

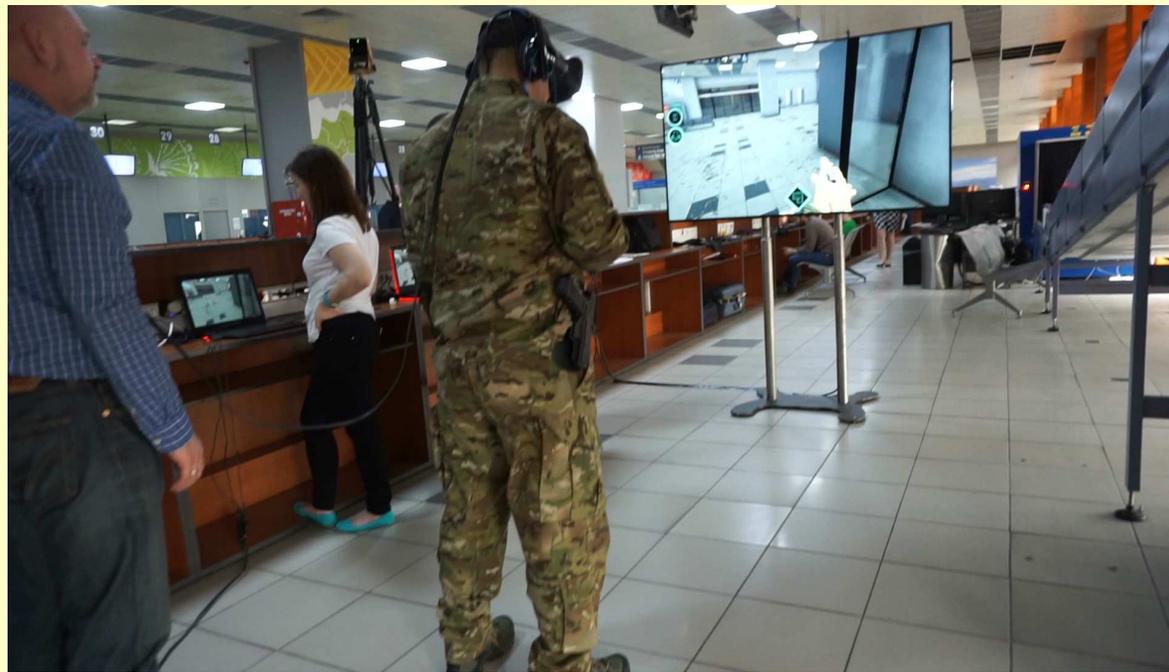
Virtual and Mixed Reality Training Environments for First Responders

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Tall Buildings, Crisis Management
30 Sept 2020

<http://fseg.gre.ac.uk>

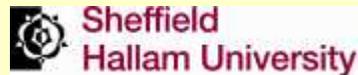


Acknowledgements

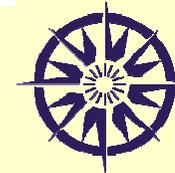
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- FSEG team who worked on AUGGMED developments:
 - Mr Darren Blackshields
 - Dr John Ewer
 - Mr Lazaros Filippidis
 - Mr Ian Frost
 - Prof Ed Galea
 - Dr Simo Haasanen
 - Dr Peter Lawrence
- AUGGMED project partners



emergències mèdiques



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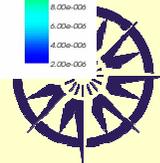
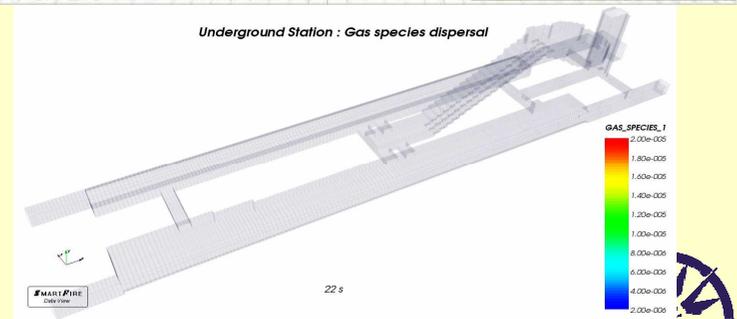
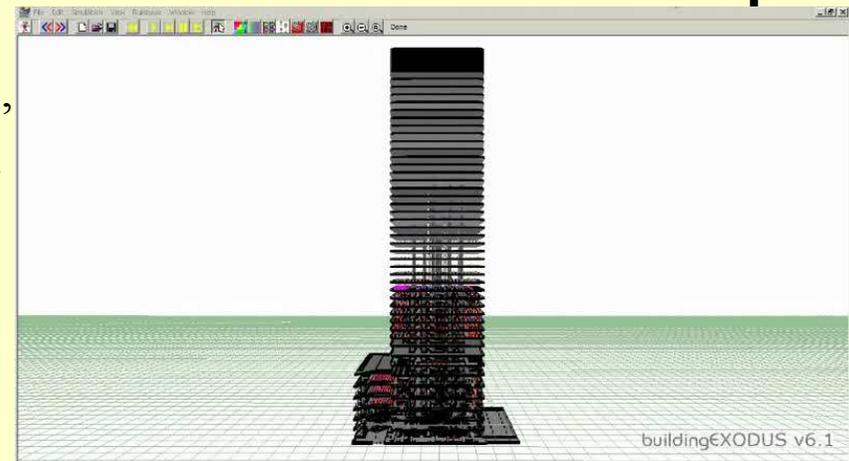
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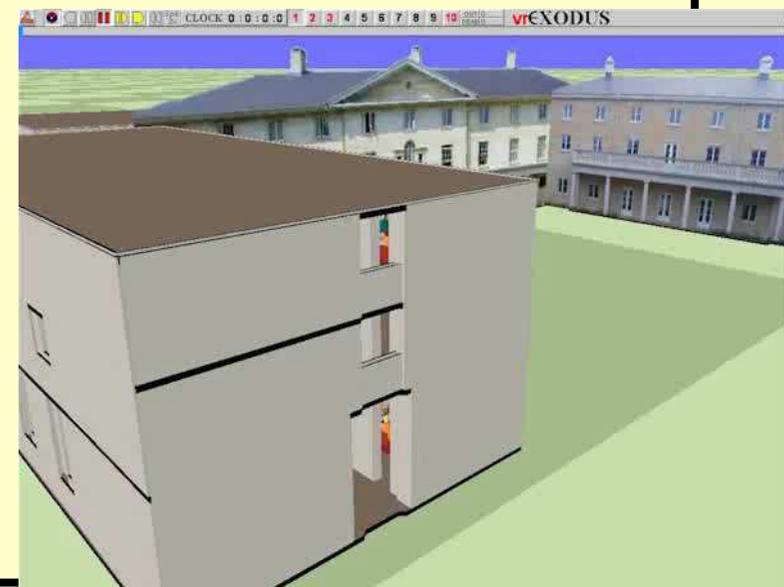
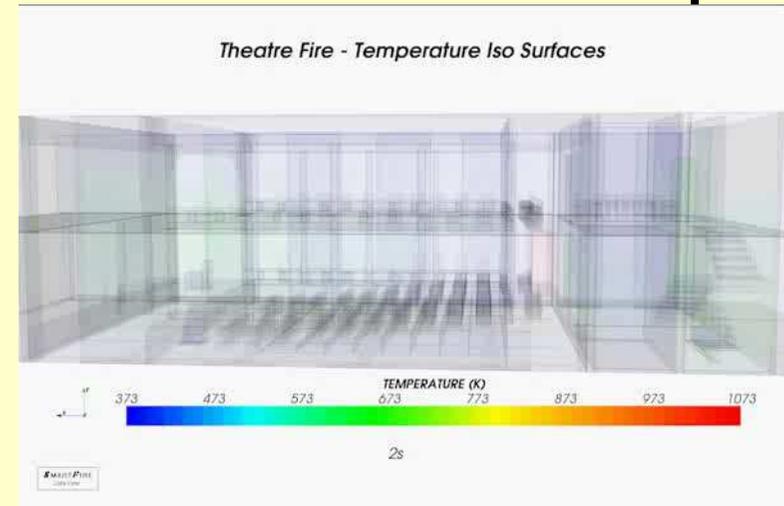
FSEG: Modelling safety and security

