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

Rome, Italy

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?*
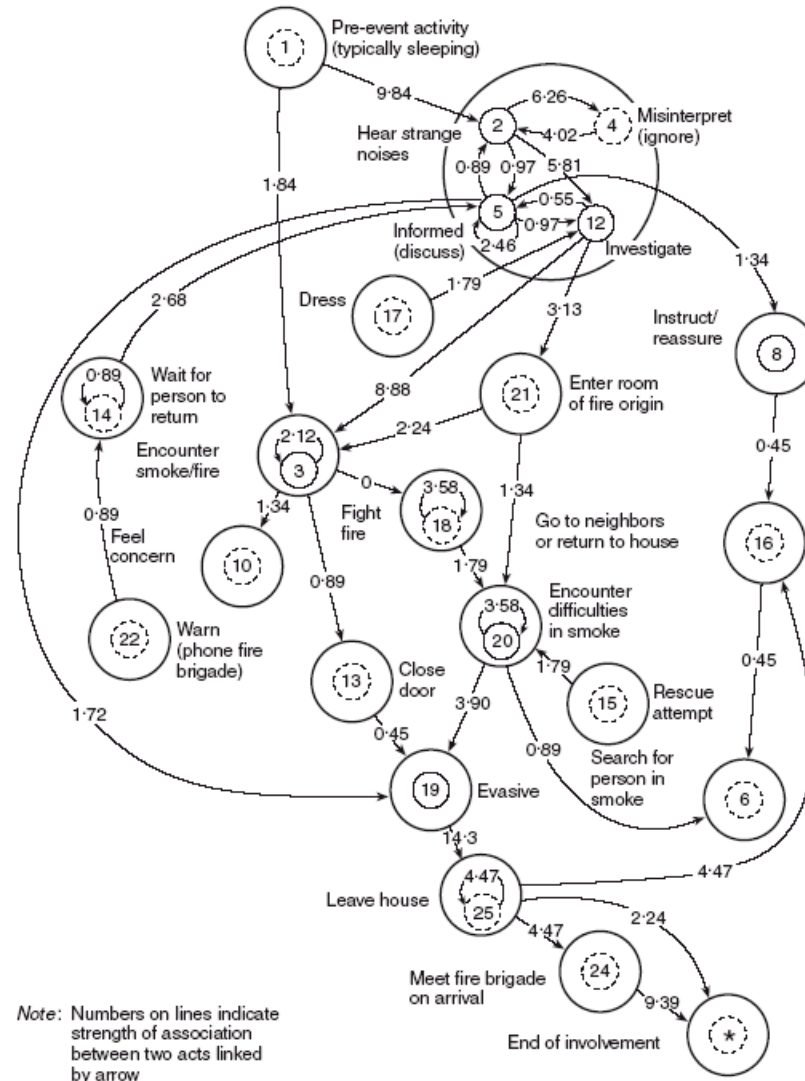
Aspects of the Evacuation Process
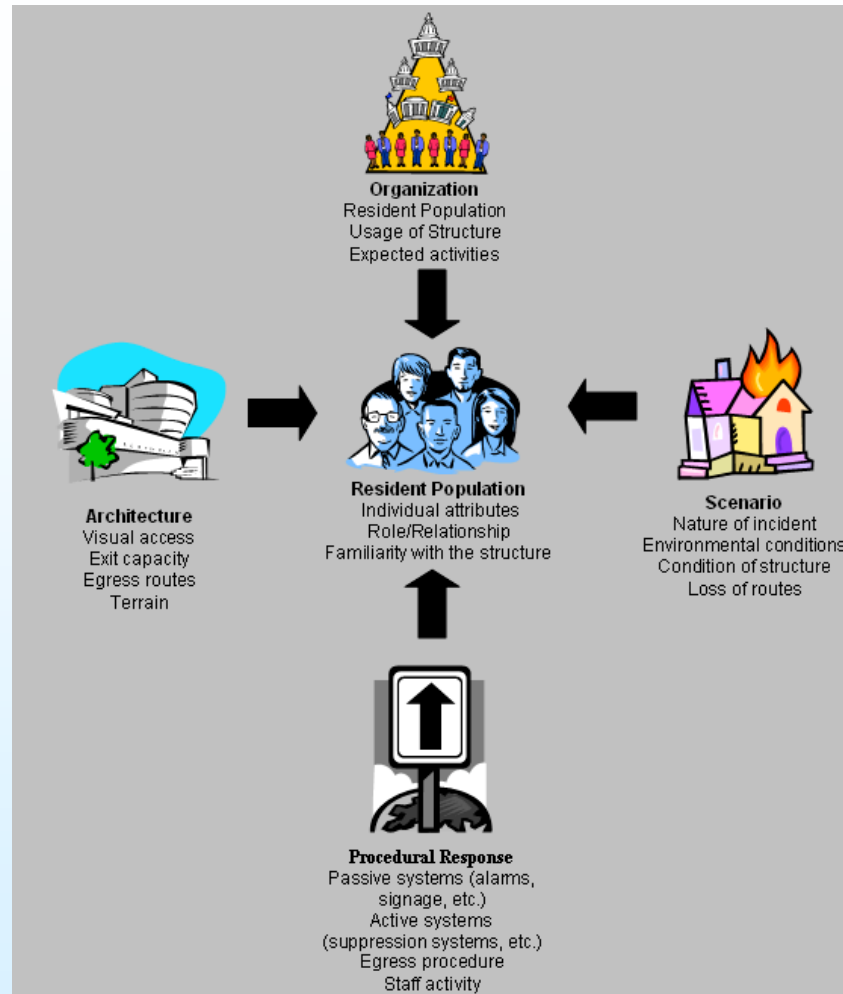
- **Large number of factors that influence the outcome of an evacuation**

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.

Pre-event activity (typically sleeping)
Hear strange noises
Misinterpret (ignore)
Informed (discuss)
Investigate
Instruct/reassure
Dress
Enter room of fire origin
Wait for person to return
Encounter smoke/fire
Feel concern
Fight fire
Go to neighbors or return to house
Warn (phone fire brigade)
Encounter difficulties in smoke
Close door
Rescue attempt
Evacuate
Search for person in smoke
Leave house
Meet fire brigade on arrival
End of involvement

Note: Numbers on lines indicate strength of association between two acts linked by arrow

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
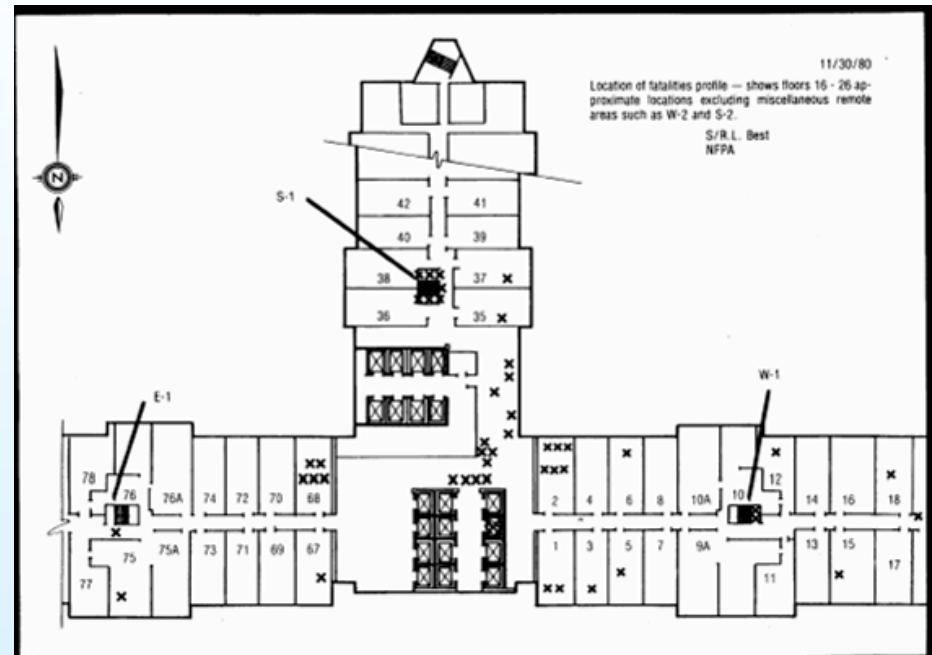
SFPE Handbook

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.

11/9/7   Rome, Italy

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
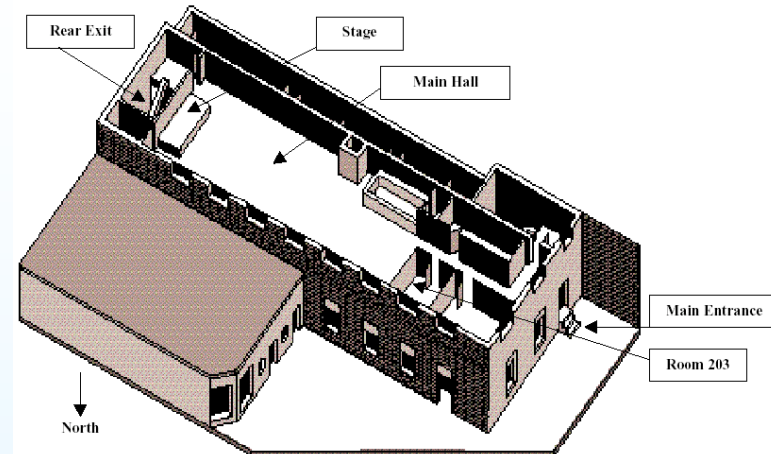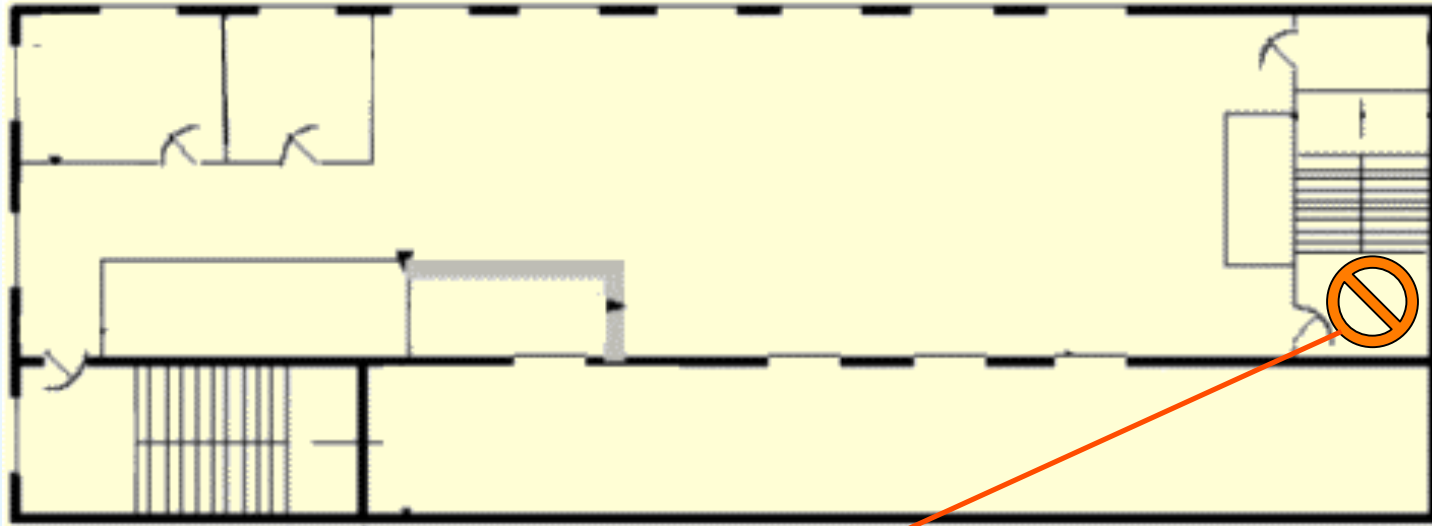

