Large Scale Evacuation Modeling
Planning and TTX – Application on the Medieval City of Rhodes

The EXODUS large scale evacuation model

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March 2020, Athens

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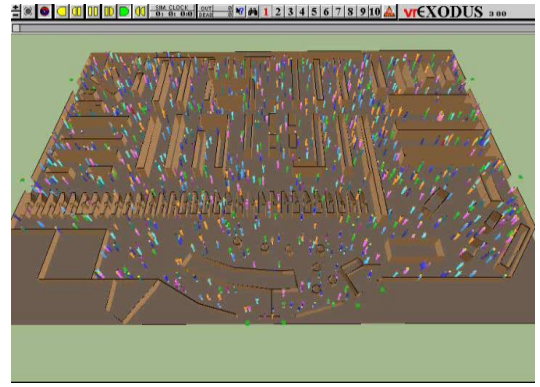
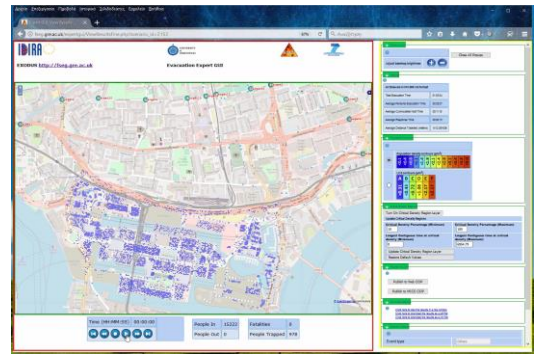
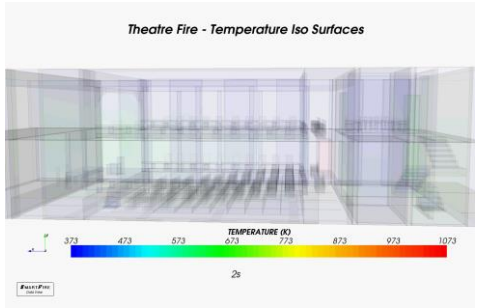
FSEG: Modelling safety and security

- Main FSEG research work includes the mathematical modelling and experimental analysis of: Pedestrian and Evacuation dynamics in complex spaces, combustion and fire/smoke spread, fire suppression
- FSEG is probably the largest, University based, fire safety engineering research group in Europe
- FSEG produces **predictive** tools for modelling both **evacuation** and **fire** propagation: EXODUS and SMARTFIRE, both with extensive validation history
- Under continual development since early 90s
- EXODUS variants for air, built, maritime, rail and **urban scale environments**

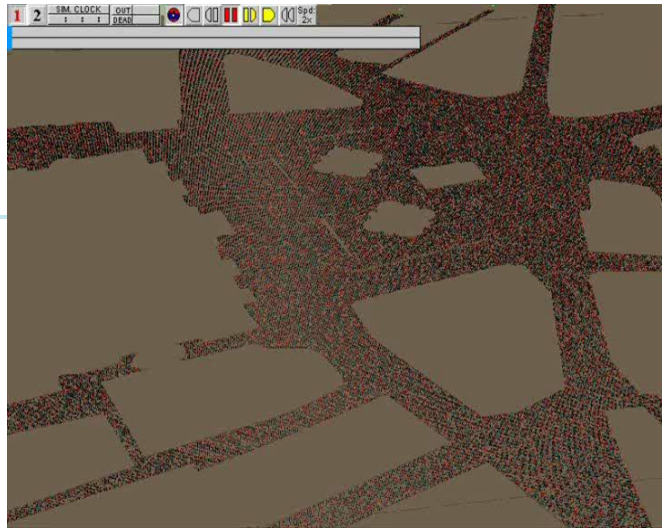




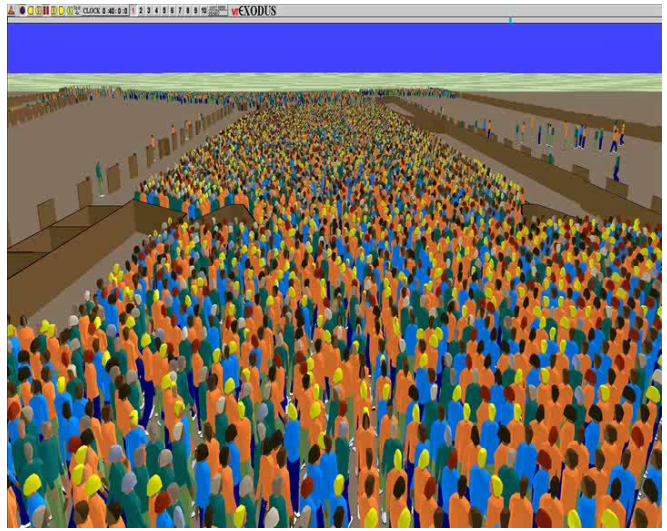


EXODUS in a nutshell…

- **EXODUS** is a microsimulation Agent Based Model (ABM)
- Capable of simulating the **evacuation process** of thousands of people (agents) from large complex spaces **predicting the likely** evacuation performance
- **Agents** are modelled **individually** each having distinct **attributes, characteristics and abilities**
- Uses a set of **rules** or heuristics to simulate **human behaviour**
- Some rules are **stochastic** (e.g. determining outcome of conflict resolution)
- Incorporates **adaptive behaviour** such as:
  - smoke avoidance, exit selection, congestion avoidance, itineraries, signage interaction, communication with other agents, use of lifts, escalators, travelators, etc
- **Data** that governs agent movement and behaviour comes from **literature**, **experiments** or **studies of real events or incidents**
- Can utilise a **hybrid** approach to represent the **discretisation of space**
- Can utilise a **hybrid** approach in **population representation**



