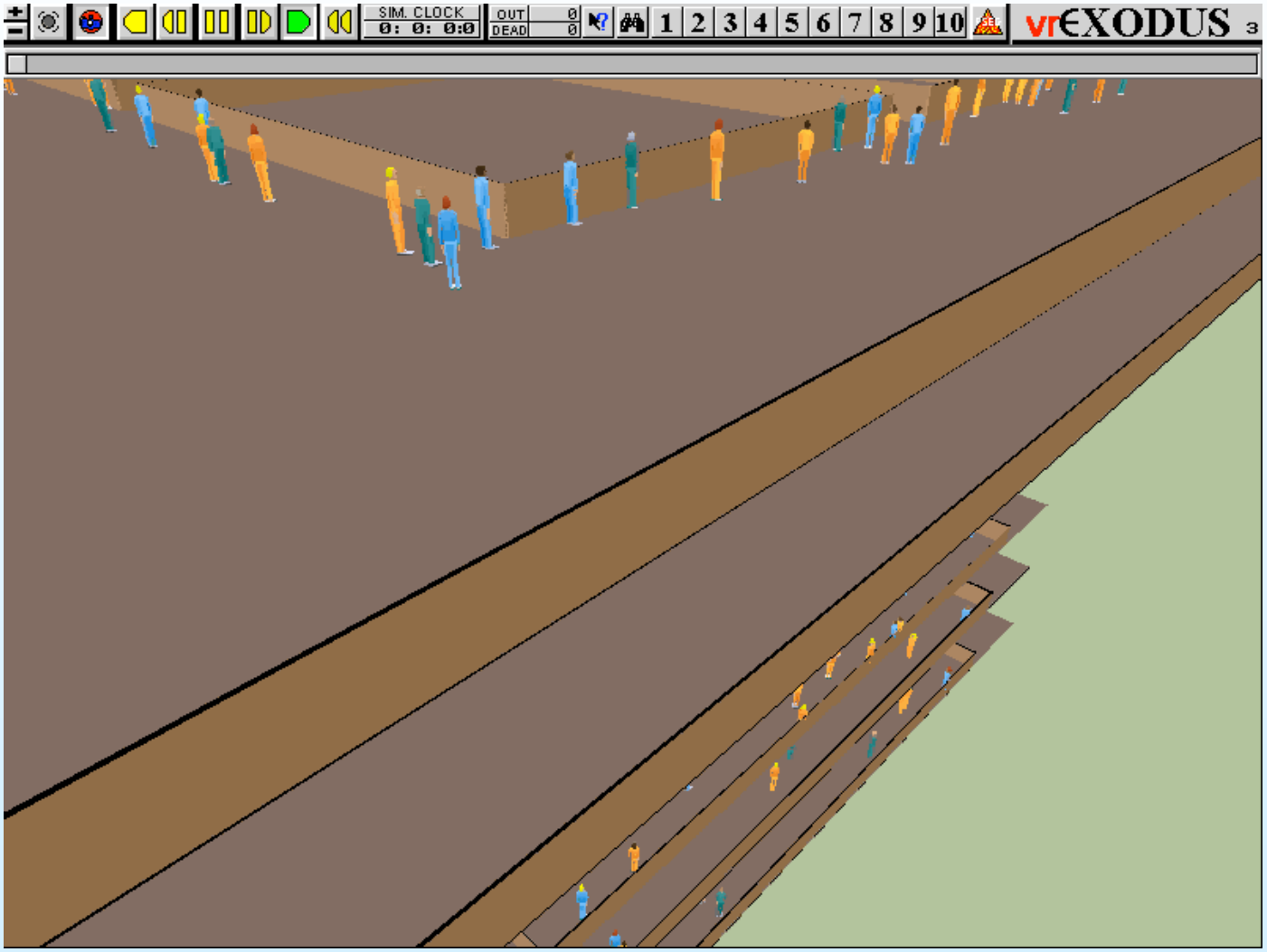
TIME	OCC NUM	ORIG NODE	FROM NODE	TO NODE	NUM OUT	NUM TRAPD
2.55	64	217	217	280	0	0
2.55	65	218	218	280	0	0
4.83	12	206	206	278	0	0
4.83	13	206	206	278	0	0
4.83	14	206	206	278	0	0
5.33	5	204	204	276	0	0
5.33	6	204	204	276	0	0
5.33	7	204	204	276	0	0
5.33	19	209	209	281	0	0
5.33	20	209	209	281	0	0
5.33	21	209	209	281	0	0
5.33	100	223	223	271	0	0
5.33	101	223	223	271	0	0
5.33	102	223	223	271	0	0
5.33	103	223	223	271	0	0
5.33	126	227	227	268	0	0
5.33	127	227	227	268	0	0
5.33	128	227	227	268	0	0
5.66	107	225	225	269	0	0
5.66	108	225	225	269	0	0
5.66	109	225	225	269	0	0
6.00	97	222	222	272	0	0
6.00	98	222	222	272	0	0
6.00	99	222	222	272	0	0
6.66	26	211	211	283	0	0
6.66	27	211	211	283	0	0



Rome, Italy

Representative rather than actual images generated

Assessment of the population size, stair use and FD ingress



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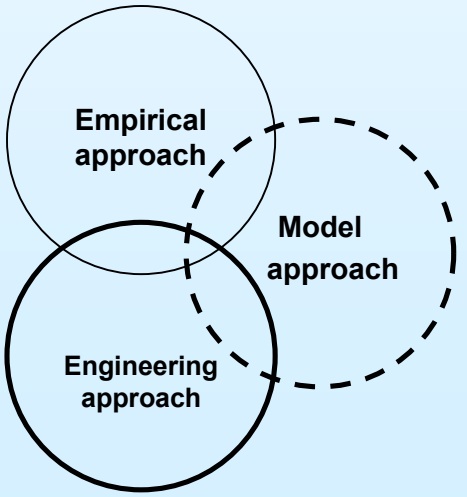
Understanding and Quantification

- Many situations in which it is critical to understand and quantify movement:
  - Structural Design
  - Procedural Design
  - Forensic Analysis
  - Security
  - Research
  - Real-Time Assessment of Conditions
- *How do we do this?*

How is Egress Performance Established?