- FSEG was Founded in 1986 by Prof Galea in response to the Manchester Airport B737 fire.
- Today it consists of 20 researchers including:
 - fire engineers, CFD specialists, psychologists, mathematicians and software engineers.
- Research interests include the **mathematical modelling** and **experimental analysis** of:
 - evacuation dynamics in complex spaces,
 - pedestrian dynamics in complex spaces,
 - combustion and fire/smoke spread,
 - fire suppression,
 - security
- Application areas include:
 - aviation, buildings, maritime and rail.
- Developed EXODUS and SMARTFIRE tools
 - Both under continual development since 90s
 - Extensive validation history
 - Users in over 35 countries



EXODUS and SMARTFIRE SOFTWARE

- **SMARTFIRE CFD fire simulation software**
- RANS with k-e turbulence model, structured and unstructured mesh capabilities, import of 2D/3D CAD and BIM (IFC), capable of representing:
 - combustion, generation of toxic gases, sprinkler/water mist and **COVID19 aerosols**.
- **EXODUS agent based evacuation software**
- Rule-Based Adaptive Behaviour, each agent is a unique individual with physical, psychological and personal characteristics
- Can specify itineraries for pedestrian circulation e.g. target destinations, tasks, dwell times, etc
- Can simulate interactions between hundreds of thousands of agents
- **COVID19 physical distancing capabilities**
- **EXODUS - SMARTFIRE**
- SMARTFIRE generated fire atmosphere can be coupled with EXODUS evacuation environment
- Agents exposed to evolving atmosphere of smoke, heat and toxic gases
- Predicts agent incapacitation and death through the use of FED (cumulative dose) and instantaneous concentration models.

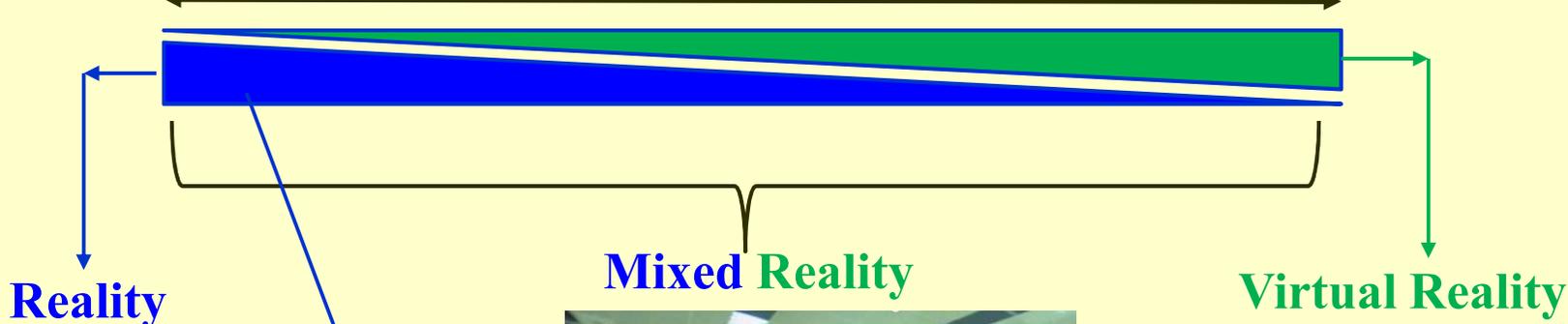


Marauding Armed Terrorists and Agent Based Modelling

- Recent (since 2008) marauding armed terrorist attacks highlight the need for clear guidance on how best to *defend, respond and react* to such events.
 - 2008 Mumbai; 11 Norway; 13 Westgate Shopping Mall Nairobi; 14 Kunming China; 15 Bataclan Paris; 15 Amsterdam-Paris train; 15 Sousse Tunisia; 17 London Bridge+Manchester UK; 18 Melbourne Australia; 19 Manchester + London UK, 20 London + Reading UK.
- Terror groups have shifted focus onto *'soft'* targets – crowded places e.g. shopping malls, public buildings, transportation infrastructure, etc.
 - Mumbai demonstrates how several individuals with small explosive devices and automatic weapons could cause significant loss of life attacking crowded places.
- Due to the dynamic nature of such attacks, it is difficult to train security forces, including first responders, to deal with these situations.
- **Ideal candidate for Virtual Training environments, but to be effective, must be realistic**



Reality Spectrum (Milgram+Kishino (1994))



Reality

Mixed Reality

Virtual Reality

Augmented Reality



Mixed Reality

RW and VW meld. User is simultaneously immersed in the RW and VW allowing user to experience and interact with virtual scenarios in the RW.

Virtual Reality



Augmented Reality

Overlay digital information over RW

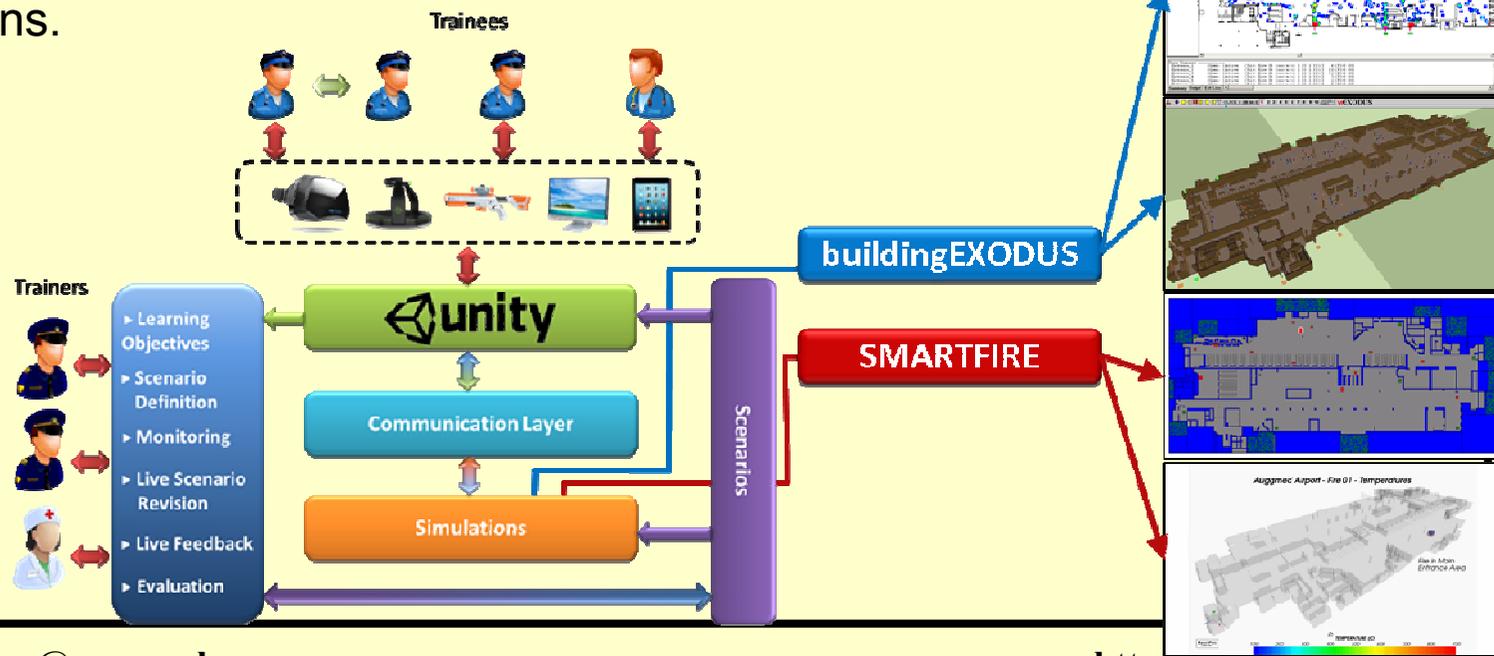
Complete VW that recreates RW. Can be *Immersive or non-Immersive*. User has perception of being there, can move around the space passively and in advanced systems can interact with virtual entities



EU Horizon 2020 AUGGMED project – Automated Serious Game Scenario Generator for Mixed Reality Training

Aims of AUGGMED:

- develop VR/MR platform enabling single/team-based training of security staff responding to terrorist scenarios in crowded places
- generation of non-linear scenarios designed to improve skills such as: problem solving, analytical thinking, quick reactions,
- Scenarios include advanced simulations of crowds (EXODUS) and hazardous environments including fire (SMARTFIRE) and explosions.