Trafalgar Square demonstration: simulation of 125,000 agents



Love Parade disaster **reconstruction:** simulation of 100000 agents (21 fatalities and >500 injured)

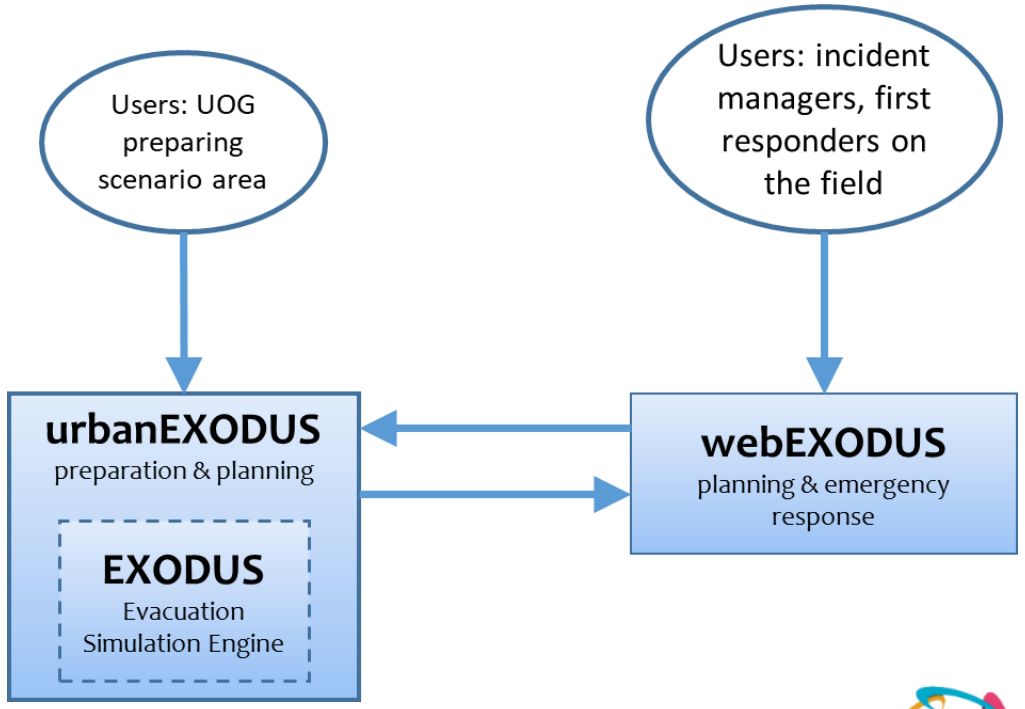
Why model evacuation?

- **How** would you answer the following questions when **planning** or **managing** for a disaster?
- **How long** it will take to evacuate the area?
- **How** can one **test** or **assess** the safety levels afforded by existing **evacuation procedures**?
- What are the **safety margins** afforded by the incoming hazards (e.g. fire front/smoke plume, flood waters) as the population evacuates?
- **How can you assess the impact of hazards** (e.g. chemical hazard, fire products) on evacuating population?
- Which are the **best routes** for the people to follow?
- How can you **compensate if a route gets blocked** during the incident? **What** will your **options** be and how will you be able to **assess** them?
- How can you **accommodate** for the **varied demographics, response times, travel speeds, behaviours** and the people's interactions with each other and with the environment?
- **EXODUS** simulates the **evacuation** process and attempts to **address** all these questions!

EXODUS for large scale evacuation modelling

- EXODUS considers **human factors** and **behaviours,** as well as the **environment** when attempting to simulate the evacuation process
- Two variants of EXODUS used for large scale evacuation simulations
  - **urbanEXODUS → Evacuation simulation model or evac. engine**
  - **webEXODUS → web GUI that uses urbanEXODUS**
  - webEXODUS is integrated with COP, training tools, etc
- Intended applications include evacuations due to natural or man-made disasters including:
  - **Wildfires**
  - **Earthquakes**
  - **Floods**
  - **Tsunamis**
  - **Chemical spills**
  - etc…