- Models Available
  1. Prescriptive Codes
  2. Full-scale evacuation demonstration.
  3. Empirical correlation/analysis at the level of the *Structure*
  4. Manual calculation at the level of the *Component*
  5. Engineering Analysis
  6. Expert Analysis

- *All 'models'*



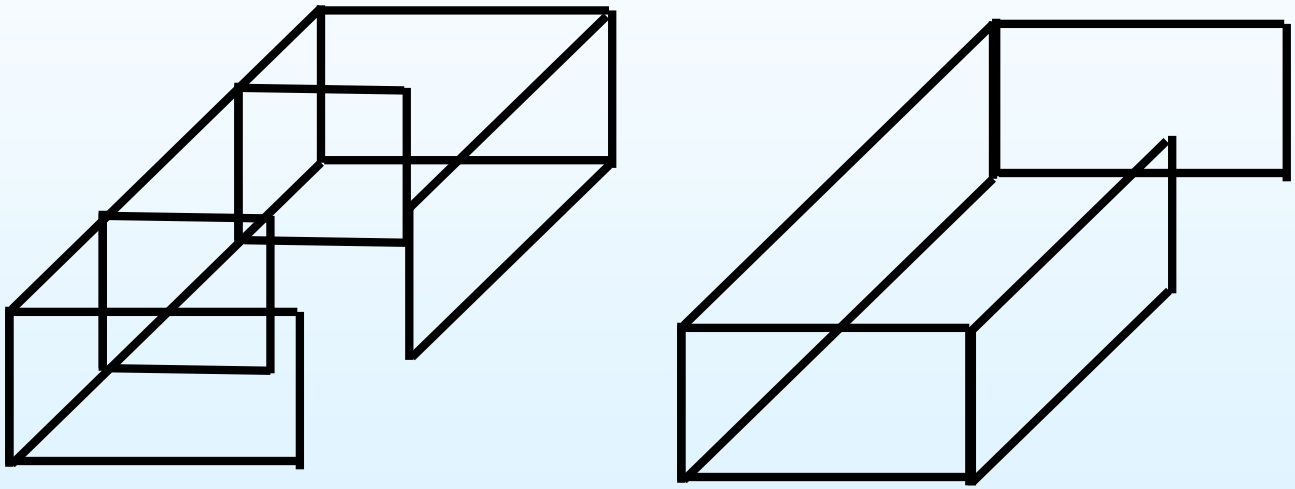
(1) Prescriptive Approach

- If certain rules followed, a level of safety will be achieved.
- Based on experience/incidents.
- Difficulties:
  - Concerns configuration.
  - Does not quantify results therefore precludes detailed analysis.
  - Designs deemed to be safe if they are compliant.
  - Comparison between compliant designs not possible.
  - Prevents analysis of procedural effectiveness.
  - Novel structures ⇒ no rational answer!

(2) Evacuation Drill/Trials

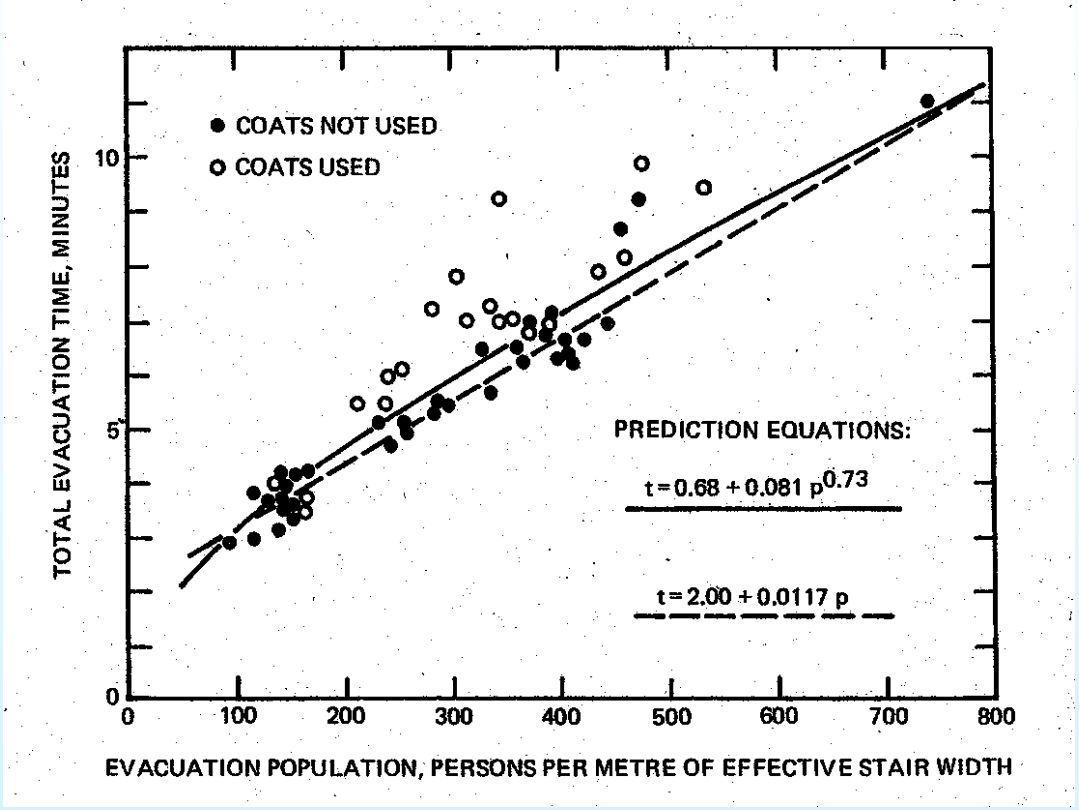
- Representative population and scenario(s).
- Difficulties:
  - Ethical
  - Practical
  - Financial
  - Produces limited number of data points - repeat trials
- Possibly the most complex ‘model’.
- Allows detailed assessment to be made of scenario examined
- Is unable to examine emergency conditions - especially the physical conditions
- Can only be employed on existing structures.