AUGGMED has 3 Capability Levels

- In all three levels, trainees can join training sessions locally or remotely.
- **Level 1: Interactive VR.** Trainee uses mouse + keyboard to move around and interact with VW, views interaction on computer screen.
- **Level 2: Immersive Interactive VR.** Trainee uses immersed VR head mounted display and hand controllers. Limited mobility. Tactile feedback possible via optional haptic vest.
- **Level 3: MR environment,** training on site, full mobility with tactile feedback via optional haptic vest. Can have mixed VR/MR trainees
- Haptic Vest provides Tactile, Impact and Thermal feedback



Modifications to EXODUS and SMARTFIRE

- Embed EXODUS into the UNITY 3D environment allowing two way communication between the tools and UNITY environment.
- Enhance SMARTFIRE smoke output to EXODUS from 2-layer to multilayer to allow better visualisation within UNITY 3D (and vrEXODUS)
- Enable external user to take control of their avatar and interact within the virtual environment with the simulation controlled avatars.
- Introduce a range of new behavioural features into EXODUS appropriate for terrorist related applications including:
 - Enabling simulation controlled avatars to respond to a range of voice commands and hand gestures.
 - Introduce fire-arm shooting capability.
 - Introduce response of agents to weapons discharge;
 - Concepts of awareness and threat zones
 - Flee and take cover behaviours
 - Introduce gun-shot and explosion injury prediction capability



EXODUS linked to UNITY3D game environment building EXODUS general circulation simulation within an Airport:



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Evacuation in smoke environments



- 8 metre visibility – light extinction coefficient is 0.375
- Computer controlled agents and human controlled agents are impacted by the fire environment.



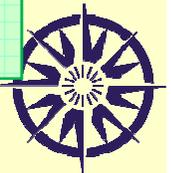
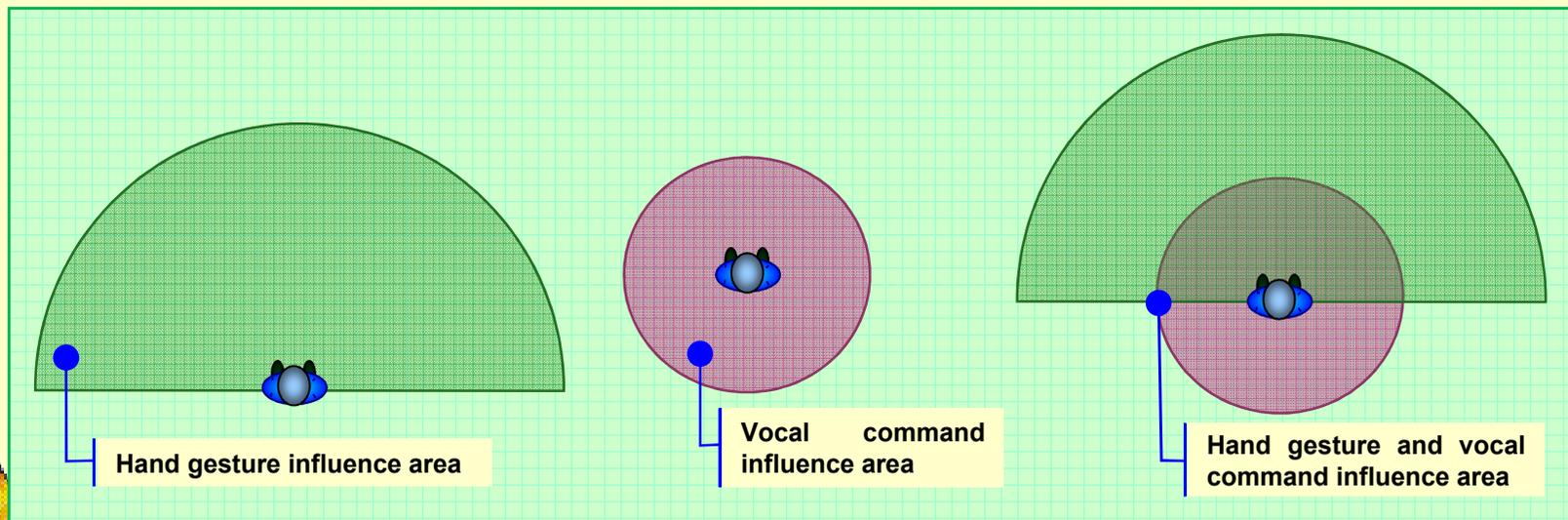
Additional EXODUS Behaviours

- Agents respond to hand gestures and vocal commands such as:
 - Get down, go there, get of the way, evacuate, evacuate in that direction, stop, etc
- Vocal and hand commands effective over different distances, hand gestures only effective if in line-of-sight, not all agents comply immediately
- Demonstration of “STOP” command issued by avatar controlled by a real person with computer controlled agents complying



Hand Gestures and Vocal Commands

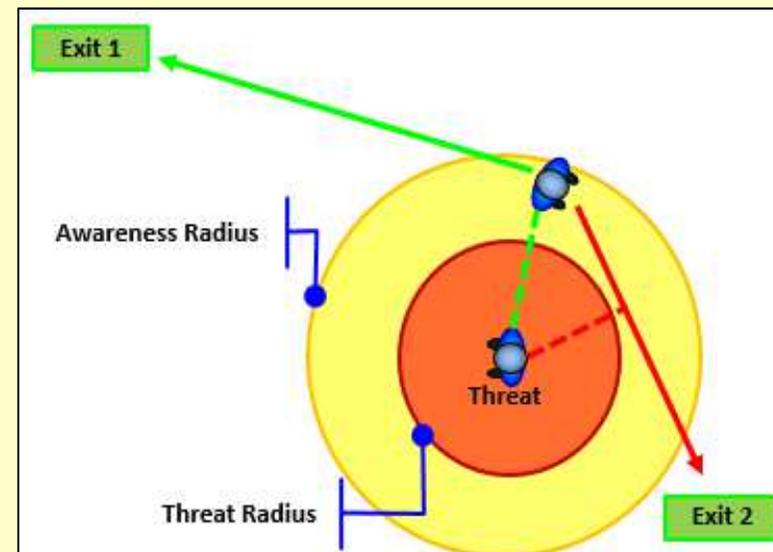
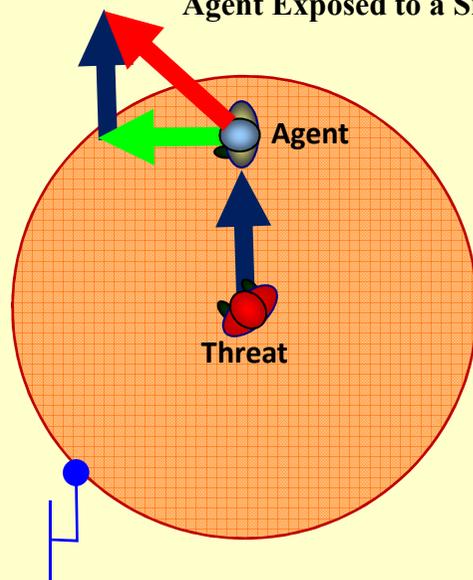
- **Hand Gestures:** Semi-circular influence area – radius set as max arbitrary visibility distance of 20m
 - % compliance parameter: function of distance to person giving order and mimicking behaviour of surrounding population.
- **Vocal Command:** Compliments hand gesture
 - Circular influence area – smaller radius compared to hand gesture, also need to specify % compliance
- Hand gesture and vocal commands: More influential, compliance increases but influence of hand gesture > influence of vocal command
- Blue team and red team able to communicate to both individuals and groups
- Total of 8 different voice commands including:
 - Stop, Go, Get Down, Get Up, Start Evacuating, Get out of the Way.



EXODUS Threat and Awareness Zone Behaviour

- Agents within the **Threat Zone** attempt to flee the terrorist as quickly as possible. They are not thinking about the nearest exit, simply attempting to get away from the perceived threat as quickly as possible.
- Agents within the **Awareness zone** will attempt to determine which (if any) exit represents the best means of escape.
- Agent considers the **shortest route** to each available exit point.
- Routes which pass through the **Threat Zone** of a known threat are excluded.
- Size of **Threat** and **Awareness Zones** change based on action of terrorist.