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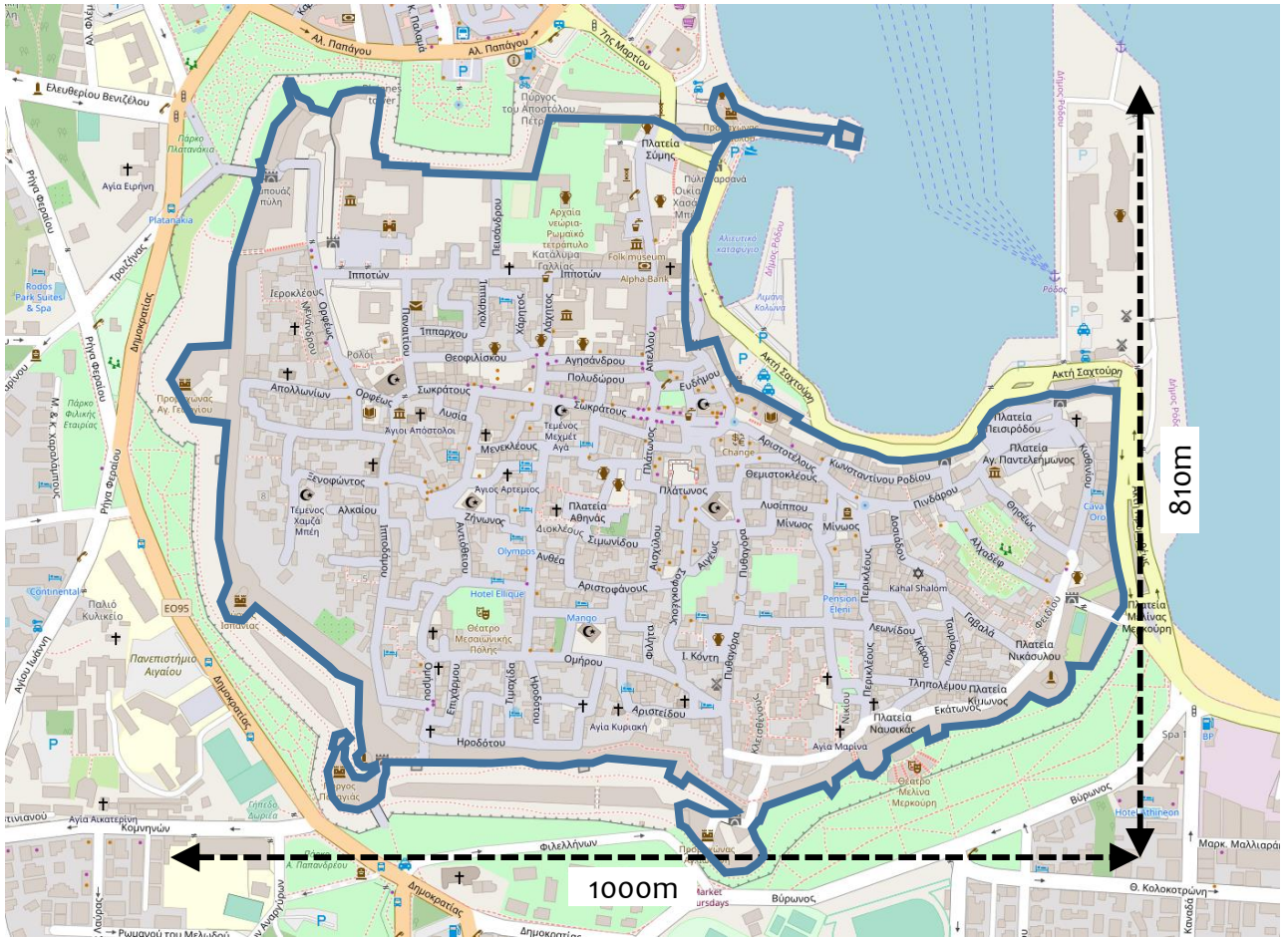
Example Application – Medieval City of Rhodes Evacuation

Incident: Earthquake

Purpose: Model assembly and evacuation process

Input to evacuation component:

- **Evacuation Area:** Medieval City of Rhodes from OpenStreetMaps
- **Exit points:** paths and roads leading to gates
- **Assembly locations:** earthquake emergency shelters/locations
- **Population distribution:** off-peak and peak session
- **Response time distribution**
- **Evacuation procedures**
- **Population notification:** EARTHQUAKE