Figure No. 2 – Detailed Site Plan
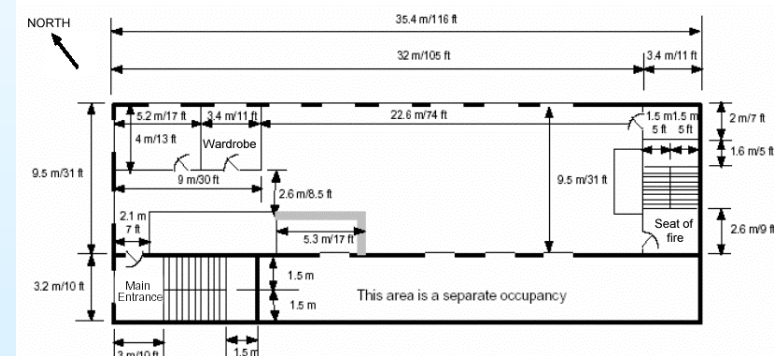
Comeau and Duval, NFPA

Detailed analysis and later computer analysis.

Gothenburg - Event Evolution

Fire develops unnoticed, blocking potential egress route

Gothenburg - Event Evolution
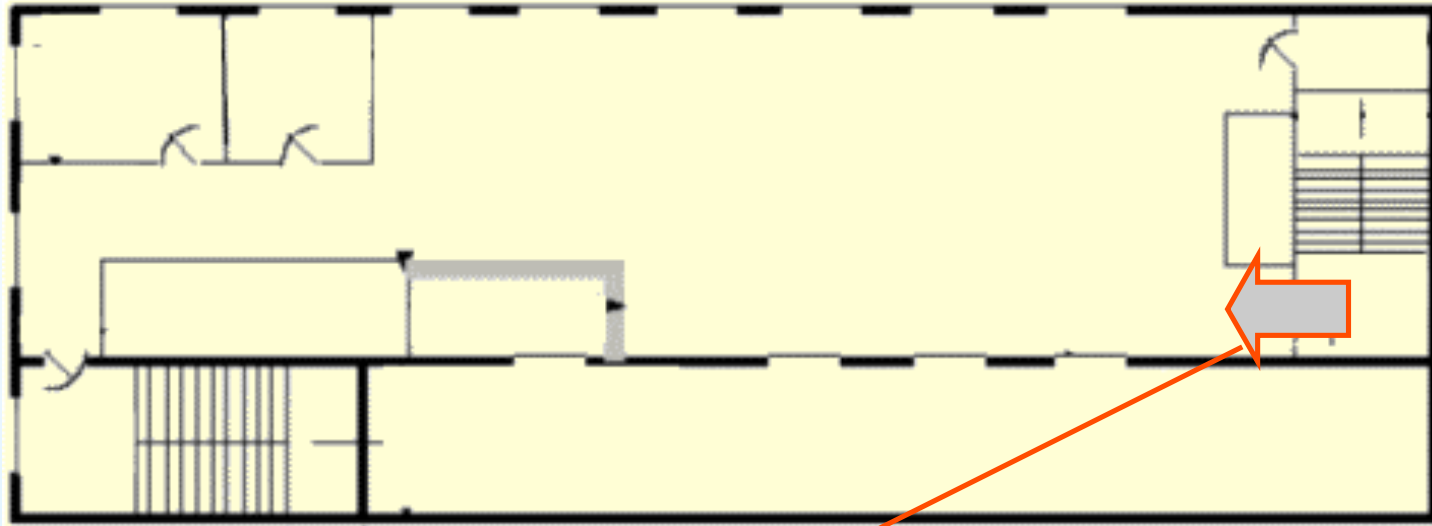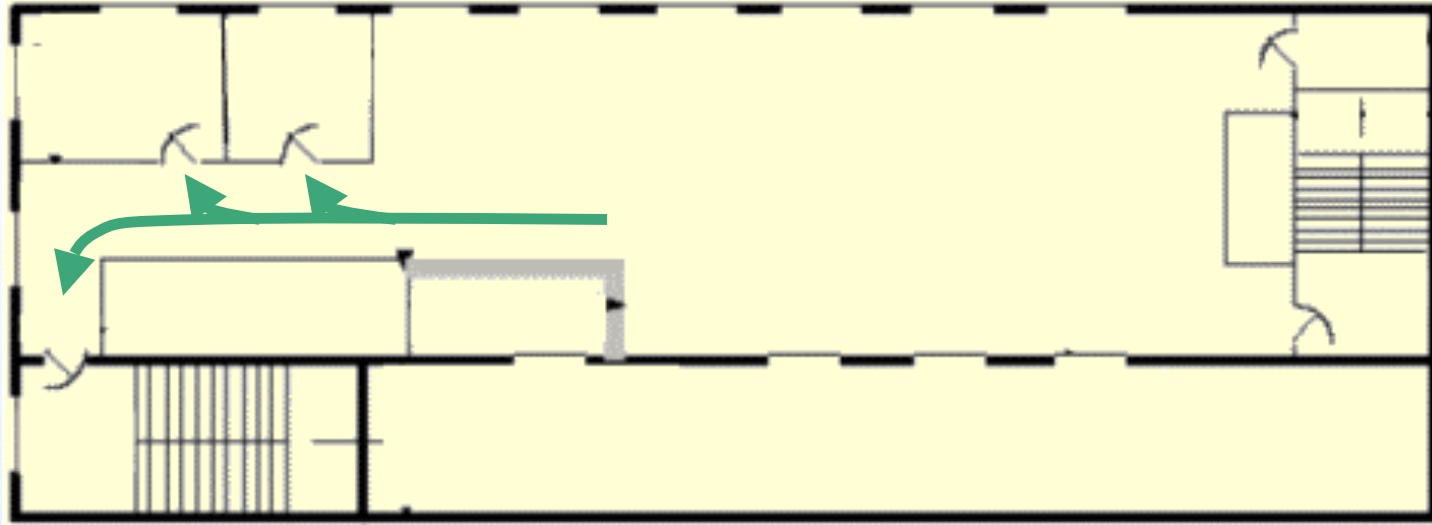

Door opens, fire bursts into main room.