Agent Exposed to a Single Threat



Threat
Radius

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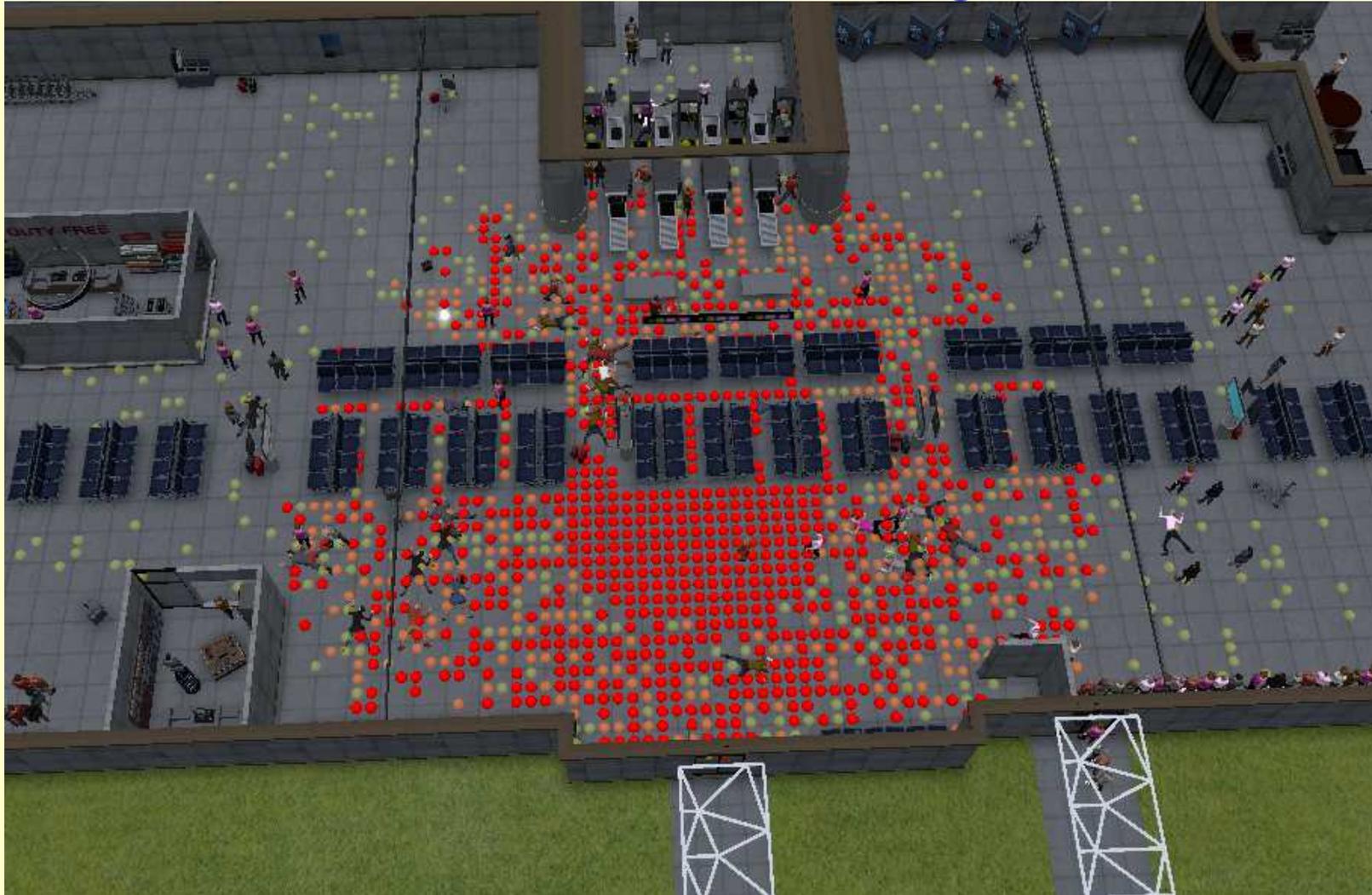


Threat and Awareness Zones

- The Threat and Awareness radii are based on **line of sight** or **distance** from the terrorist, depending on the action of the terrorist.
- When the terrorist **fires** their **Threat and Awareness radii** are based on **distance**, so agents with no direct line of sight of the terrorist can become **threatened or aware of the threat**.
- When the terrorist **reloads**, their **Threat and Awareness radii** are based on **line of sight** i.e. only agents who can see the shooter become **threatened or aware of the threat**.



EXPLOSION MODELLING – Damage to Structure



RED = Severe Damage, **Orange** = Moderate Damage, **Light Green** = Medium Damage

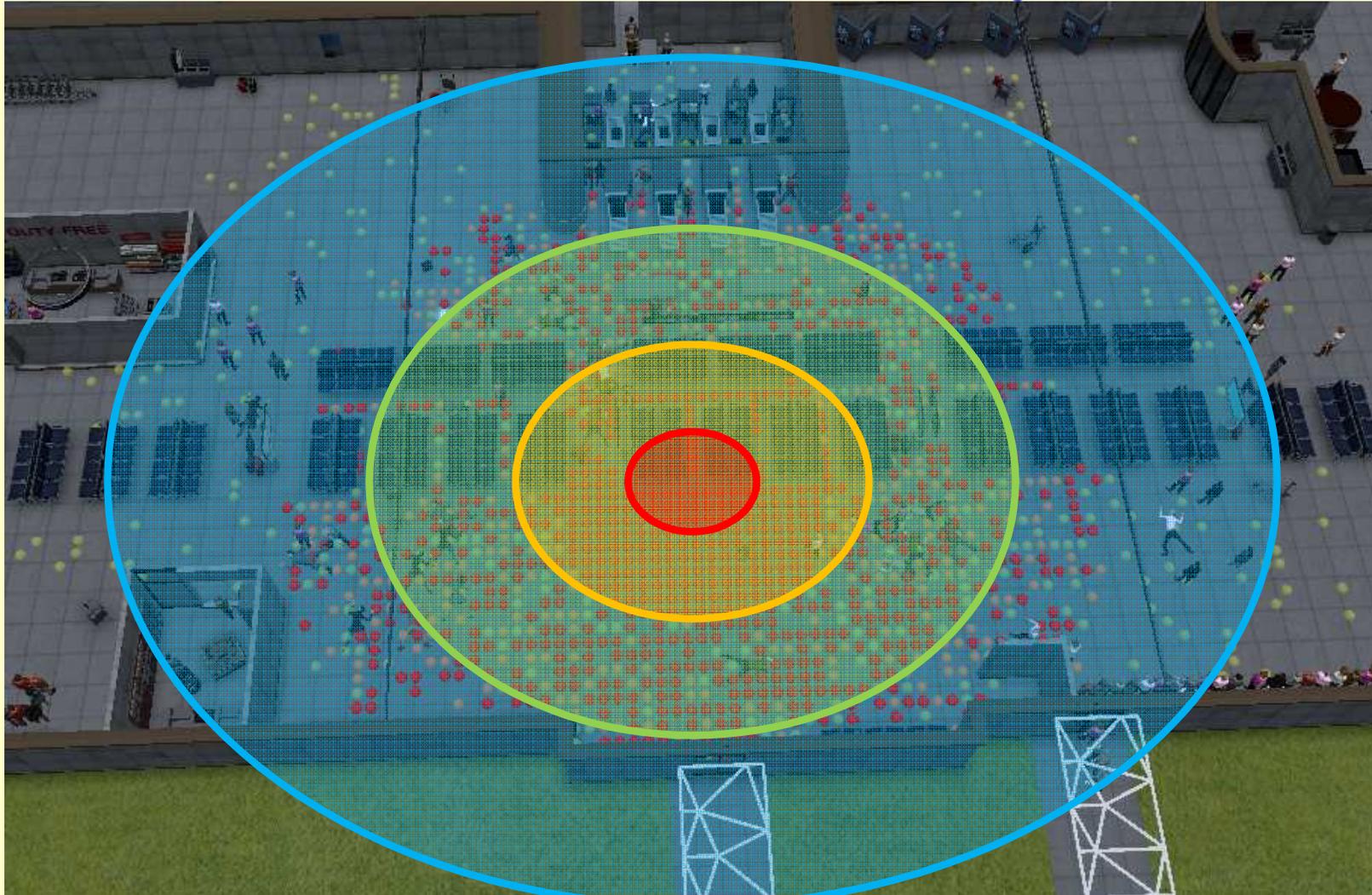
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EXPLOSION MODELLING – Injuries

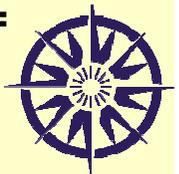


RED = Very Serious/Fatal, **Orange** = Serious, **Light Green** = Medium, **Cyan** = Minor



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Level 2 : Immersive VR Environment

- Demonstration of the terrorist player shooting at simulated population
- Threat (red) and Awareness (yellow) zones shown around terrorist player.
- This changes as the terrorist player fires and reloads.