(3)Engineering Analysis – Empirical correlation/analysis at the level of the Structure



Evacuation time = f (Design A) ***Evacuation time = f (Design B)***

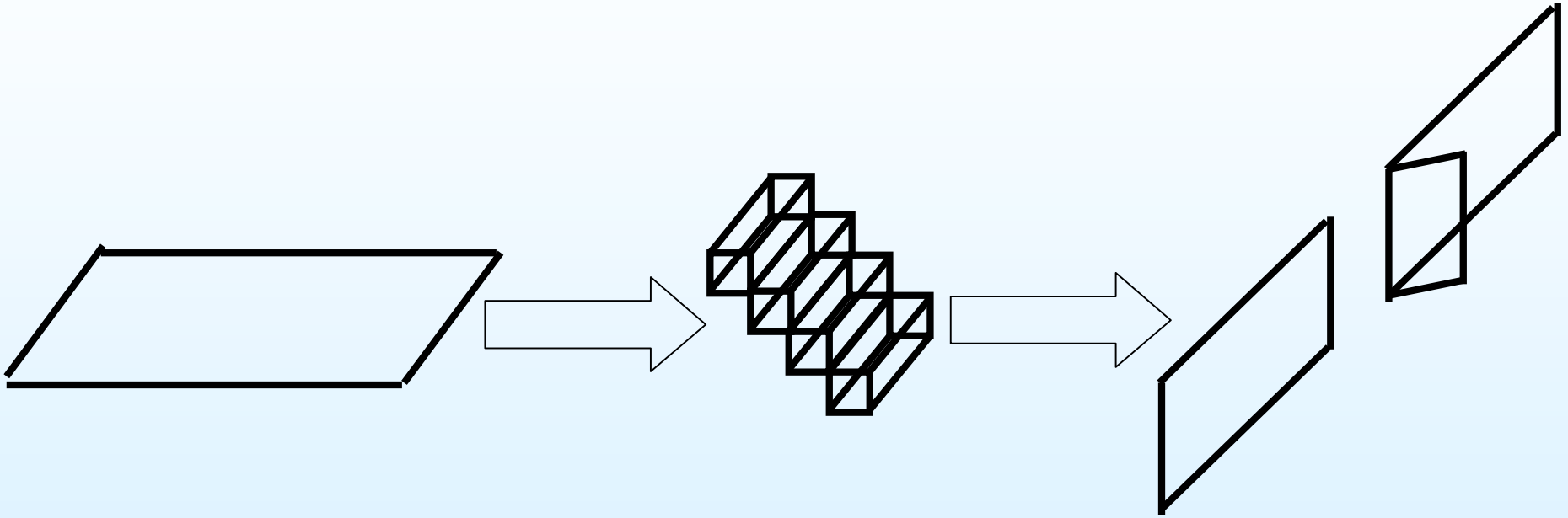
(3)Paul's Fire Drill Data



- Low-level factors?
- Building type is dominant factor
- Assessment of overall egress time
- Unable to look at subtle scenario changes

From Pauls

(4)Engineering Analysis – Manual calculation at the level of the Component



Evacuation time = f (Component A, Component B, Component C)

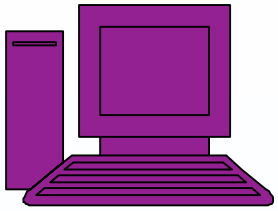
(4) Engineering analysis:Functionality

- Excludes sub-optimal behaviors
- Primarily physical considerations
- Averages across the populations
- Able to produce a range of different scenarios
- Able to quantify egress performance
- Based on simple assumptions
- Is able, to a degree, to represent different scenarios.
- Can be used for assessment and procedural design.

(5) Expert Analysis

- Knowledge/experience of expert forms ‘model’
- Use to understand impact of scenarios and procedural responses
  - Walkthrough - visual inspection of site
  - Examination of egress routes, occupant loads and available capacity.
- Identification of critical points.
- Unable to quantify impact
- Reliant on other approaches for quantification.
- Ideally expert analysis would be supported by other models in order to quantify results.