Medieval City of Rhodes Evacuation – Importing geometry

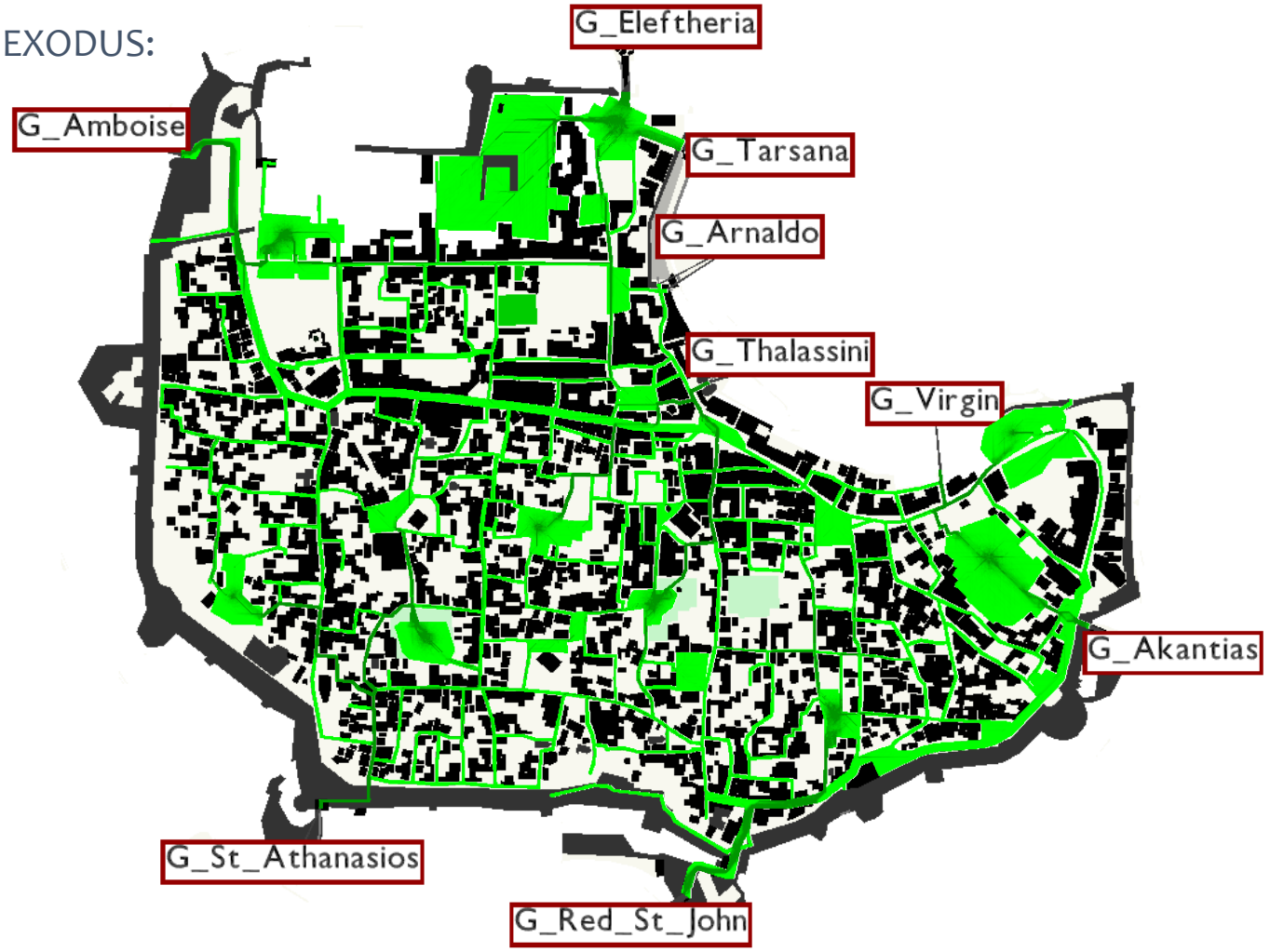
Imported area from OpenStreetMaps (OSM) and meshed in EXODUS:

Buildings, Streets *and* ***Open Spaces***

In total 11 Gates exit on the perimeter walls of the Medieval City of Rhodes

Out of these 9 Gates have been modelled, these are:

1. Gate d' Amboise
2. Liberty Gate
3. Gate of the Arsenal
4. Arnaldo Gate
5. Marine Gate
6. Gate of the Virgin
7. Acandia Gate
8. Gate of St John
9. Gate of St Athanasios



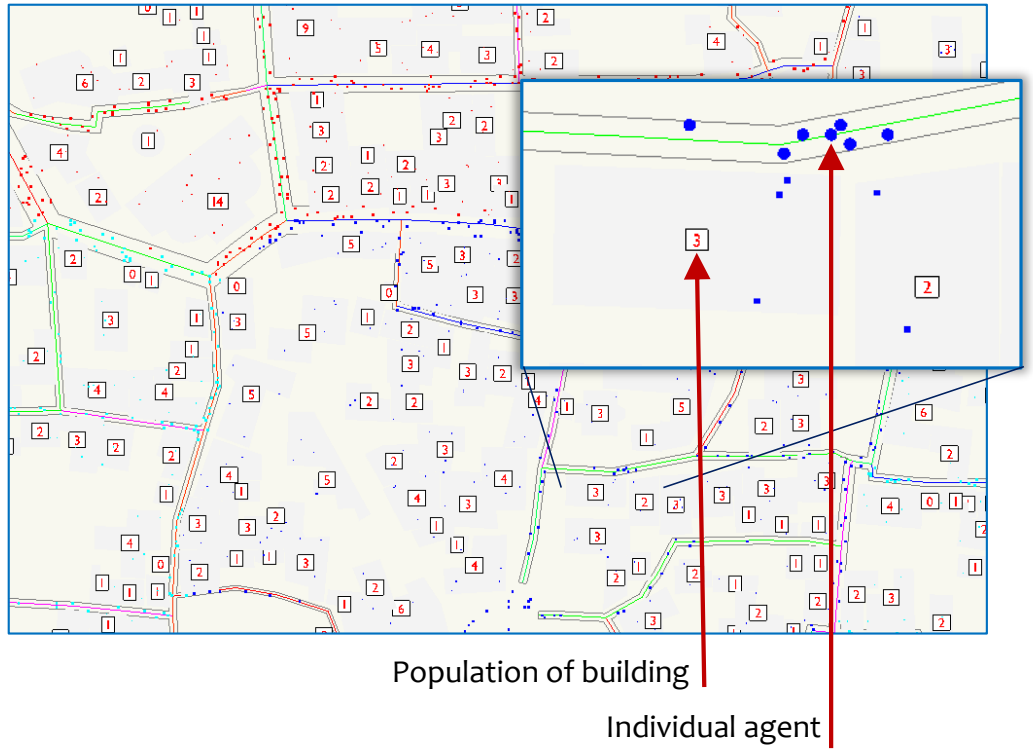
Example – Population and Procedures

Population

- The population of the Medieval City of Rhodes varies significantly depending on the season
- Off-peak season (winter) population assumed to be ~6,000
- Population distributed evenly across Medieval City