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Level 1 : External user control of EXODUS agent

- 'TRAINER' can switch between TRAINERS view (can see everything) and the trainees view.
- Trainee view displayed on insert, trainee is controlling movement and behaviour of red flagged agent



Level 1 : External user control of EXODUS agent

- Red user has set off a bomb, starting a fire and is known to be still in the terminal
- Blue users sent in to track down Red team while computer population attempt to evacuate from burning building.

AUGGMED

Simulating a Terrorist Incident within an Airport

Scenario:

- **A Red Team Member (i.e. Terrorist) has started a fire within an airport and fled the scene.**
- **Blue Team members (i.e. Armed Police) respond to the incident and engage the crowd telling them to start evacuating before searching for, and then neutralising, the terrorist.**

Red Team = Single person playing the role of the terrorist

Blue Team = Two people playing the role of armed police response

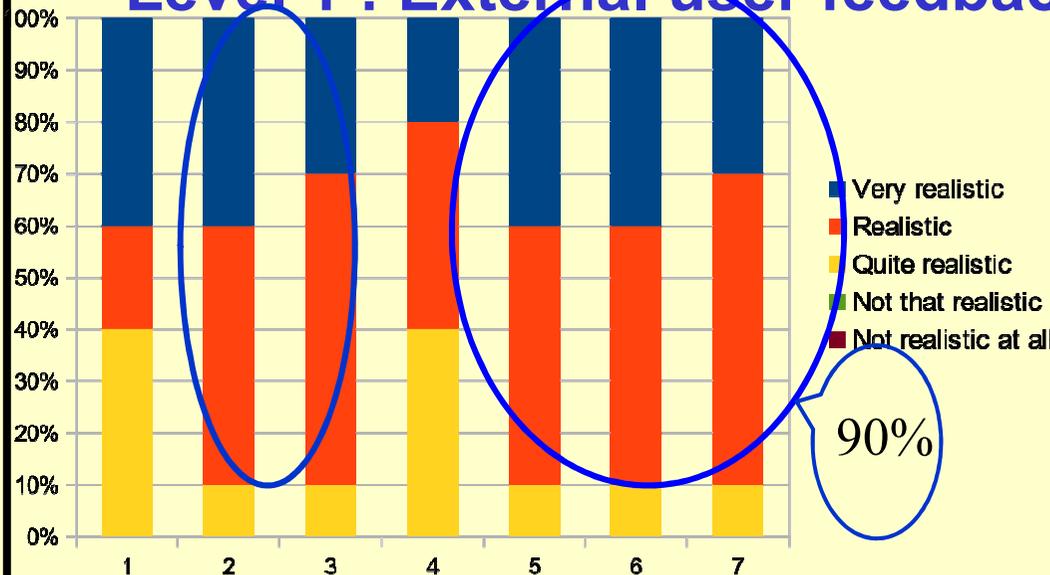
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Level 1 : External user feedback (10 participants)



How realistic / realistically ...

- 1 ... you thought the simulation was?
- 2 ... did the agents evacuate the building?
- 3 ... did the agents respond to your gestures?
- 4 ... did the agents move / navigate?

How credible was the agent behaviour ...

- 5 ... in response to your commands?
- 6 ... in the non-smoke environment?
- 7 ... in the smoke environment?

- Participants stated the system would be an effective tool to identify, develop and explore new tactics.
 - One stated that occasionally more than one command was necessary before computer-controlled agents complied.
 - As expected as computer-controlled agents can ignore commands.
- Suggested improvement: enable control of loudness of commands
- Lowest satisfaction score: keyboard control of agent – but 70% of participants ‘agree’ that the keyboard and mouse controls are intuitive and easy to use.
 - Written feedback identified use of keyboard/mouse broke sense of immersion for some users.



Level 2 : Immersive VR Environment



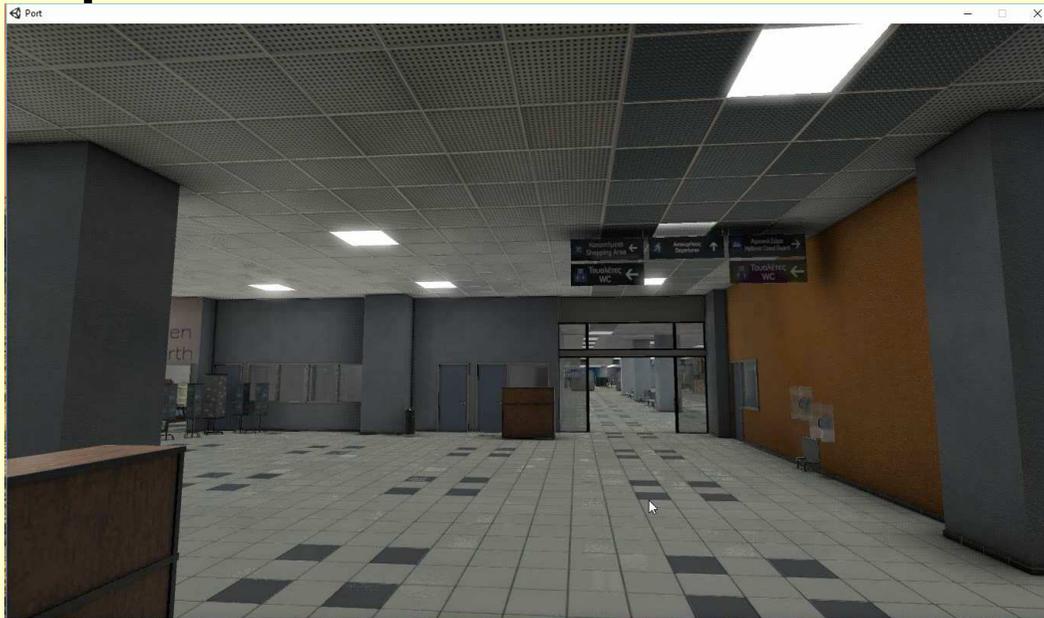
- Headset: HTC Vive.
 - Provides the user with an immersive experience.
- Orientation of headset and hand controllers tracked via 2 beacons (~ 5m apart).
 - Detects player facing direction, whether crouching, raising hand controller.
 - Information sent to UNITY so players avatar orientated as required in VW.
- Hand controllers are used for:
 - Translation movements within the VW (i.e. walking or running in VW),
 - Issuing voice or gesture commands to avatars within the simulation
 - Tagging injured avatars during triage scenarios,
 - Selecting, Aiming, Firing and Reloading weapons (i.e. pistols, automatic weapons, knives and explosives)
- In MR, beacons track translation in RW/VW - require many more beacons.



Level 2 : Immersive VR Environment

Virtual World

Immersive view from VR head-set



Real World



Pilot 2 location in Piraeus Port, Greece.



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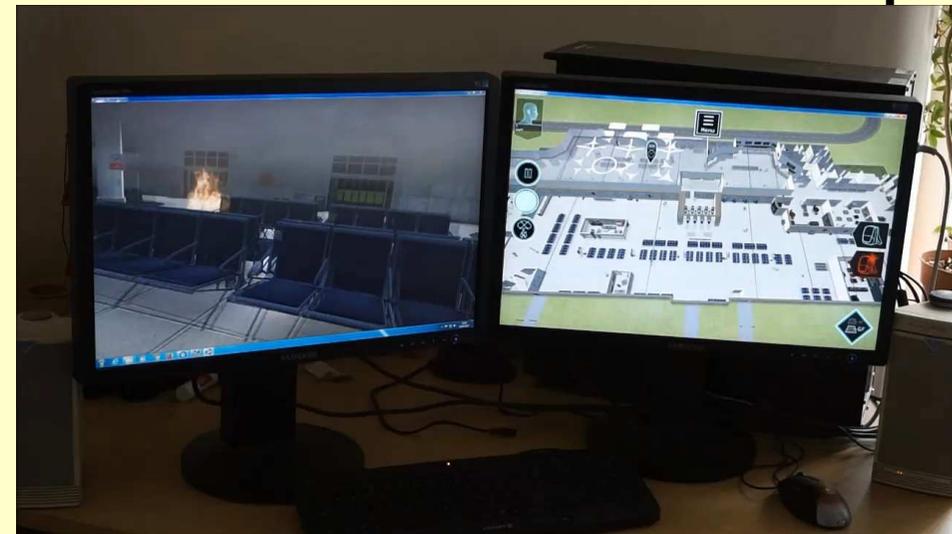


Level 2 : Immersive VR Environment

- Left screen shows the trainees view through head-set
- Right screen shows trainers view. Trainer can switch between the view from any trainees perspective and the overall view.



- Trainee assists with the evacuation of the terminal.
- Instructing airport staff to evacuate.