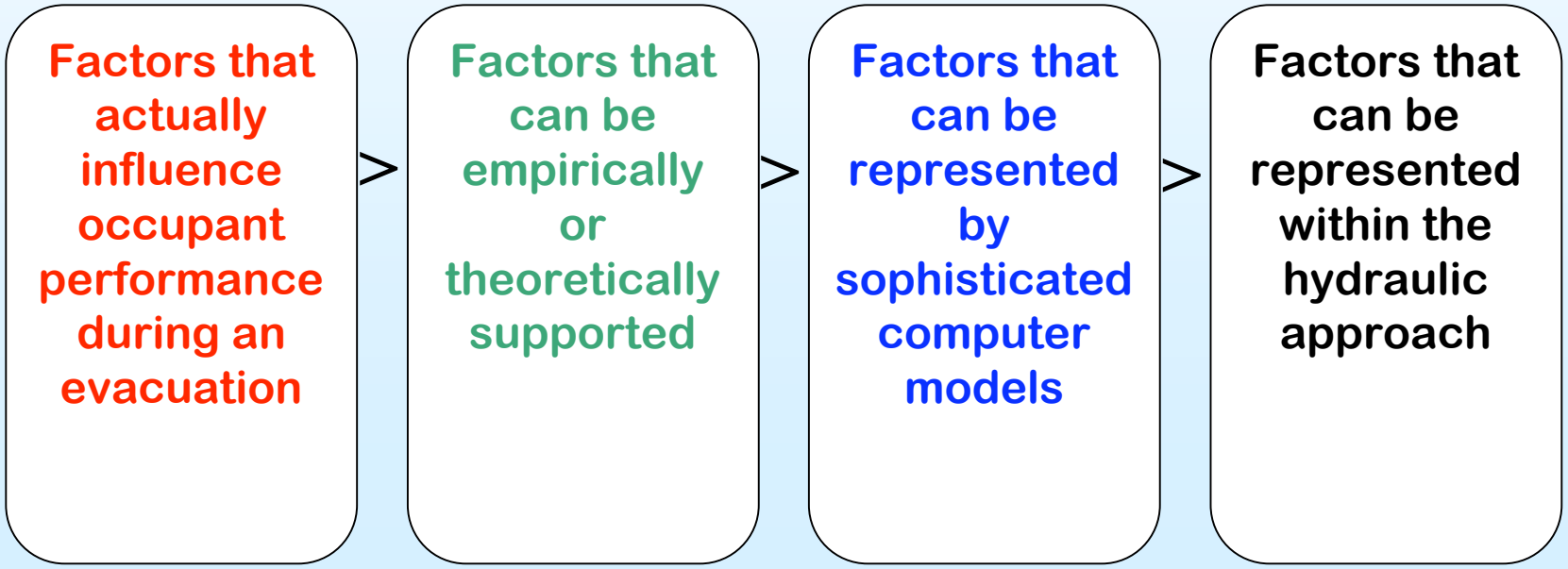
(6)Computational Evacuation Modelling



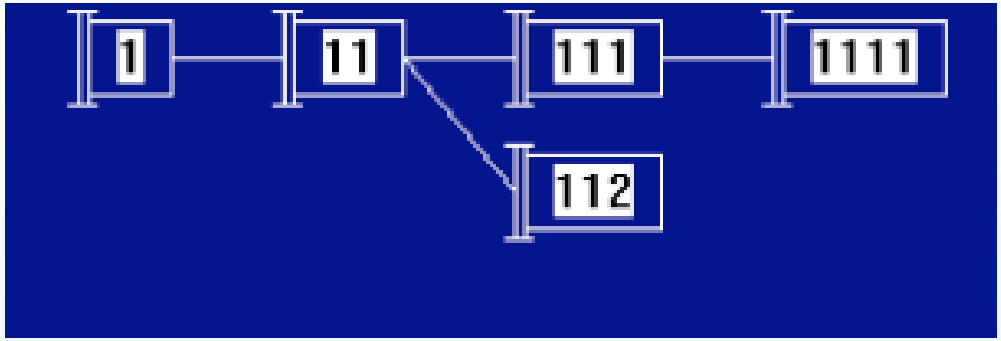
- *Increasingly applied to egress problems.*
- *Due to*
  - *Limitations of trials and engineering approaches;*
  - *Adoption of Performance-based codes;*
  - *Complexity and scale of new designs;*
  - *and the wider availability of the models themselves.*
- *Requires that we:*
  - *understand factors that influence development,*
  - *can differentiate between them,*
  - *apply them responsibly*
- *Now widely applied to a range of different structures and scenarios.*

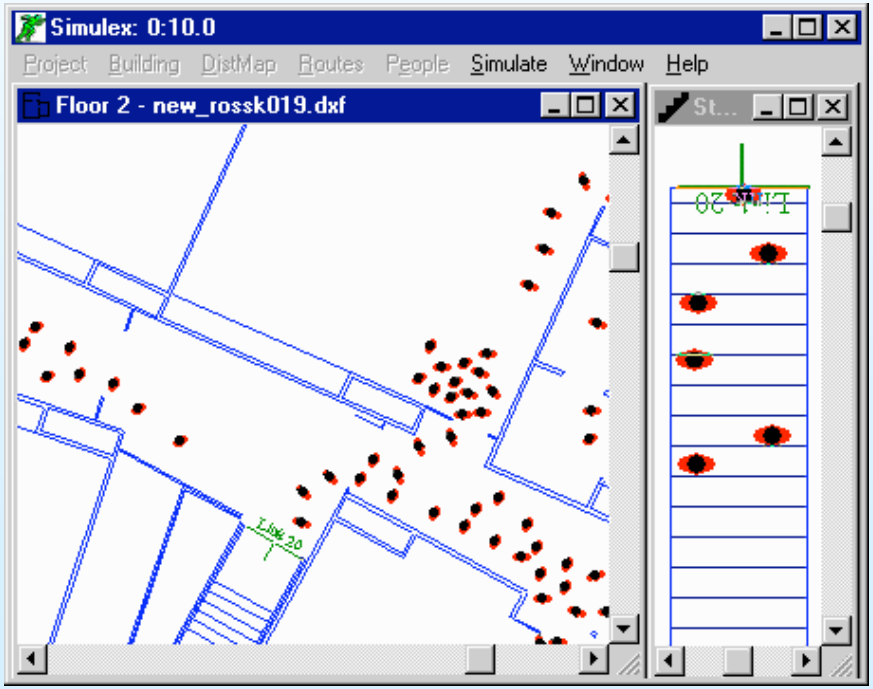
Gap between modeling and reality

- These are the models available to assess performance.
  - All imperfect.
- Irrespective of model employed, always a gap between modelled world and real world.