Gothenburg - Event Evolution
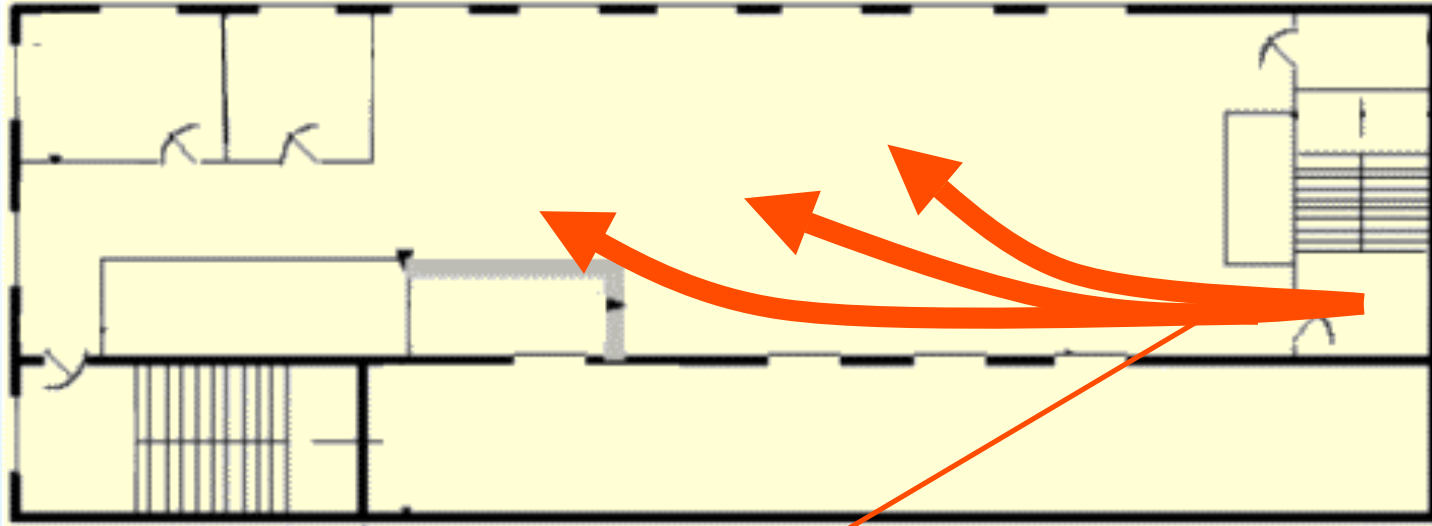
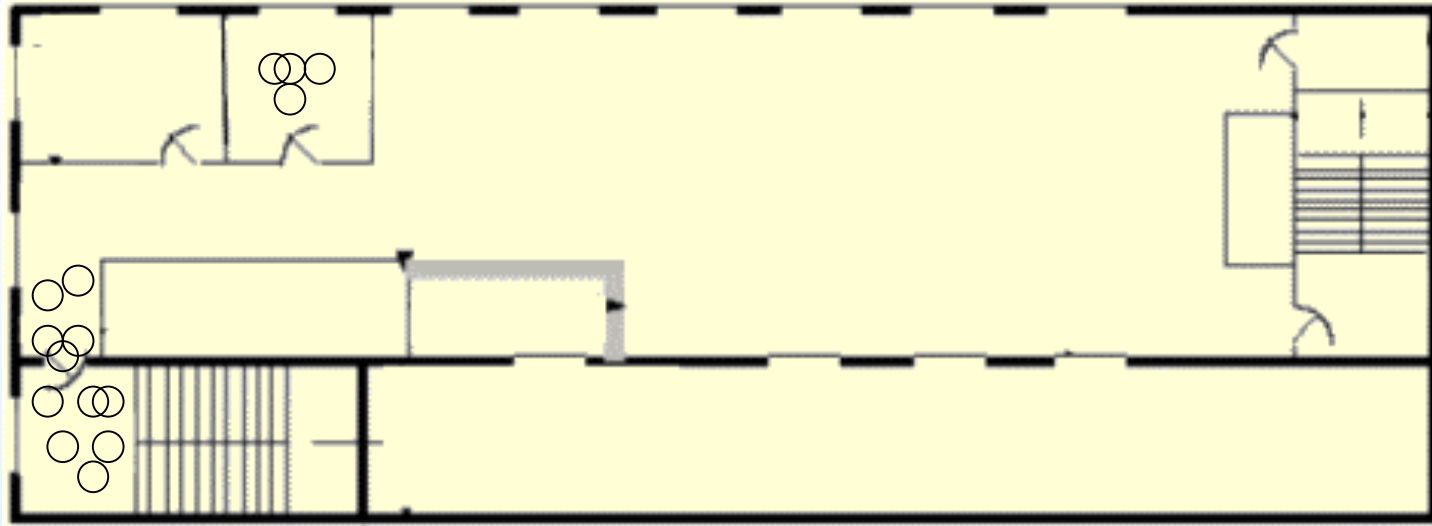Fire spreads into room, forcing people to evacuate.

Gothenburg - Event Evolution

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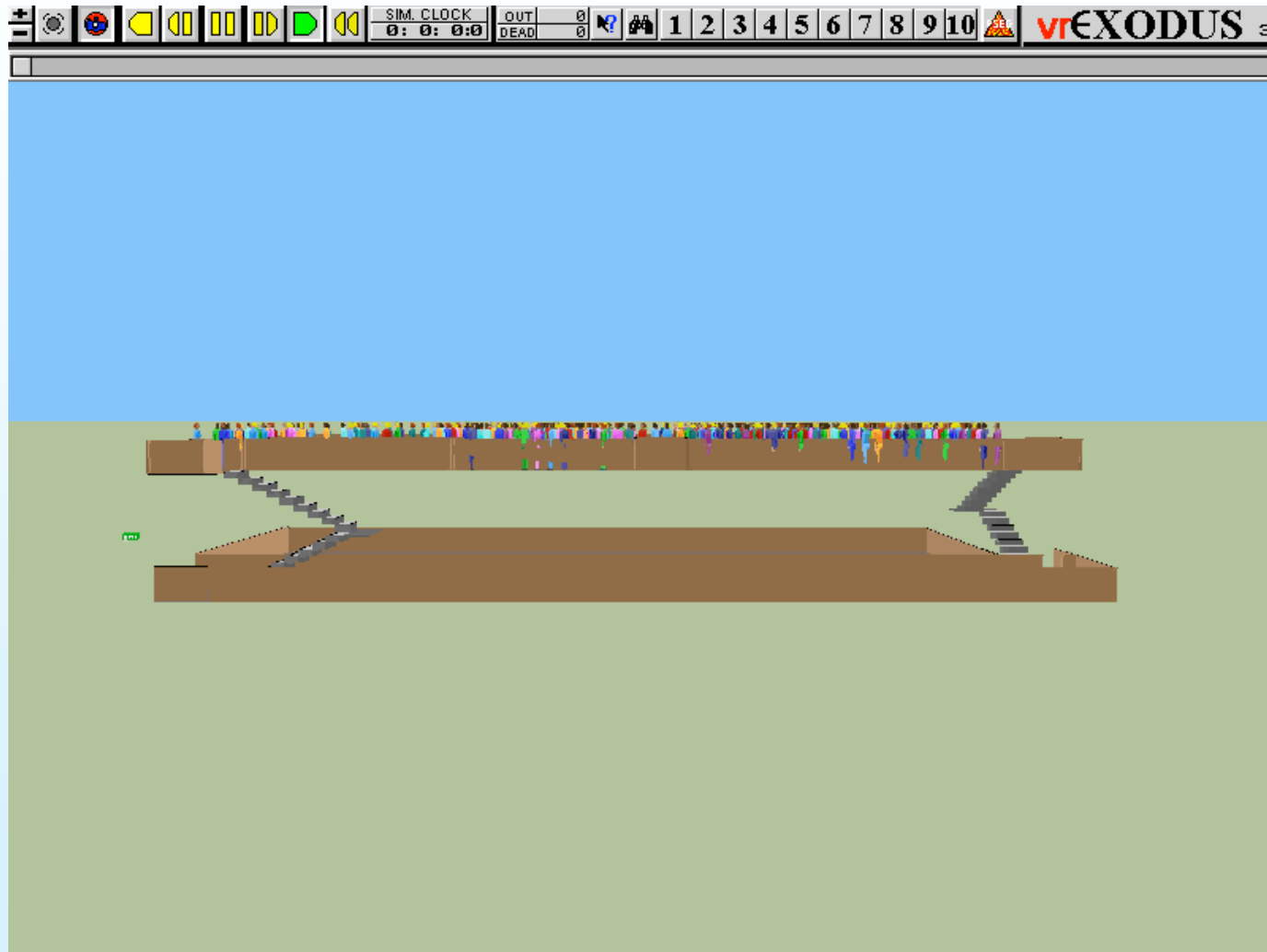
Gothenburg - Event Evolution

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.
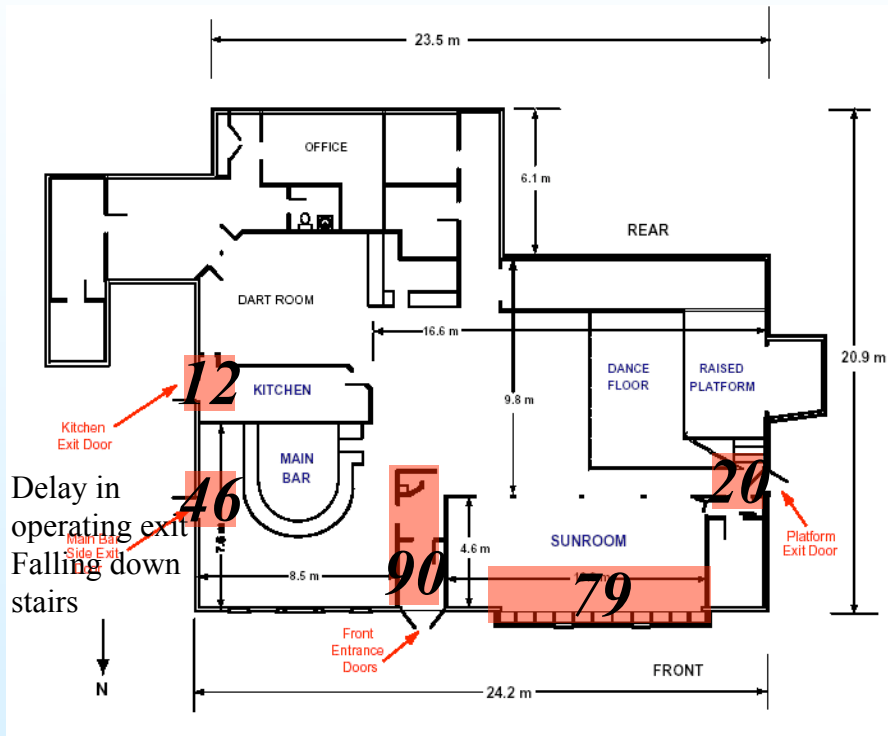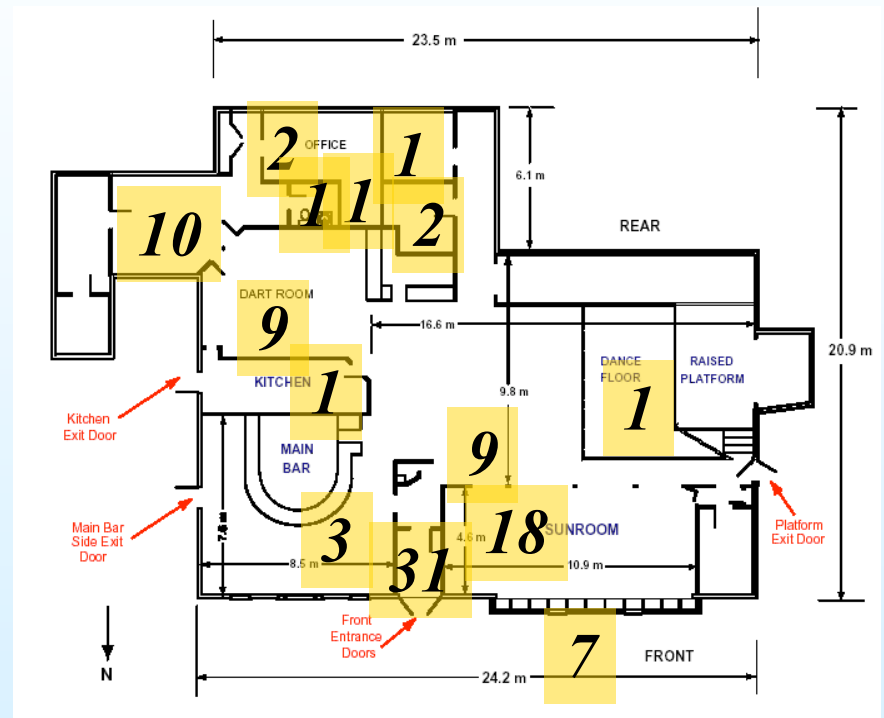

University of Greenwich

Detailed analysis and computer analysis using several egress models.