- Trainee views the fire.
- Fire is determined by SMARTFIRE including smoke, heat and toxic gases
- FED is being calculated, so trainee may be overcome by toxic products or heat.



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Level 2 : Immersive VR Environment – triage scenario

- Actual training session with real paramedics familiar with the station
- 2 paramedics and trainer involved in the scenario.



- Large screen flicks between trainer and trainee view.
- Both paramedics stay together to assist each other.
- Paramedics should ignore the walking wounded.

- Laptops show the player view.
- Working as a team, players assess victims condition through observation and communication.
- Trainer views and interjects when necessary.



Level 2 : Immersive VR Environment



- Greek military special forces (BLUE team) performing a sweep of the Piraeus Port looking for terrorists (RED Team) following attack



Level 2 : Immersive VR Environment



- Greek Special Forces personnel undertaking a sweep of the Piraeus Port looking for terrorists - using VR headset and Haptic Vest
- Haptic Vest provides Tactile, Impact and Thermal feedback.

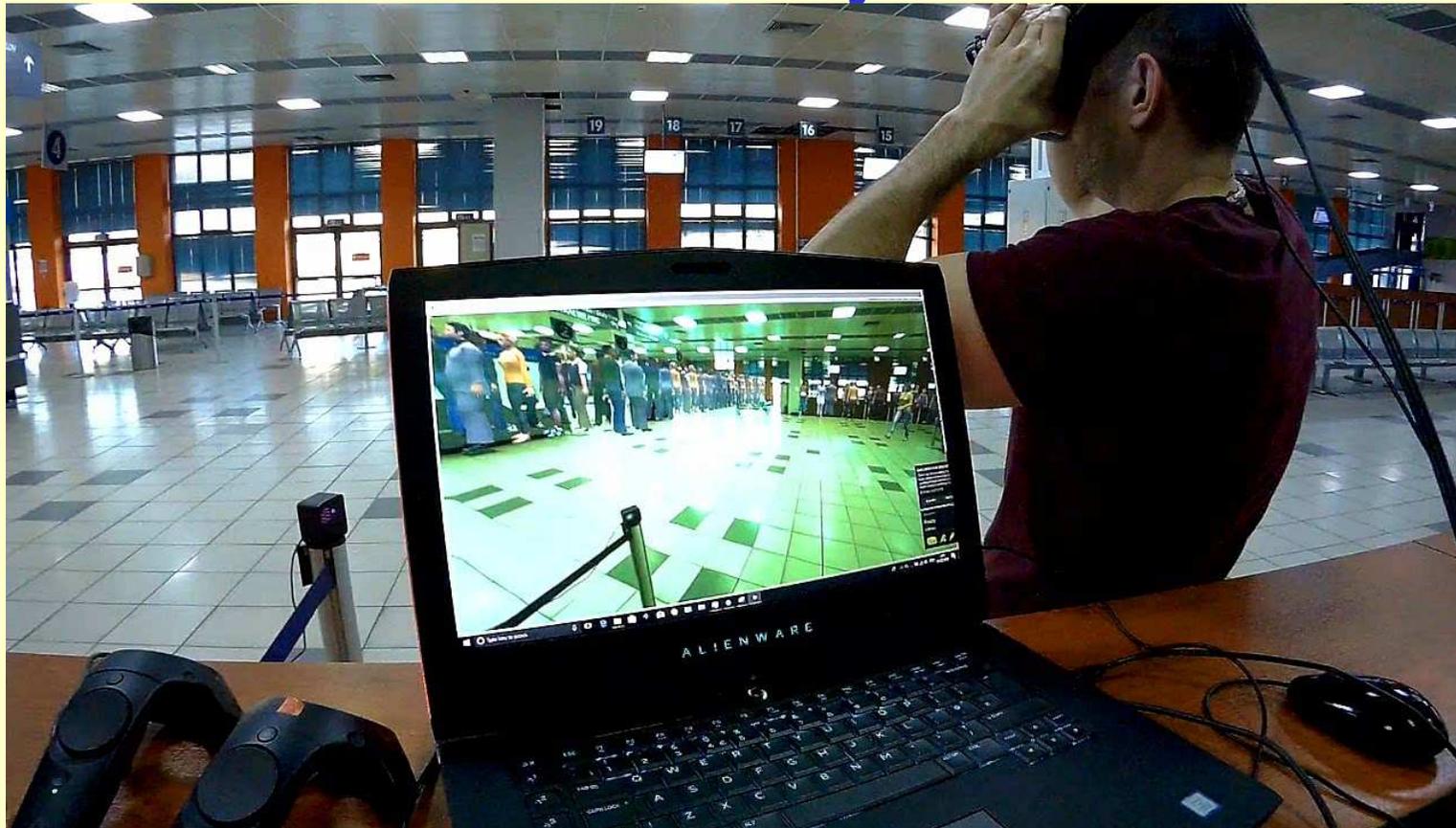


Level 3 : Mixed Reality Environment

- Hololens-1 was considered but not used due to severe limitations with the hardware at that time:
 - Unrealistic very narrow viewing window provided by the headset requires unnatural head movements to capture full field of view (HL1 34°, HL2 52°)
 - Images of avatars appear semi-transparent (still an issue with HL2).
- MR uses HTC Vive set-up as with the Level 2 arrangement.
 - HTC headset modified with addition of centrally mounted HD camera.
 - Camera streams real-time HD video into L+R displays within the headset.
 - Beacons track translation movement of players.
- Simulated avatars are rendered on top of streamed video images to each eye.
 - Avatars appear as if they are actually present and moving around the real structure.
 - Due to the slight delay associated with the time taken to capture and stream the real video, some disconnect between the avatars and the real world is observed – particularly with rapid head movements.
 - Due to inconsistencies between the virtual geometry and the real world e.g. location of taped barriers, agents may appear to walk through objects e.g. tape barriers.



Level 3 : Mixed Reality Environment



View on computer screen is the user view through headset. User can see:

- the actual terminal plus the virtual people queuing at check-in desks and walking around the terminal.
- virtual people controlled by the simulation and respond to interaction with players



Level 3 : View through the MR Head-Set

Real Space

Virtual Crowd

Virtual fatalities



Virtual character attempting to reduce profile

Users real hand firing virtual gun

- Terrorist scenario where real person plays the role of the terrorist and real people play the role of the armed tactical response team.
- Crowd response is controlled by buildingEXODUS.



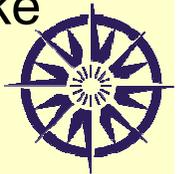
Additional Safety and Security Applications Explored by FSEG

- matEXODUS – version of EXODUS that simulates marauding armed terrorist attacks in crowded places.
- SMARTFIRE and EXODUS COVID19 applications