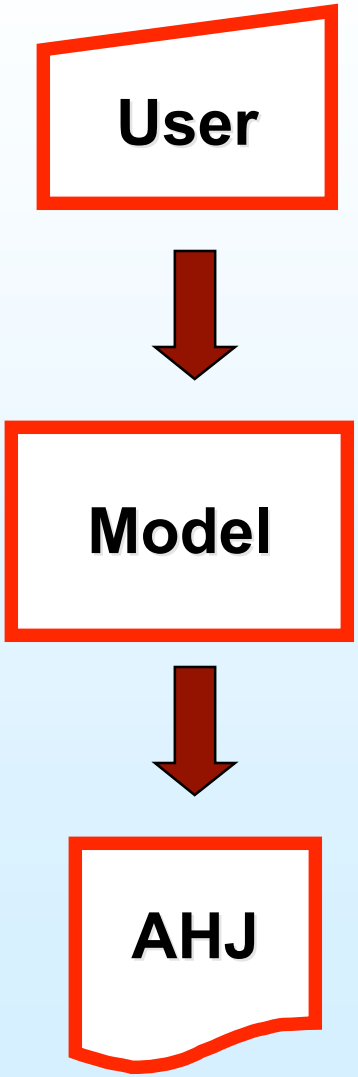


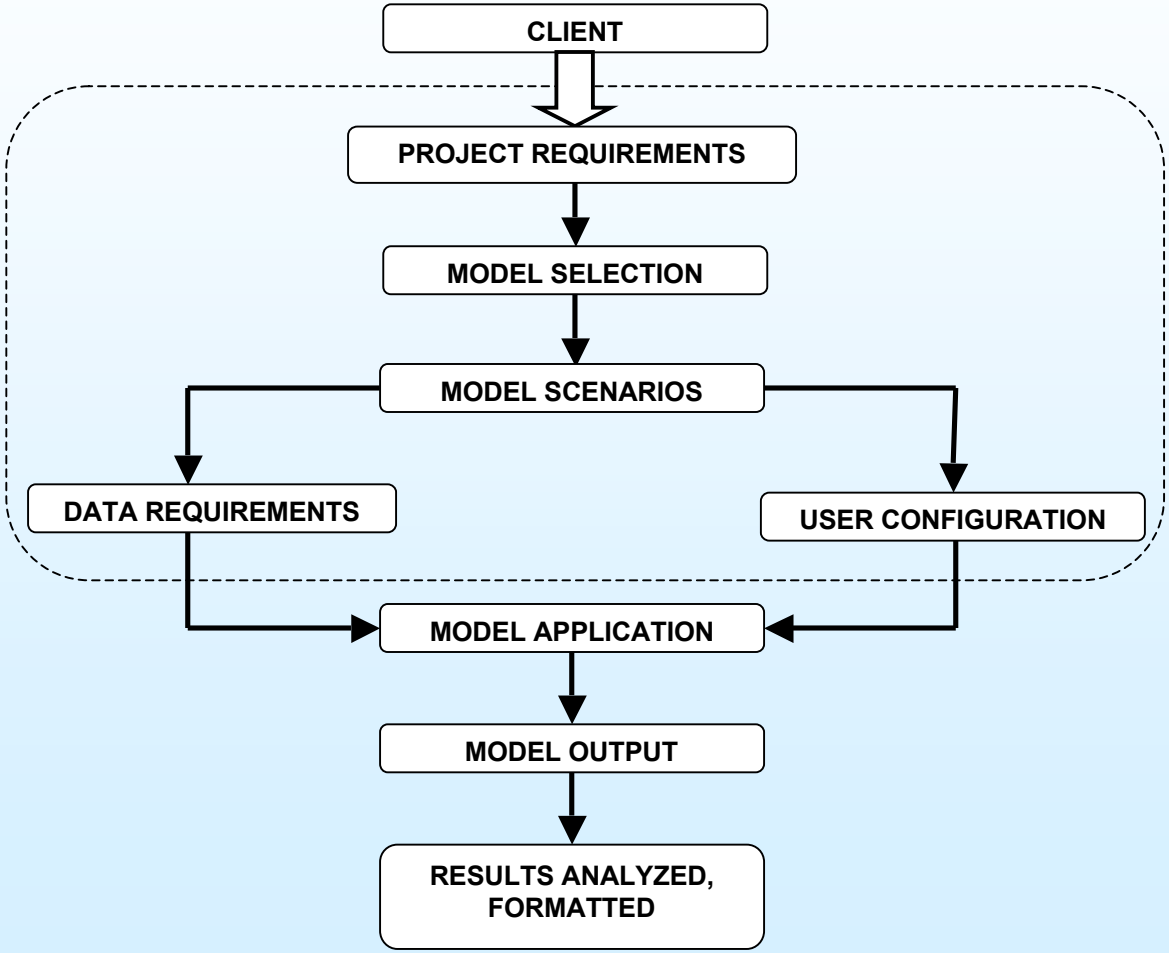
Not all computer models are the same



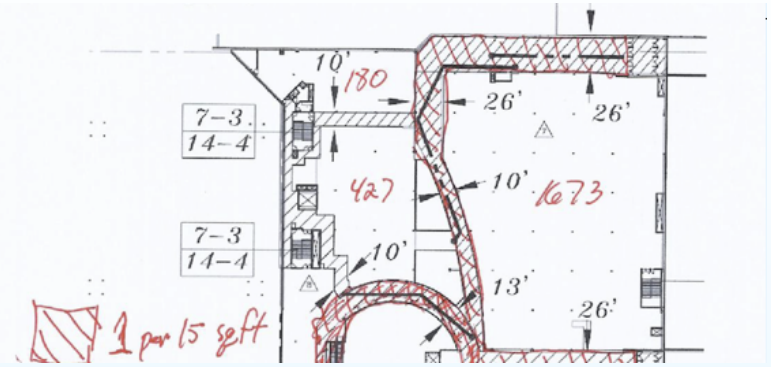


Modelling Process

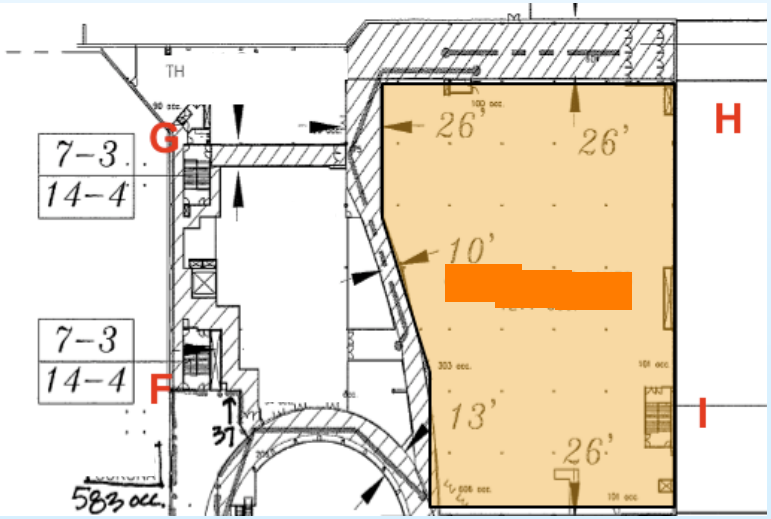


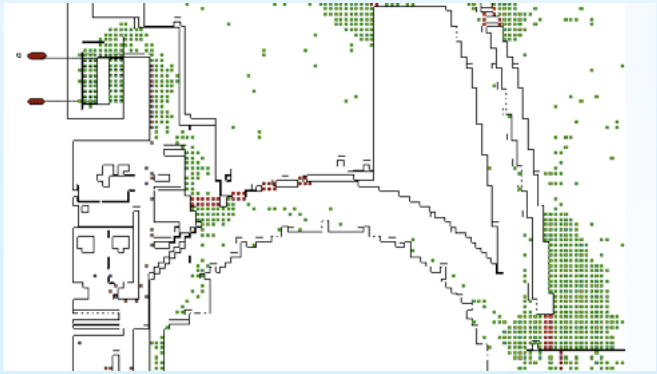


Action: Building Considerations



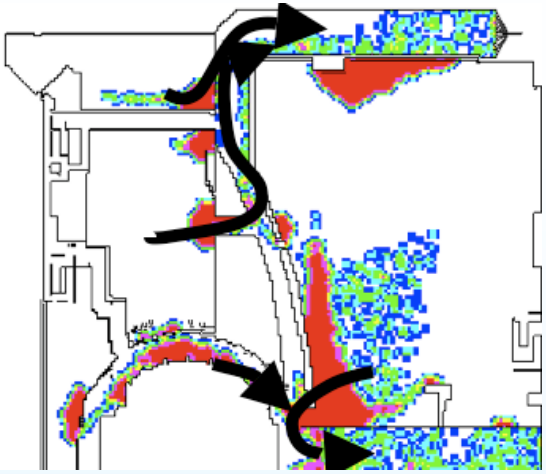