Assumptions

- The **earthquake event** can alert the entire population of the city ∴ all people become aware of the earthquake incident
- **Locals** and **visitors** have **full knowledge** of Medieval City i.e. they **know** the **locations of the emergency shelters, available Gates** and the **optimal paths** to reach desired locations
- The **response time** of the population set to **45 sec** to **7 minutes**



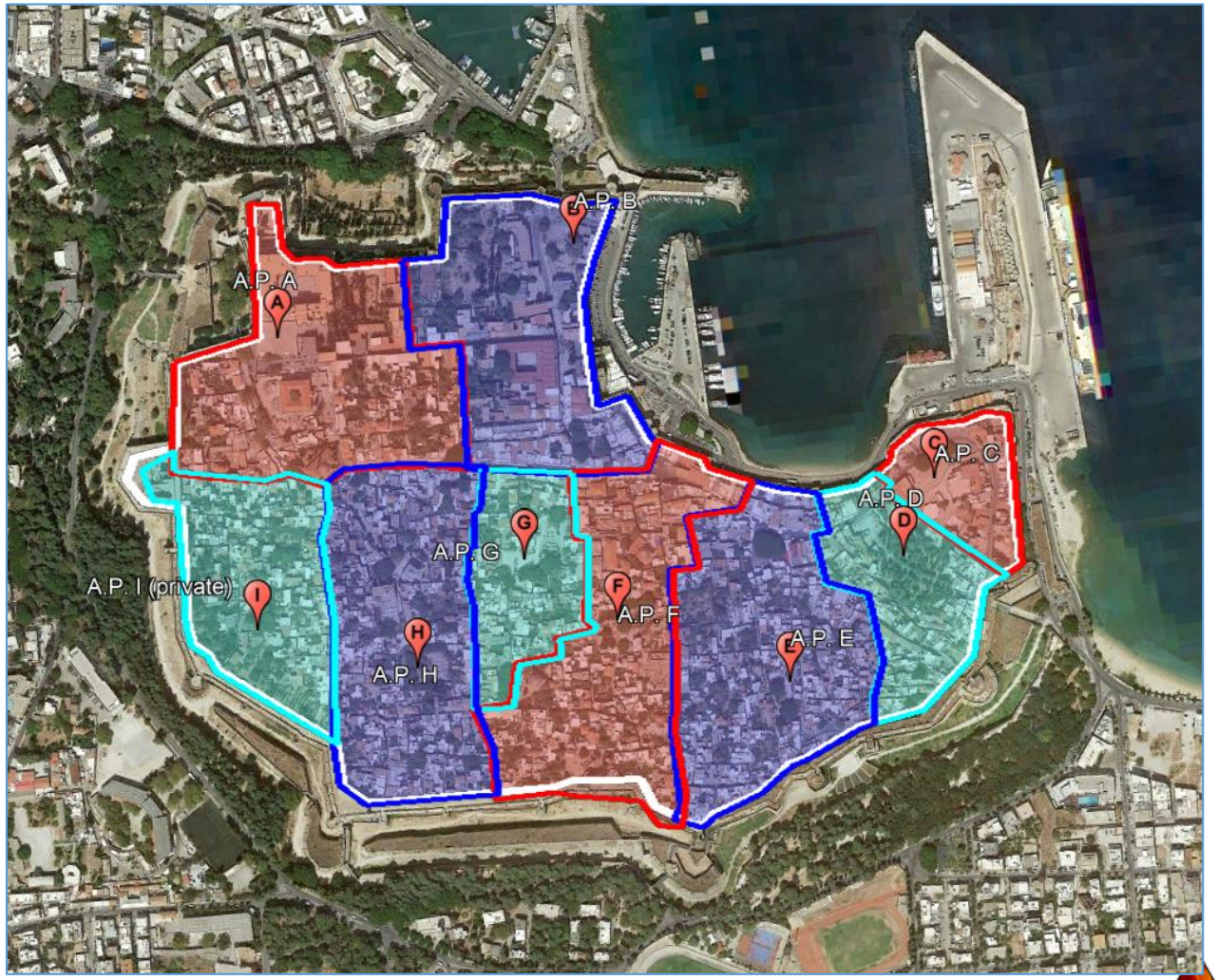
Procedures

- First **assemble** to the designated emergency shelter location and then, if instructed to do so, **evacuate** via the nearest available Gate