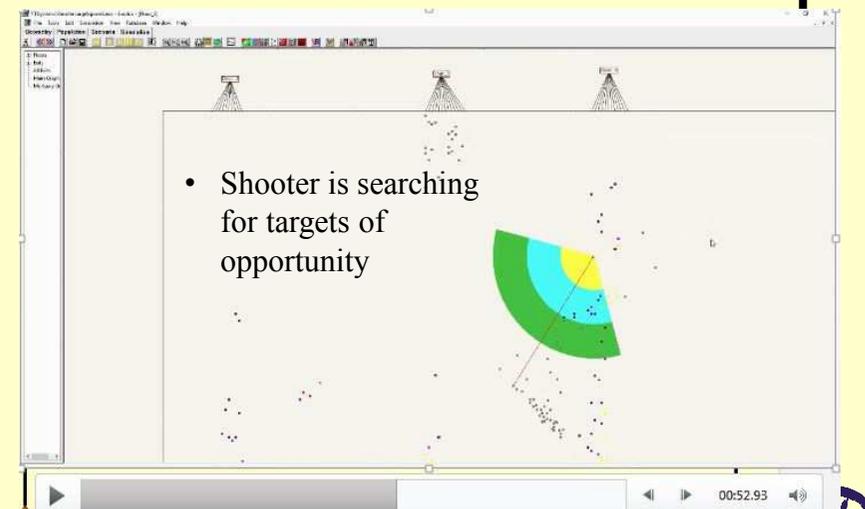
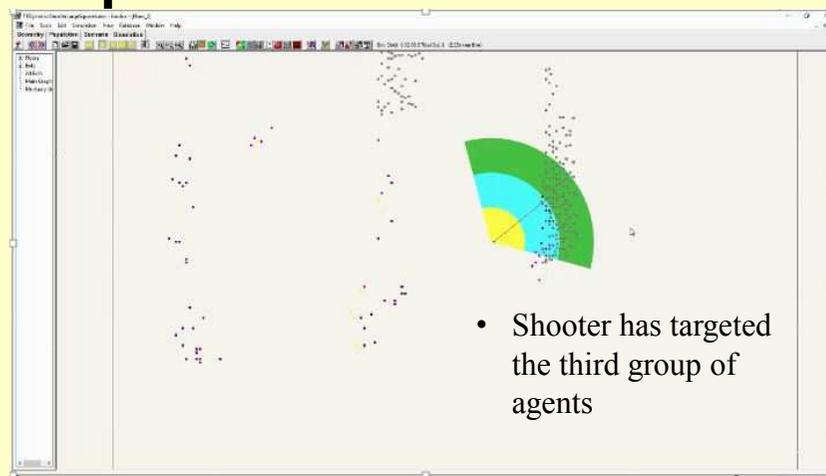
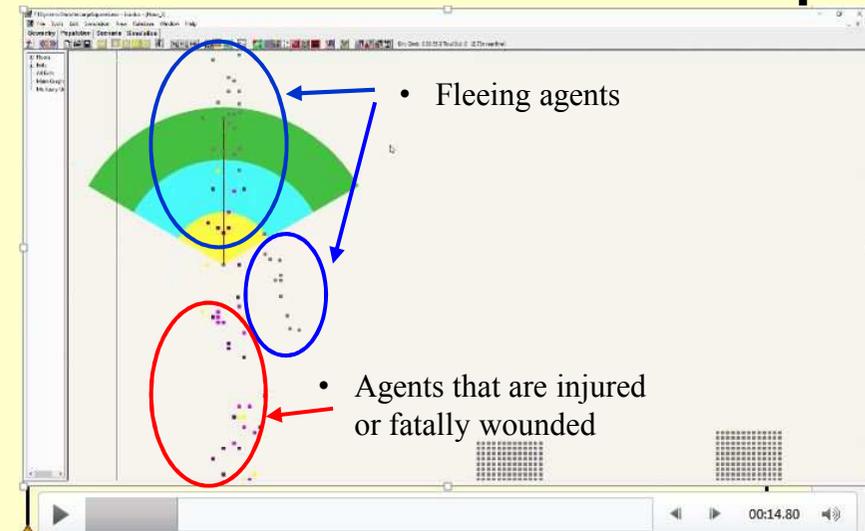
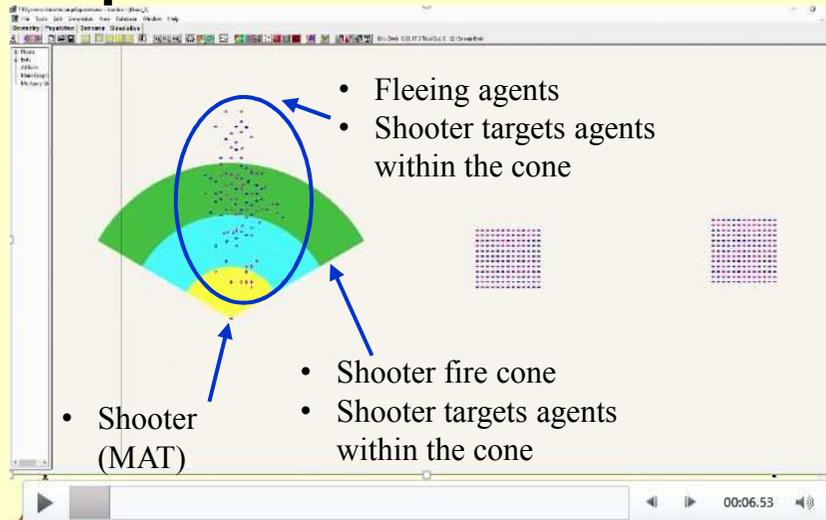


matEXODUS

- MAT – Marauding Armed Terrorist
- **matEXODUS**: Simulates impact of marauding armed terrorist in crowded places – currently under development with support from DSTL.
- ‘MAT’ agent assigned a mission goal (e.g. maximise fatalities), follows a set itinerary, with a given weapon type, ammunition supply and proficiency
 - ‘MAT’ agent may go off pre-set itinerary to ‘hunt’ for targets of opportunity if none available on set path.
 - Each round fired can hit or miss target, defined using a probabilistic approach.
 - If a target is hit, there are a range of outcomes which are defined probabilistically.
- Agents can respond to ‘MAT’ agent and attempt to flee or take cover.



matEXODUS

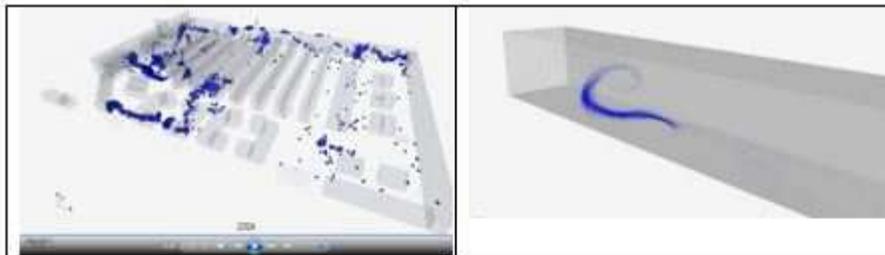


COVID19 mitigation analysis –SMARTFIRE dispersion of respiratory aerosols

- SMARTFIRE capabilities relevant for COVID19 applications include: sprinkler/mist modelling using Lagrange particle tracking, two-way particle/air momentum coupling, particle drag, and evaporation; and modelling both forced and natural ventilation.
- The water mist model has been modified to represent respired droplets and aerosols.
- Wake flows produced by moving people have a more significant effect on the dispersal of respired aerosols than ventilation flows. To represent the wake produced by moving people within SMARTFIRE requires a new capability to simulate moving obstacles. This is being developed using the Immersed Boundary Method.
- SMARTFIRE output has been coupled with the Wells-Riley formulation to generate probability of infection.
- For more details, see my LINKEDIN article:
<https://www.linkedin.com/pulse/fseg-covid-19-mitigation-analysis-harnessing-cfd-fire-ed-galea>

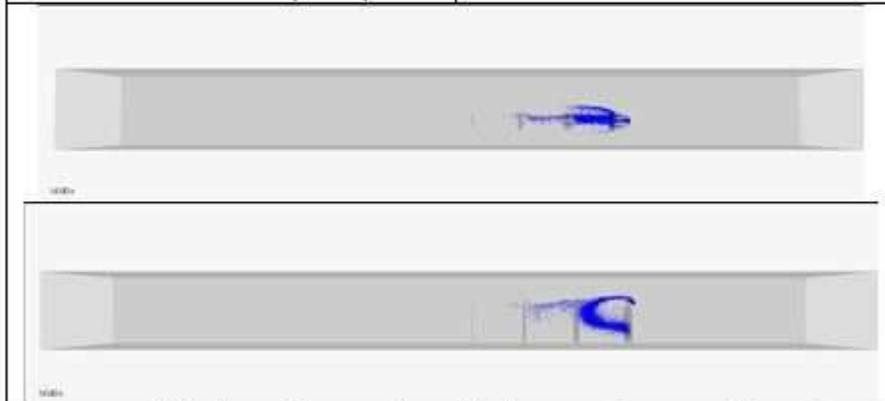


COVID19 mitigation analysis –SMARTFIRE dispersion of respiratory aerosols



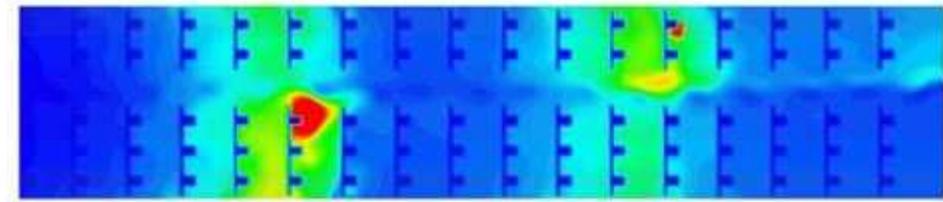
Example of mobile source of aerosol within a supermarket geometry with forced ventilation (6 ACH)

Trail of aerosol particles caught in the wake of a person walking down a corridor



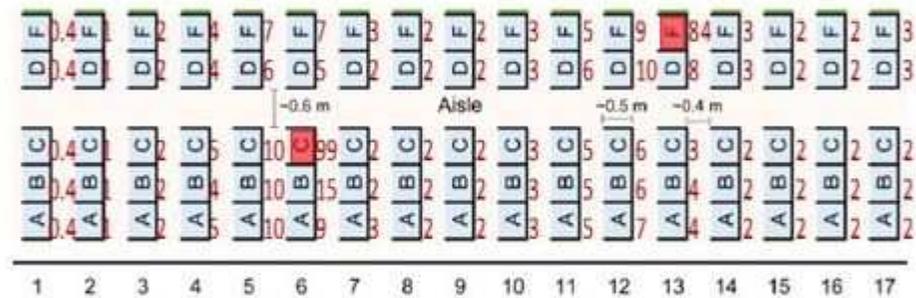
Top and side view of four people walking in a row down a corridor each separated by 2m. The person in the lead is emitting aerosols which are caught in their wake and the wake of the other people, engulfing the two people immediately behind. This type of analysis is important when considering the effectiveness of physical distancing.