Action: Population Parameters





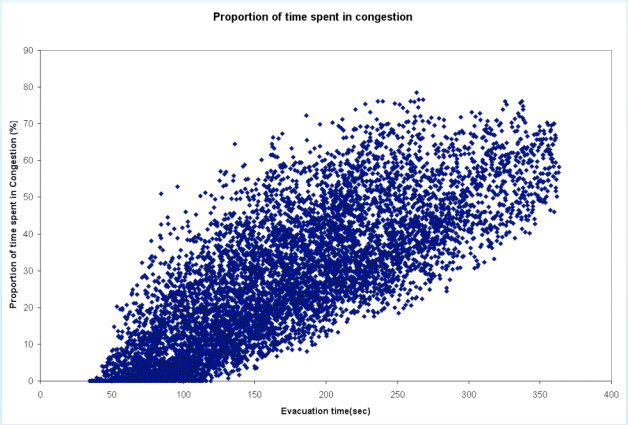
Action: Behavioural Issues

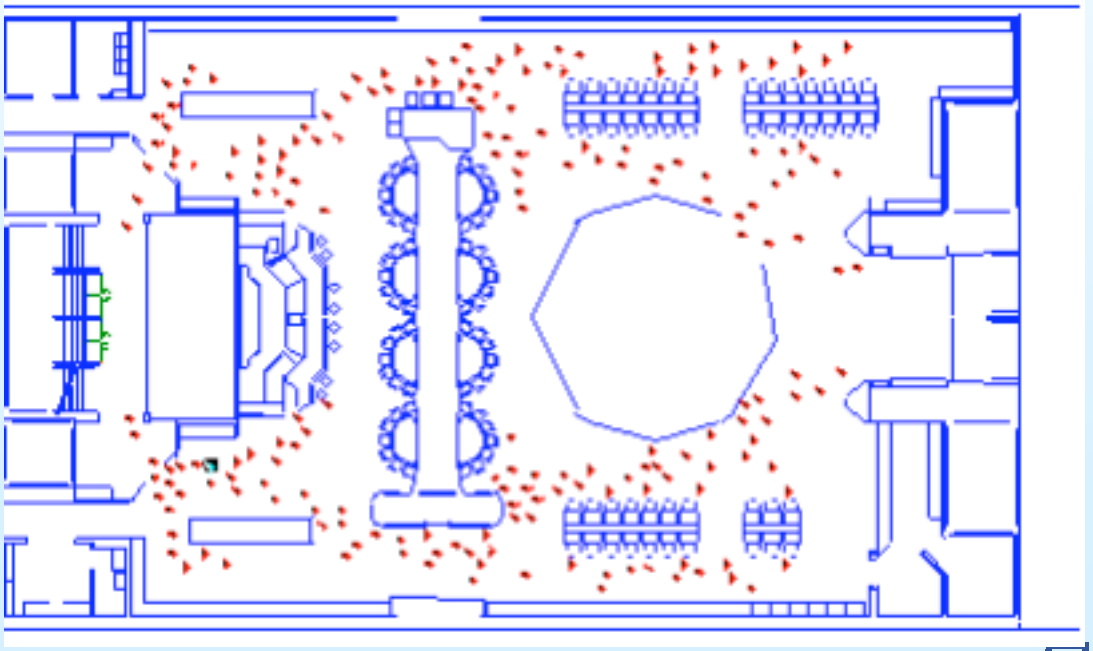
- Routes Adopted
- Response of Population



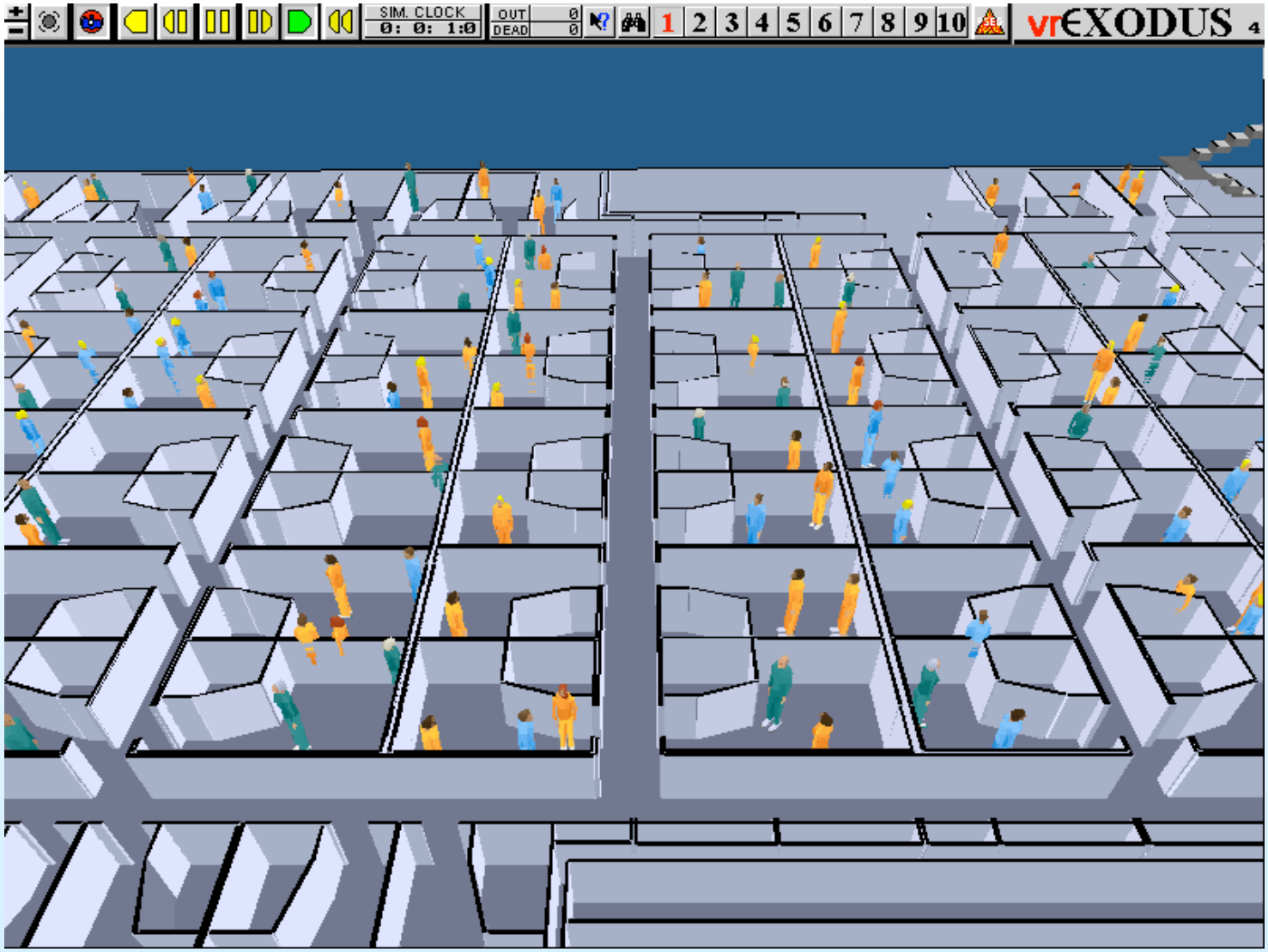
Interpretation: Output

- Data – individual, population, structural, etc.
- Textual, graphical, etc.