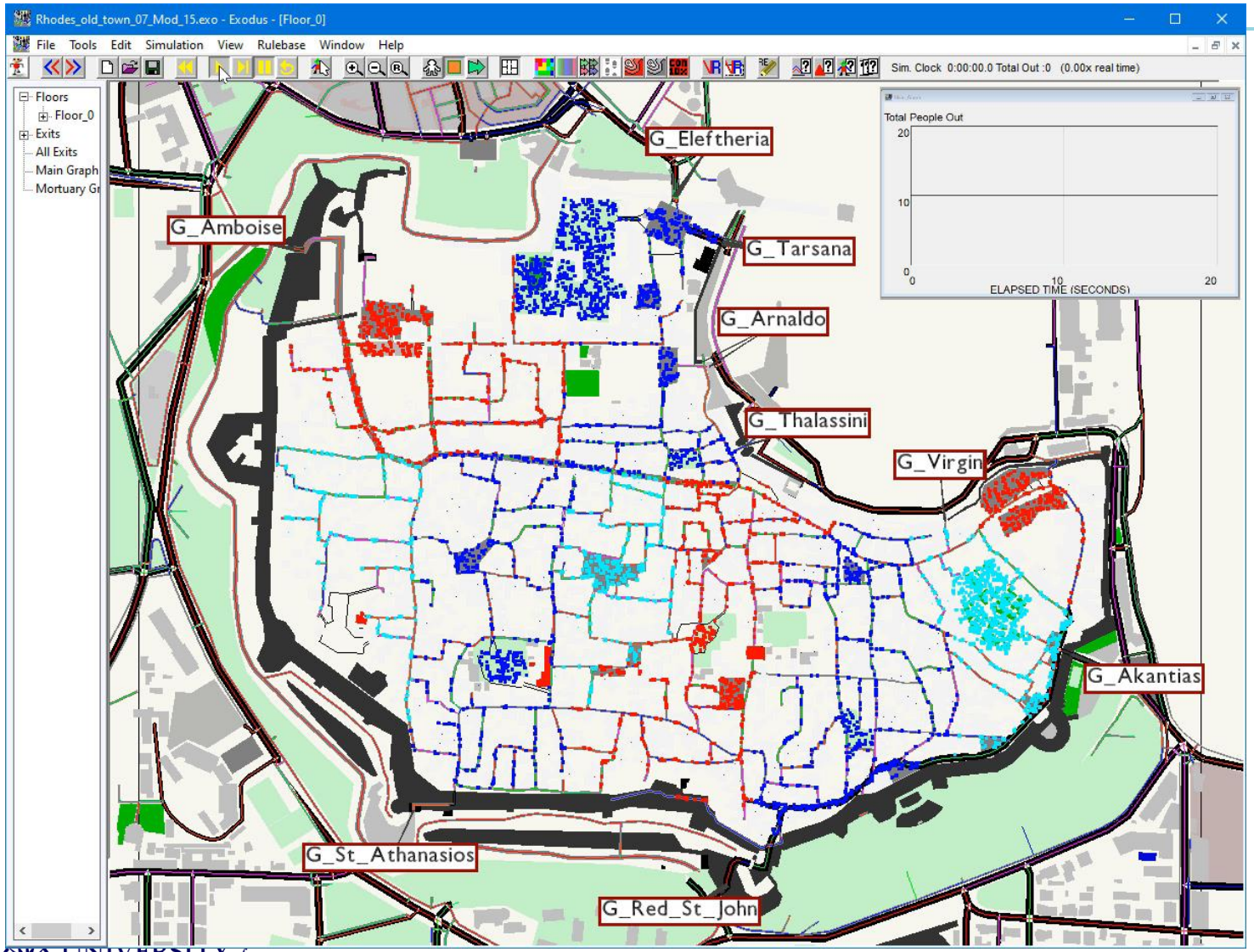
Medieval City of Rhodes Evacuation – Assembly locations

Emergency shelters or locations:

- **Nine assembly locations** have been identified and implemented – all within the Medieval City walls
- In the event of an earthquake the **population** is instructed to move towards the assembly locations
- The population will be instructed to stay at these locations for some time by the authorities – the authorities may choose to issue a further **evacuation** command in which case the population will be instructed to leave the Medieval City via their **nearest available Gate**



Medieval City of Rhodes Evacuation – First assemble then evacuate



Example scenario

- Evacuation trigger event: **EARTHQUAKE**
- **Population:** 6000 evenly distributed
- Distribution: 30% within buildings 70% outside

- **Assumptions:** Best case scenario, all agents are fully familiar with the area and know the nearest assembly location and available gate