Station Disco Fire Analysis

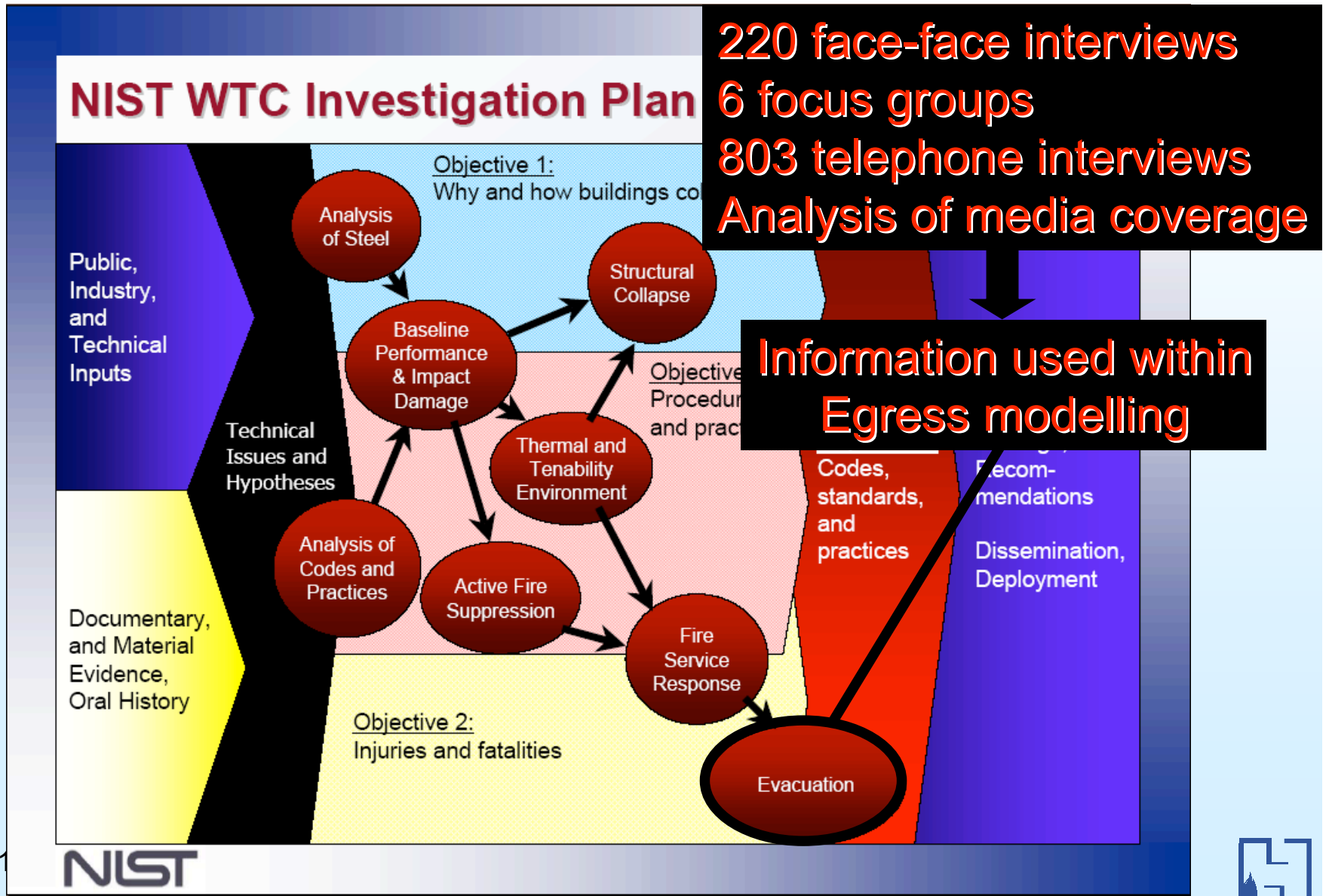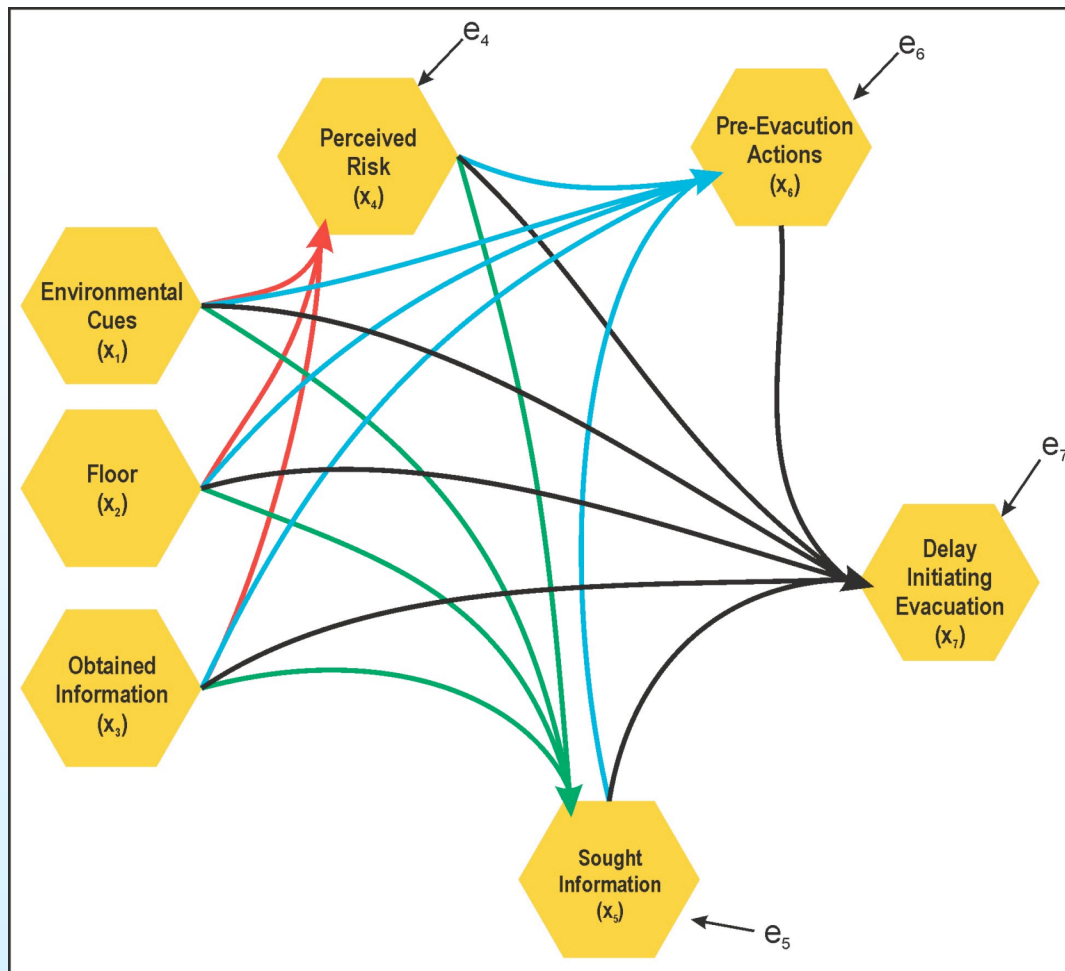
Exit Usage

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

220 face-face interviews
6 focus groups
803 telephone interviews
Analysis of media coverage

Information used within Egress modelling

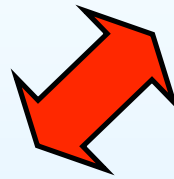*From NIST*

NIST - Behavioural Analysis

WTC: Averill et al. 2005

NIST Egress Modeling

- Adopted a 'triangulation' approach to modeling

Rome, Italy
Representative rather than actual images generated

Assessment of the population size, stair use and FD ingress

University of Greenwich
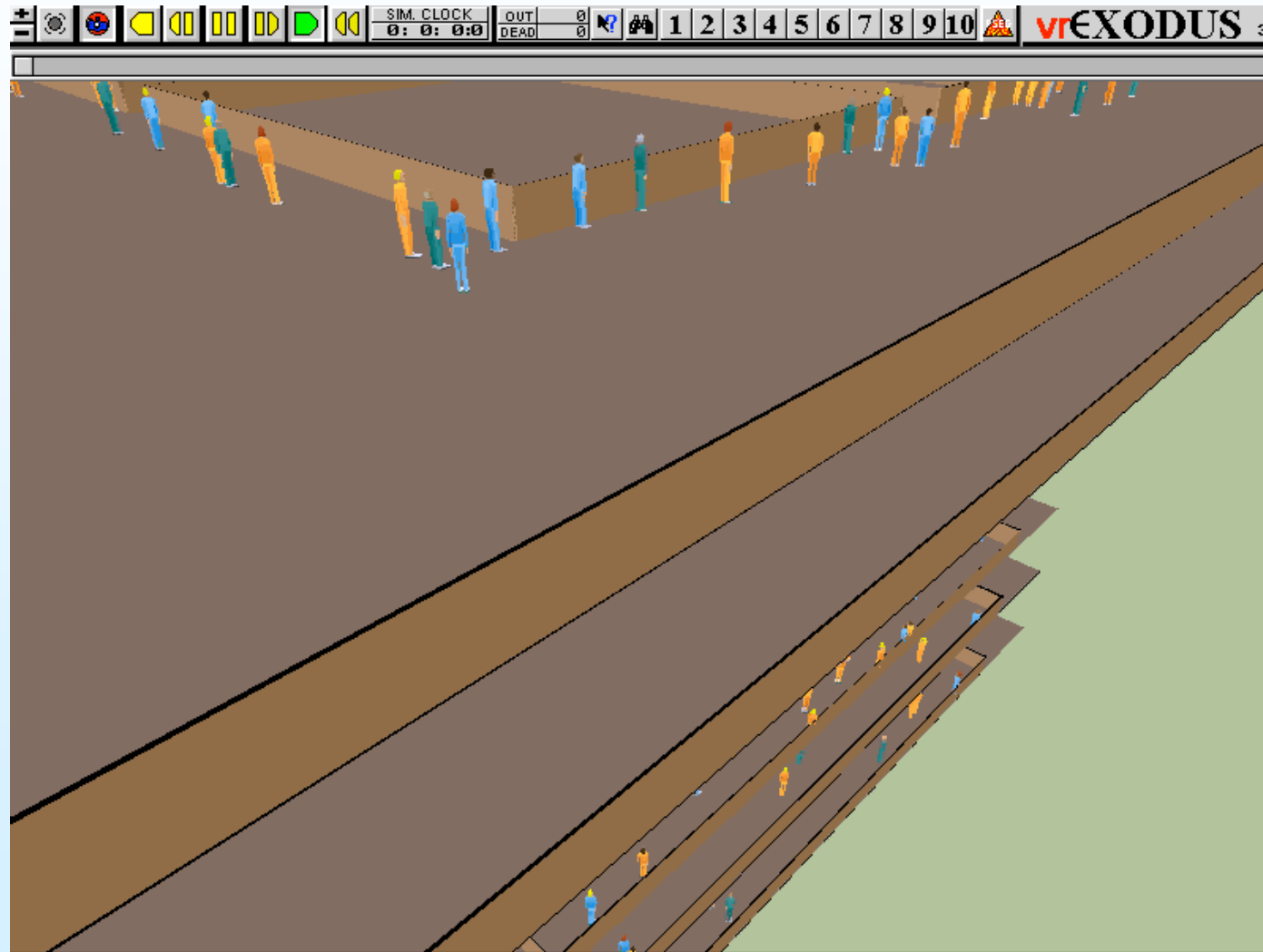
Understanding and Quantification