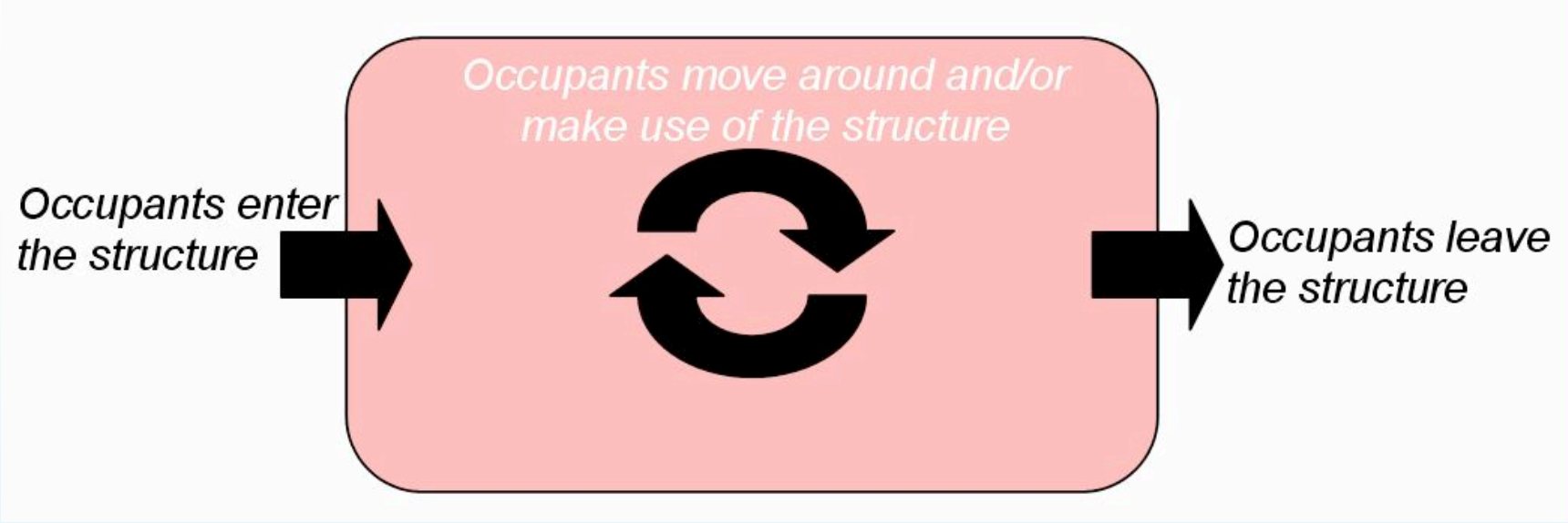




Action: Environmental Issues

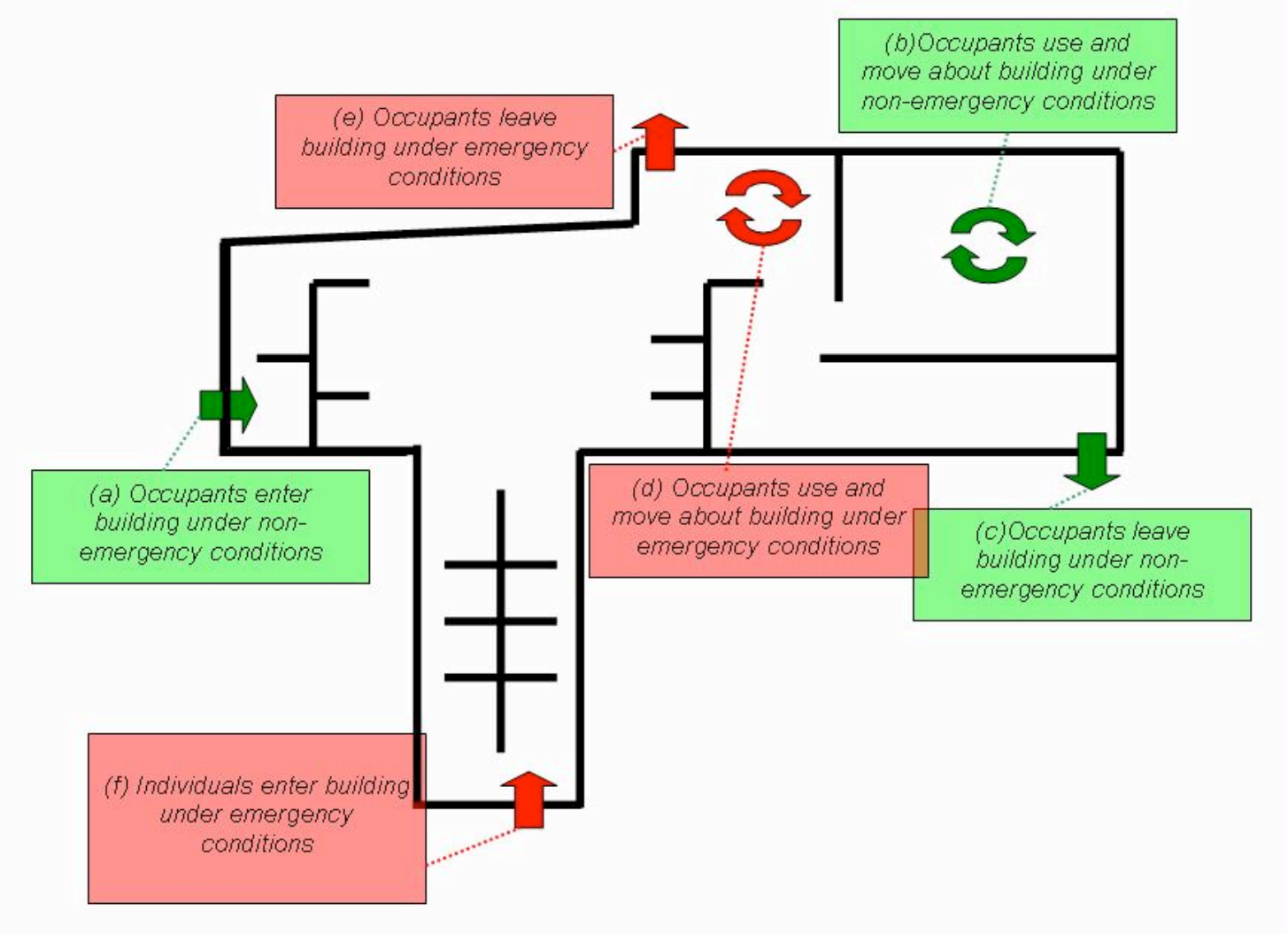


Tall Buildings: People Movement



- Any non-emergency or emergency procedure will need to be sensitive to the different uses of the structure.
- Ideally, models should be able to take this into consideration.