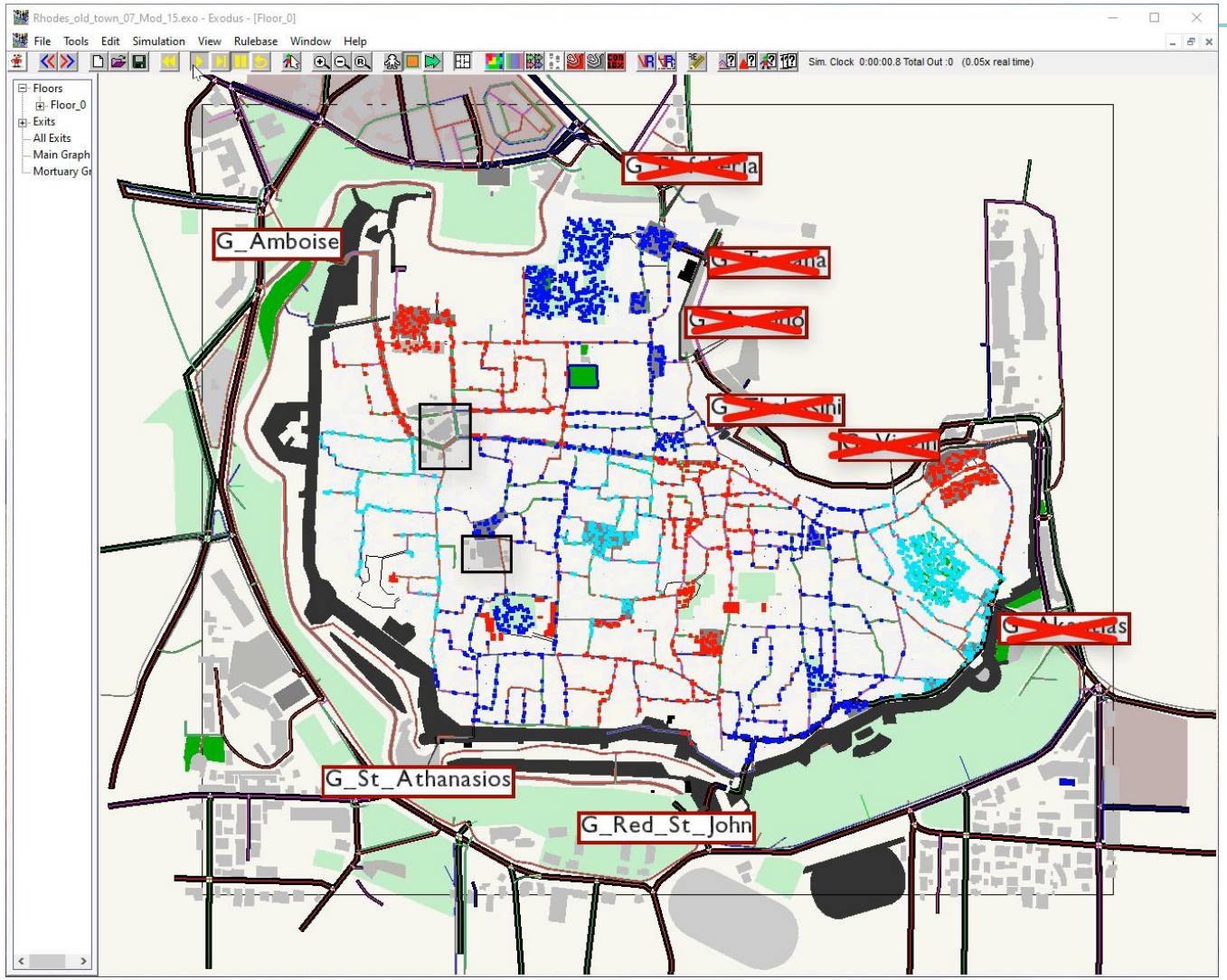
1. **First person** to respond at 45”
2. **Last person** to respond at 7 minutes
3. **Assembly process** ends at ~15 minutes
4. Pop. remains at assembly location for 5 minutes
5. **Evacuation starts** at 20 minutes
6. **Evacuation process** ends at ~31 minutes

- **NOTE:** a full study would require more realistic scenarios and assumptions e.g. non-uniform distribution of people, reduced familiarity with area and gates, possibly blocked routes or debris…

Rhodes Project 2019 – TTX Evacuation of Medieval City of Rhodes

- During the **Rhodes Project 2019 TTX** co-organised, amongst others, by Kapodistrian National University of Athens and Rhodes Municipality EXODUS was used to represent the TTX
- The **TTX scenario** assumed a series of events taking place throughout Rhodes island
- Only those events affecting the Medieval City were included in the **EXODUS model** including:
  - **Earthquake** → Notifies population, forcing them to act
    - Action → Assemble then evacuate
  - **Collapse of historical buildings** → people get trapped inside, evacuees must choose alternative routes to assemble and exit the Medieval city
  - **Fear of tsunami** → Exits facing the sea are considered inappropriate for use
  - **Fire near one of the gates** → People would need to redirect to alternative exit

Medieval City of Rhodes TTX Scenario



TTX scenario:

- Evacuation trigger event: **Earthquake and fear of tsunami**
- **Population:** 4000 evenly distributed
- Distribution: 30% within buildings 70% outside
- **Assumptions:** Best case scenario, all agents are fully familiar with the area and know the nearest assembly location and available gate
- Two historical buildings have collapsed

1. **First person to respond at 60”**
2. **Last person to respond at 15 minutes**
3. **Assembly process ends at ~23 minutes**
4. **Pop. remains at assembly location for 7 minutes**
5. **Evacuation starts at 30 minutes**
6. **Gate D’Amboise closes at ~35 minutes**
7. **Evacuation process ends at ~56 minutes**

Medieval City of Rhodes Evacuation – TTX Results

Evacuation performance

Evac. Time (min)	30.6		
PET (min)	20.2	24.9	30.6
CWT (min)	0.0	0.9	4.0
Distance (m)	22.4	384.1	817.1
Response (sec)	23.0	229.1	419.9