SMARTFIRE predictions of aerosol dispersion using the droplet model (Euler-Lagrange)



Quanta concentration (Quanta/m³)
0.000 0.0143 0.0286 0.0429 0.0571 0.0714 0.0857 0.100

(a)



(b)

CFD output produced by SMARTFIRE coupled to Wells-Riley equation to produce probability of infection as a function of seat location. Two index patients are located on the train located in seats 6C and 13F, the carriage has an air exchange rate of 15 ACH. The index patients are emitting 14 quanta/hour through normal respiration.

Presented in (a) is the SMARTFIRE prediction of the quanta distribution at head height after an 8 hour exposure while in (b) is the probability of infection. The SMARTFIRE analysis makes use of a passive scalar to represent the dispersion of the respiratory droplets (Euler approach), rather than the droplet model (Euler-Lagrange approach).

Clearly probability of infection is not simply dependent on distance of the susceptible from the index patient. Results produced by this model is currently being compared with actual infection data collected on Chinese trains.

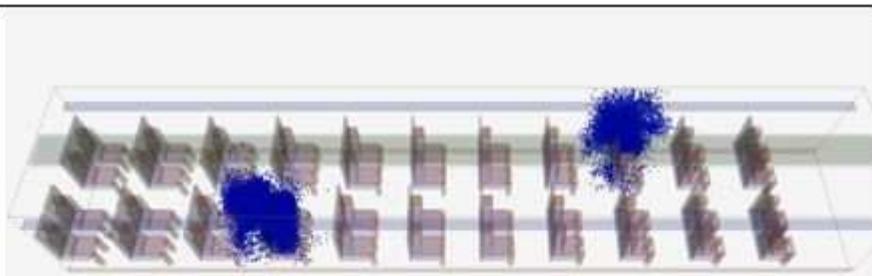


COVID19 mitigation analysis – EXODUS physical distancing

- The behaviour rules within EXODUS have been modified to enable agents to maintain physical distance.
- To achieve this agents are prepared to divert their path slightly to avoid being too close.
- Using this approach, we can explore the impact of imposing SDA (e.g. 2.0m, 1.5m, 1.0m) and other physical separation methods on people flows, throughput and operational efficiency.
- The severity and duration of proximity breaches can be measured using a new 'dose concept' (that I have termed, 'proximity dose') providing a means for evaluating the effectiveness of implemented mitigation strategies.
- For more details, see my LINKEDIN article:
<https://www.linkedin.com/pulse/fseg-covid-19-mitigation-analysis-harnessing-cfd-fire-ed-galea>

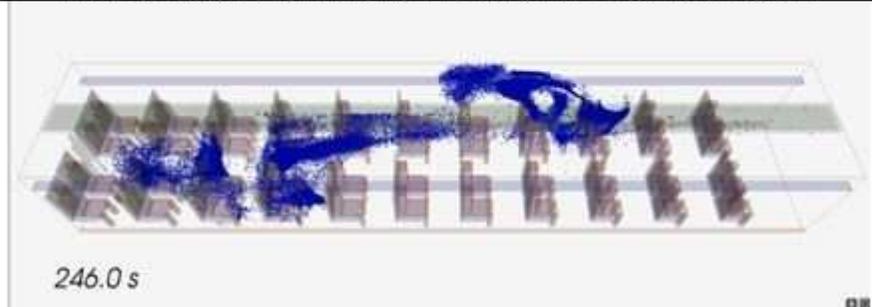


COVID19 mitigation analysis –SMARTFIRE dispersion of respiratory aerosols, EXODUS physical distancing



246.0 s

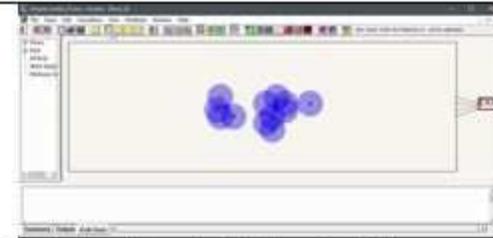
Aerosol dispersion produced by two rail paxs, one seated on the aisle seat (rear) and one seated on the window seat (front) at $t = 246$ s (ventilation inlet at floor; outlet at ceiling) with 10 ACH. The rail carriage has 11 rows and 44 seats.



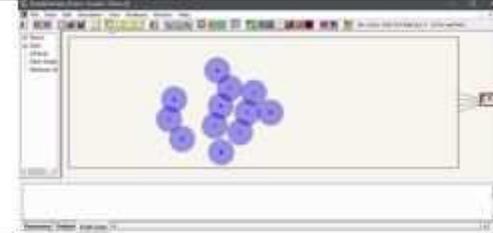
246.0 s

Aerosol dispersion produced by two paxs, one seated on the aisle seat (rear) and one seated on the window seat (front) at $t = 246$ s disrupted by a pax walking down the aisle from back (200 s) to front (217 s) of the carriage (ventilation inlet at floor, outlet at ceiling).

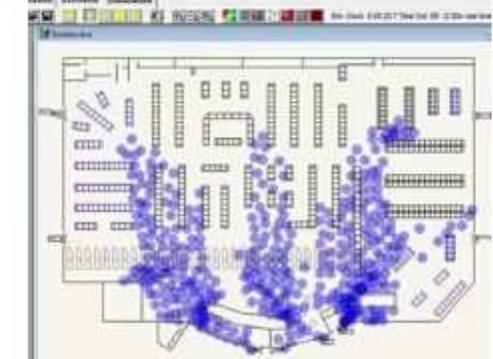
Disruption of respired aerosol clouds caused by a pax walking down the aisle of a rail carriage generated by SMARTFIRE using the droplet model (Euler-Lagrange).



Standard buildingEXODUS simulation without physical distancing (circle represents 1m distance surrounding each agent). Overlapping circles mean agents are within 2m of each other



Modified buildingEXODUS simulation with agents attempting to maintain 2m physical distancing (circle represents 1m distance surrounding each agent)



Modified buildingEXODUS simulation with agents attempting to maintain 2m physical distancing. Congestion at exit point results in the 2m separation breaking down as agents attempt to exit (depicted by overlapping of 1m radius circles)

Modified version of buildingEXODUS in which agents attempt to maintain a 2 m separation



CONCLUDING COMMENTS

- Virtual and Mixed reality training environments provide a means to improve realism in training.
- Enables the creation of training scenarios that would otherwise not be possible or viable e.g. involving large crowds, fire, explosions.
 - VR environment allows realistic training to take place anywhere
 - MR environment allows realistic training to take place in the actual target facility
- However, to ensure a quality training experience essential for the simulated environment and scenario to respond realistically rather than theatrically.
 - Thus essential to utilise validated engineering quality simulation tools to provide the response behaviour of the physical and human system.
- Use of *engineering quality modelling* tools in conjunction with *good data* enable ‘immersion’ to be maintained enhancing the training experience.
- VR/MR environment can also be used to assist in the development and testing of proposed mitigation strategies.



CONCLUDING COMMENTS

Potential training applications include:

- Reducing the frequency of actual full-scale evacuation drills, provide evacuation training tailored to your building, at your desk, at any time, without the disruption caused by an actual full building evacuation.
 - Highrise office buildings, highrise residential buildings, financial centres, hospitals, airport terminals, rail stations, off-shore facilities, etc
- Staff don't even have to be on site to receive evacuation training.
 - Enable training prior to joining a new facility
- Provide specialist training for staff managing large-scale evacuations, for:
 - Aircraft cabin crew
 - Crew on cruise ships and passenger ferries
 - Train crew
 - Facility managers.
- Provide specialist training for managing incidents associated with terrorism.

If you are interested in exploring training opportunities please get in touch with Prof Ed Galea, e.r.galea@gre.ac.uk