Tall Buildings: Simultaneous Use of the Building



Tall Buildings

- Issues:
  - Occupied by multiple tenants
    - Larger populations
    - Likelihood of numerous procedures
    - Lack of co-ordination
    - Presence of multiple information systems
    - *WTC:application of several conflicting procedures*
  - Potential for overloading staircases
    - *WTC: imbalanced use, loss of routes, ingress, unmanaged response*
  - Distances that need to be traversed
    - *WTC: people needed to traverse over 75 floor - likelihood of fatigue.*

Tall Buildings

- Issues:
  - Proximity to incident - influence on perception and exposure to danger
    - *WTC: Perception of incident influenced by location of individual*
  - Issues of security
    - *WTC: Attempt to maintain perimeter security can influence both emergency and non-emergency activities.*
  - Issues of route usage
    - *WTC: Stairs would not normally have been used to leave the building.*
  - Problems posed to responding Fire Department
    - *WTC: Access and understanding of the situation.*

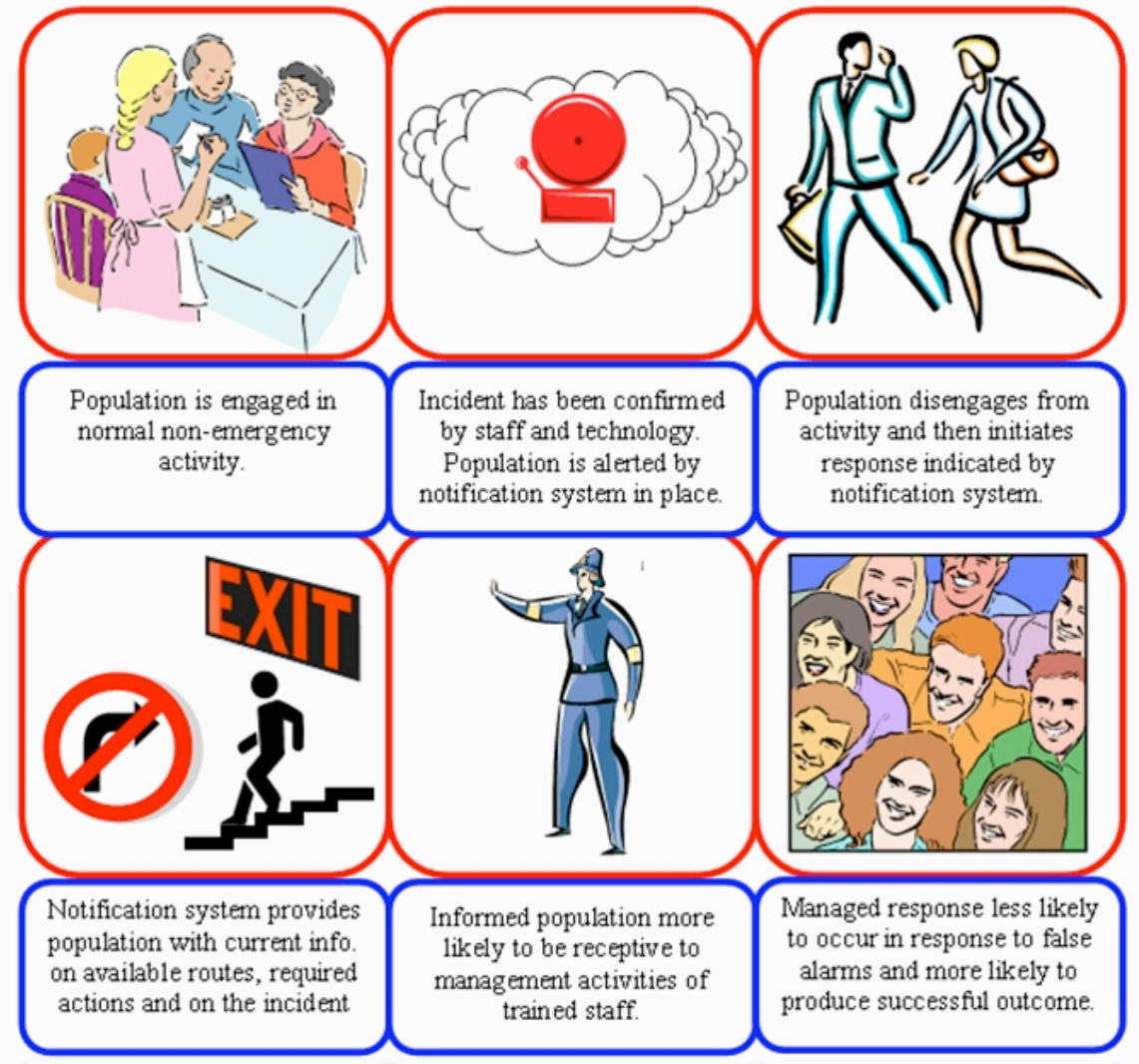
Tall Buildings and Use of Models

- Response to Issues:
  - Require an integrated and coordinated response
    - ***Models enable complex procedures to be designed and tested***
  - Potential for overloading staircases / Issues of route usage
    - ***Models enable impact of overloading to be quantified***
  - Distances that need to be traversed
    - ***Models enable impact of different evacuation behaviours to be assessed; e.g. distances, congestion, response, etc.***
  - Proximity to incident incident
    - ***Models enable a range of incident scenarios to be examined***
  - Issues of security
    - ***Models enable interaction of emergency and non-emergency components to be established.***
  - Problems posed to responding Fire Department
    - ***Problems can be established before arrival of FD, possible congestion outlined and detailed information provided.***

Managed Response Based on Assessment

- *Assessment of Design*
  - *Procedural/Structural*
- *Preparation*
  - *Training/Drills/Documentation/Demonstration*
- *Operation*
  - *Daily activities within structure*
- *Implementation*
  - *Managed response to incident*
- *Investigation*
  - *Understanding the influential factors*

Ideal Scenario



Reasons to be Careful

- Model is only a tool - albeit a useful one.
- User is a vital component.
- Vital that results are presented along with model assumptions/limitations.
- Non-expert user can produce inaccurate results
- However, the expert user
  - *Can examine a range of scenarios in greater detail demonstrating the outcome and the reasons for it.*

Conclusion

- Vital that egress performance is understood.
- Underlying assumptions are critical to validity of results.
- Quality of the modeling approach depends on the user and the model.
- Able to examine complex situations, a range of hazards, quantify the outcome and test validity and robustness of response.
- Tall buildings present a number of issues that need to be addressed - many evident during 9/11.
- Computational egress models aid in the resolution of these issues in a way that other approaches are unable to do.

Thanks for your time

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