Evac. Time (min)	55.6		
PET (min)	33.5	42.9	55.6
CWT (min)	0.0	0.8	4.0
Distance (m)	223.4	821.4	1665.5
Response (sec)	22.5	483.7	899.9

Population data

Population (total)	6000
Pop. (evacuated)	6000
First (min)	20.2
Last (min)	30.6

Population (total)	3930
Pop. (evacuated)	3930
First (min)	33.5
Last (min)	55.6

Base case

TTX scenario

Gate usage

Name	Used	First (min)	Last (min)
G_Amboise	751	23.1	27.3
G_St_Athanasios	972	24.5	30.6
G_Red_St_John	790	24.0	28.3
G_Akantias	433	21.5	23.5
G_Virgin	598	21.6	25.3
G_Thalassini	1118	23.9	29.6
G_Amaldo	0	0.0	0.0
G_Tarsana	480	20.7	21.7
G_Eleftheria	858	20.2	21.3

Name	Used	First (min)	Last (min)
G_Amboise	110	33.5	34.6
G_St_Athanasios	2055	34.1	55.6
G_Red_St_John	1765	34.4	45.3

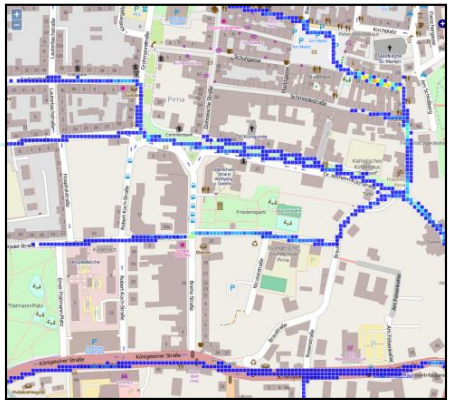
Medieval City of Rhodes Evacuation – Limitations and further study…

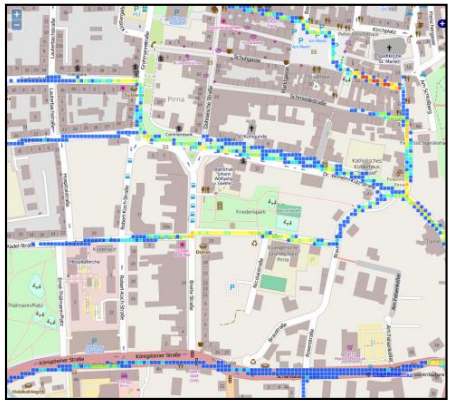
- Examined evacuation scenarios stipulates **first assemble then evacuate**
- **Assumptions** include perfect knowledge of Medieval city's layout, location of assembly points, location of gates as well as the shortest routes to these locations, all agents know what they should do
- **Examined scenarios** are **optimal** but **more realistic scenarios can be examined**, include:
  - More accurate representation of **map region** – OSM data is often incomplete and/or wrong
  - More accurate **distribution of population** – Data of exact building, street and open space occupancy can be used
  - Distinction of **locals** and **visitors** – Different population characteristics and demographics can be applied for each population group
  - More accurate **response time distribution** for locals and visitors
  - Different and **reduced familiarity** with the region can be implemented for both locals and visitors
  - Effects of **debris** and **blocked** routes can be assessed

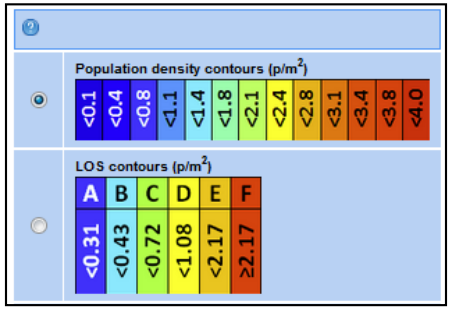
Data Output from Evacuation Simulation

EXODUS can provide a plethora of **quantitative** and **qualitative** output data including:

- **Overview** of entire evacuation process (visual data)
- **Evacuation times**
- Time agents **reach safe locations** (shelters or leaves danger zone)
- Usage of **exit** routes and **assembly** locations
- **Total time** people forced to **travel slower** or **remain stationary** in congestion
- Average **distance** travelled
- **Impact** of **hazards** on evacuating population (if applicable)
- Population **density** and **Level of Service** (LOS)
- Identify **critical density** regions (> 4pm^2 for more than 10% of TET)







EXODUS – final comments

- **Without** simulating the assembly and evacuation process it is difficult, if not impossible, to:
  - Test and assess validity of existing evacuation procedures
  - Test *what-if* scenarios
  - Predict what may happen during a crisis
- **With** modelling you can achieve all the above plus…
  - You do not have to rely only on the crisis manager's experience to determine the evacuation outcome
  - You can augment the operator's knowledge and experience (which may be scenario/region specific) allowing them to take informed decisions at both planning stage and during incident management stage
- **With** modeling you can plan for future incidents
  - Save lives, time and money!
  - Public's confidence in the preparedness for future incidents is increased!
  - Provide increased safety during the management of a disaster.

Evacuate safely and…

Any questions?

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