- 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'*

Empirical approach

Model approach

Engineering approach
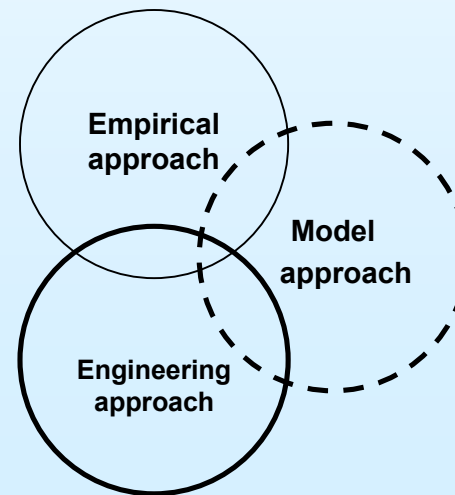
(1) Prescriptive Approach

- 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.
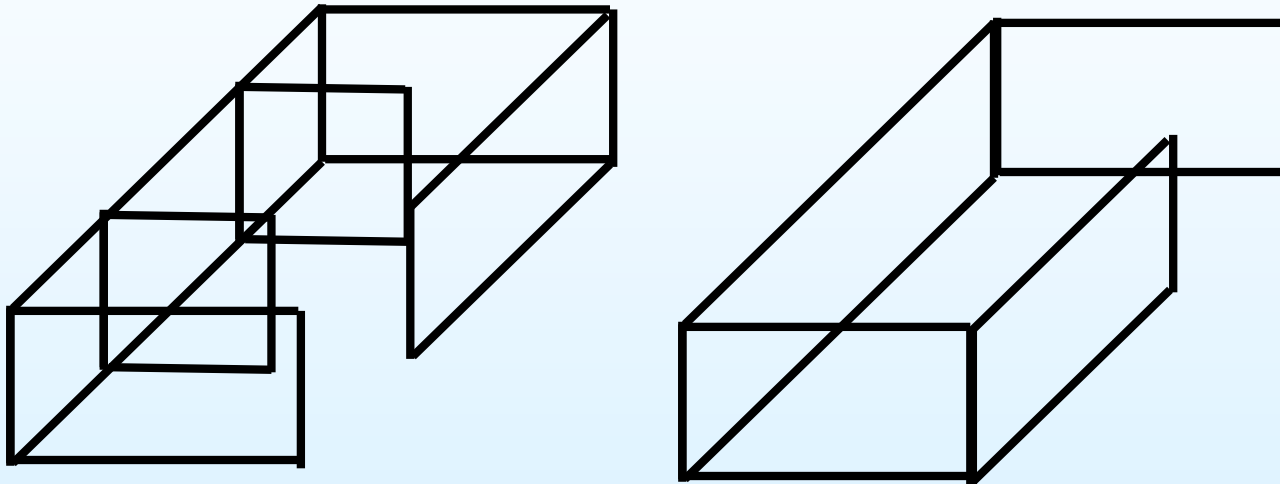 - Novel structures $\Rightarrow$ no rational answer!

(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
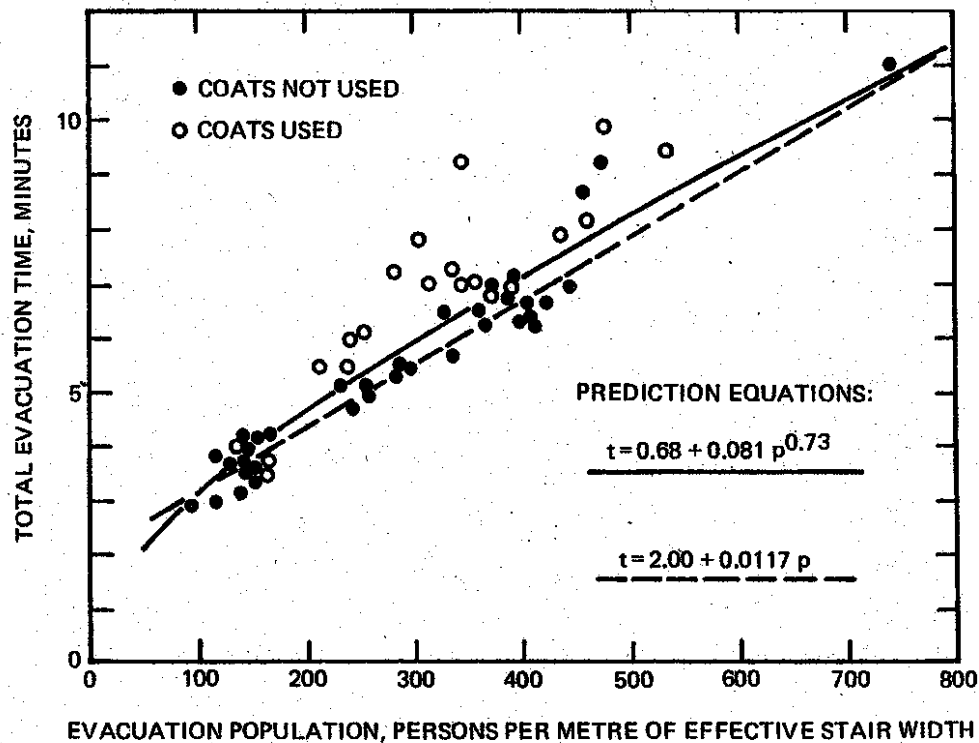- Can only be employed on existing structures.

(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

COATS NOT USED
COATS USED

TOTAL EVACUATION TIME, MINUTES

PREDICTION EQUATIONS:

$$t = 0.68 + 0.081\ p^{0.73}$$

$$t = 2.00 + 0.0117\ p$$
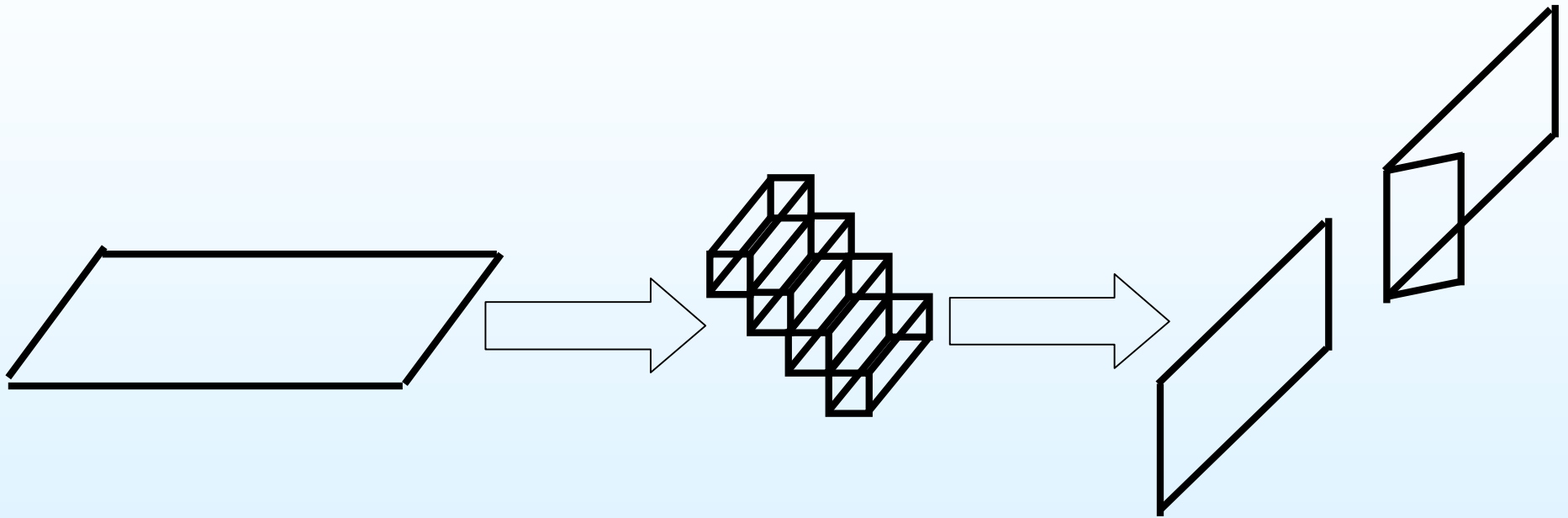
EVACUATION POPULATION, PERSONS PER METRE OF EFFECTIVE STAIR WIDTH

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

(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.
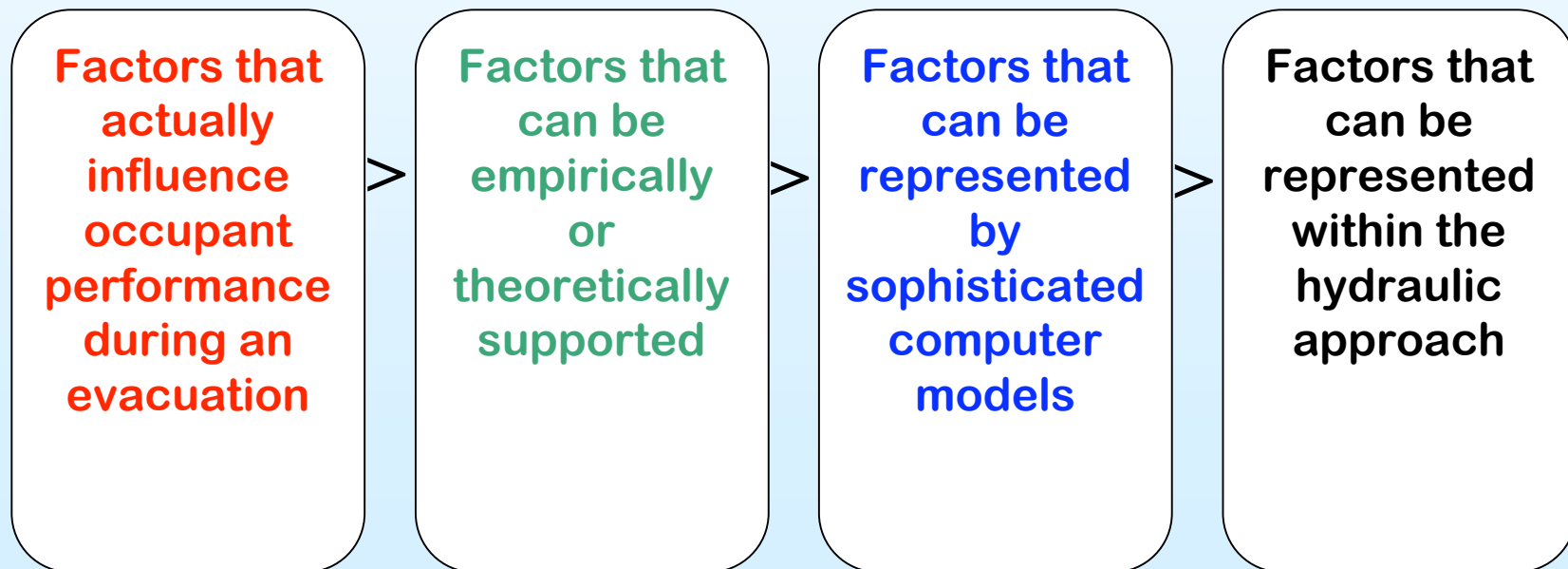
(6)Computational Evacuation Modelling
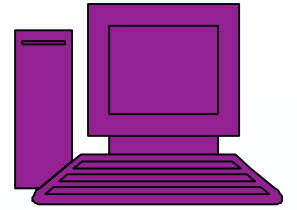
- *Increasingly applied to egress problems.*
- *Due to*
  - *Limitations of trials and engineering approaches;*
  - *Adoption of Performance-based codes;*
  - *Complexity and scale of new designs;*
  - *and the wider availability of the models themselves.*
- *Requires that we:*
  - *understand factors 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.

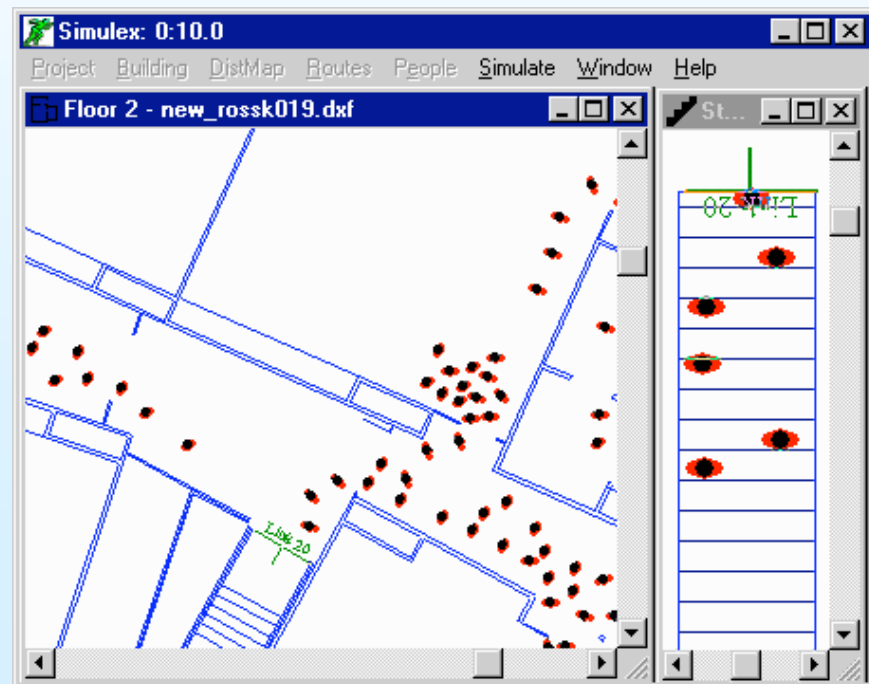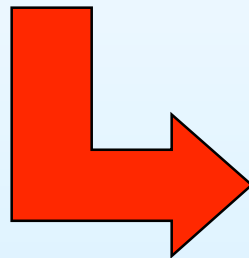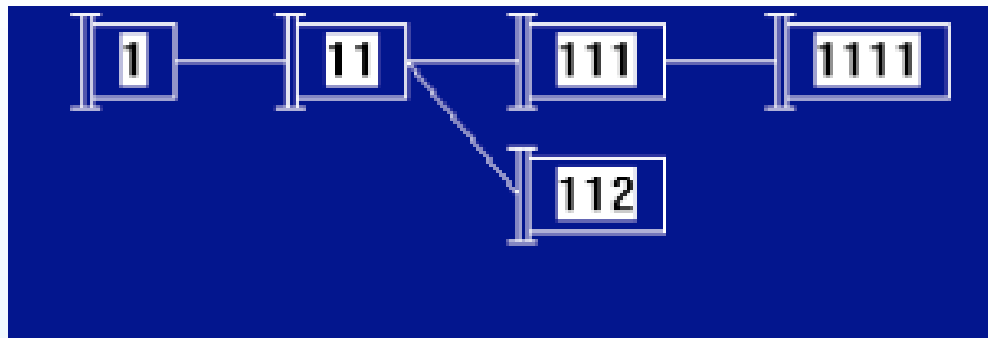- Irrespective of model employed, always a gap between modelled world and real world.

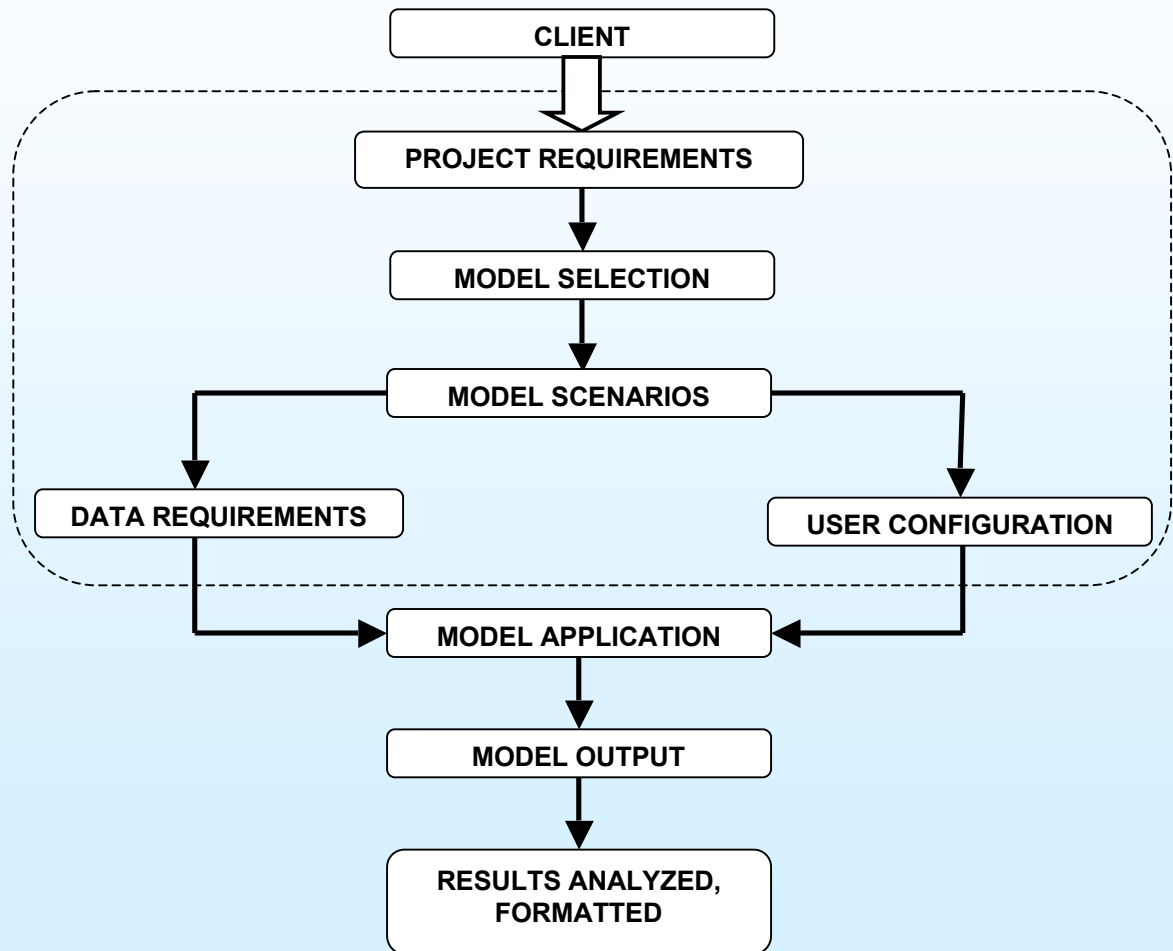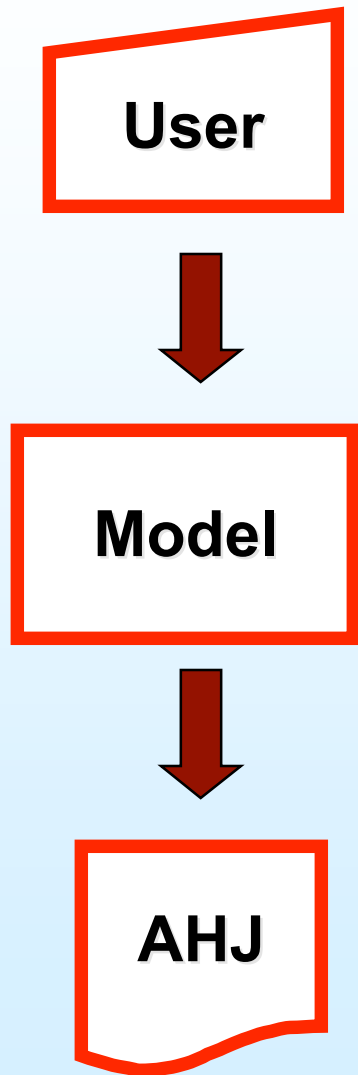| Factors that actually influence occupant performance during an evacuation	>	Factors that can be empirically or theoretically supported	>	Factors that can be represented by sophisticated computer models	>	Factors that can be represented within the hydraulic approach

11/9/7   Rome, Italy

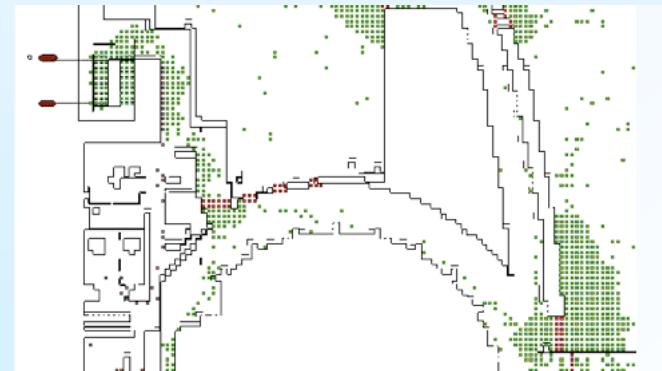# Not all computer models are the same

Rome, Italy

Modelling Process

User

Model

AHJ

CLIENT

PROJECT REQUIREMENTS

MODEL SELECTION

MODEL SCENARIOS

DATA REQUIREMENTS

USER CONFIGURATION

MODEL APPLICATION

MODEL OUTPUT

RESULTS ANALYZED, FORMATTED

Action: Building Considerations
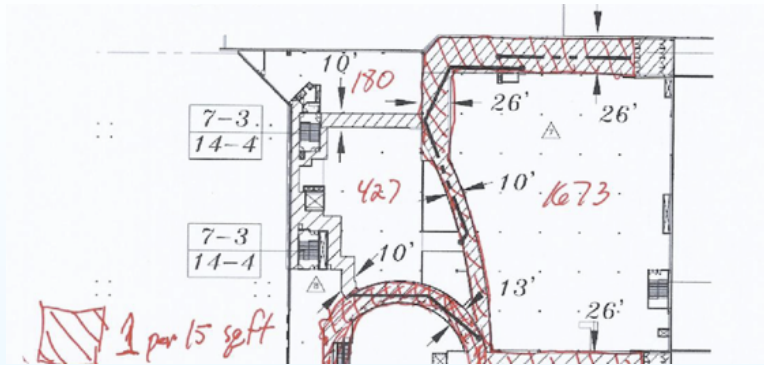
Action: Population Parameters
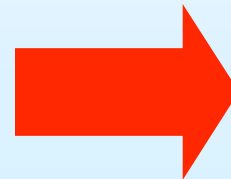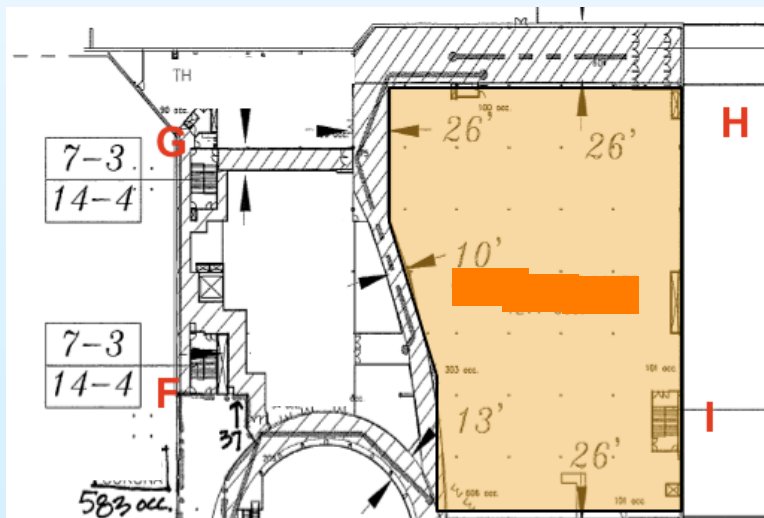
Rome, Italy

Action: Behavioural Issues

- Routes Adopted
- Response of Population

Interpretation: Output

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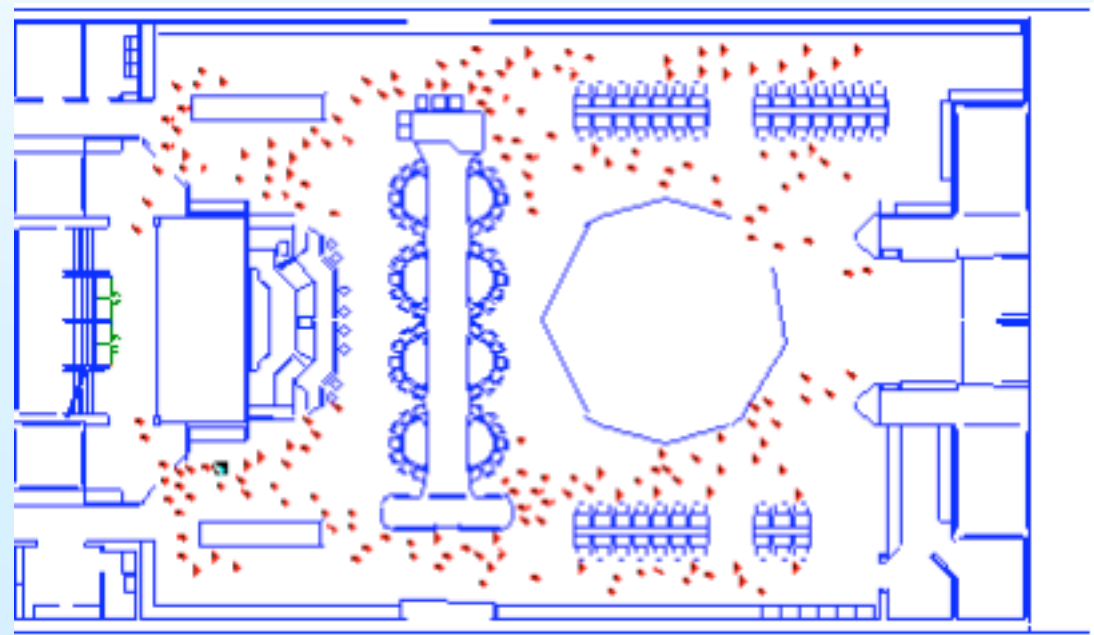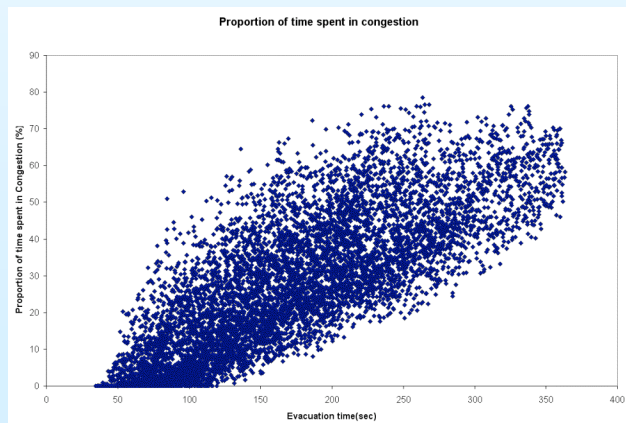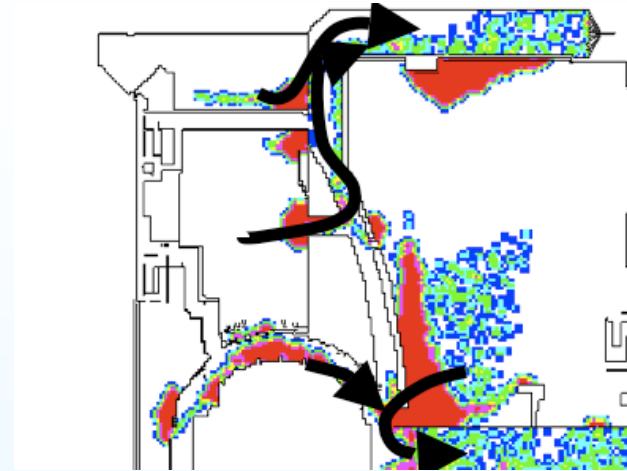
Rome, Italy

Action: Environmental Issues
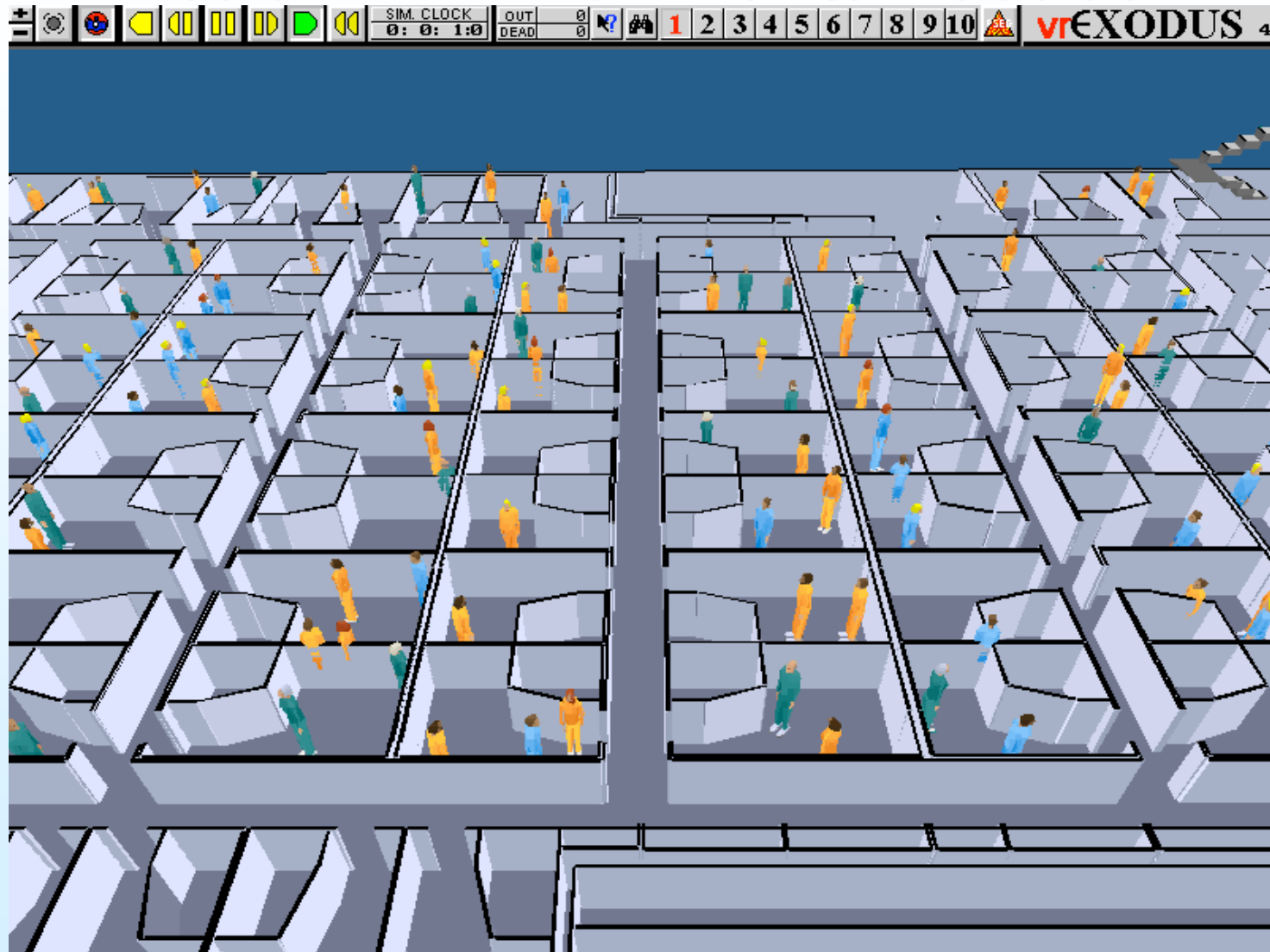
Rome, Italy

Tall Buildings: People Movement
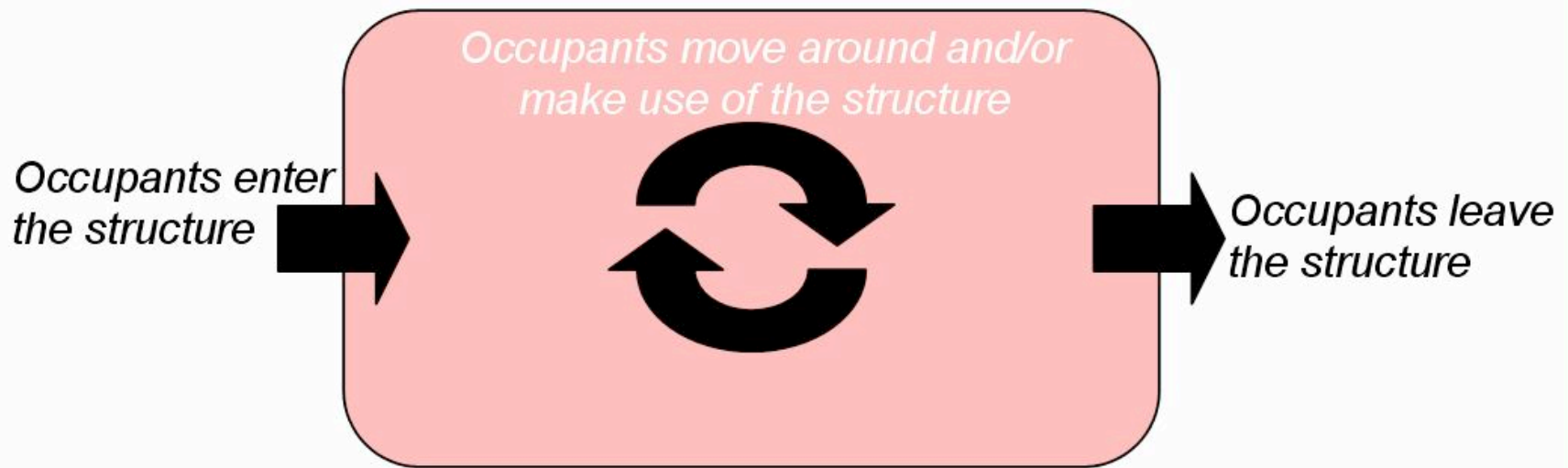
- Any non-emergency or emergency procedure will need to be sensitive to the different uses of the structure.

- Ideally, models should be able to take this into consideration.

Tall Buildings: Simultaneous Use of the Building
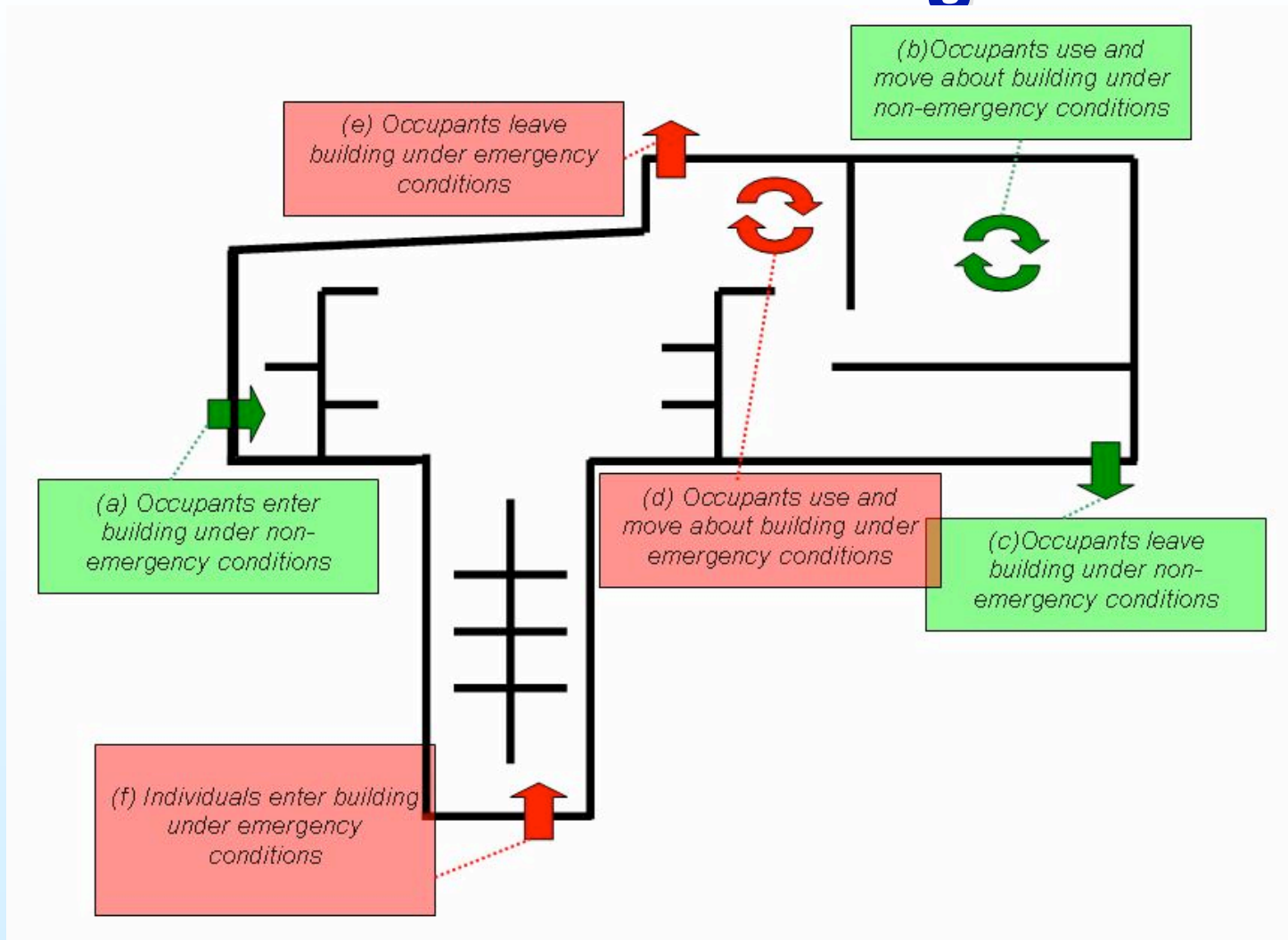
Tall Buildings

- 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

Population is engaged in normal non-emergency activity.

Incident has been confirmed by staff and technology. Population is alerted by notification system in place.

Population disengages from activity and then initiates response indicated by notification system.

Notification system provides population with current info. on available routes, required actions and on the incident

Informed population more likely to be receptive to management activities of trained staff.

Managed response less likely to occur in response to false alarms and more likely to produce successful outcome.

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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