# METHODS FOR SIMULATING CROWD MOVEMENTS IN LOW GRAVITY ENVIRONMENTS FOR SAFE EMERGENCY EGRESS DESIGN

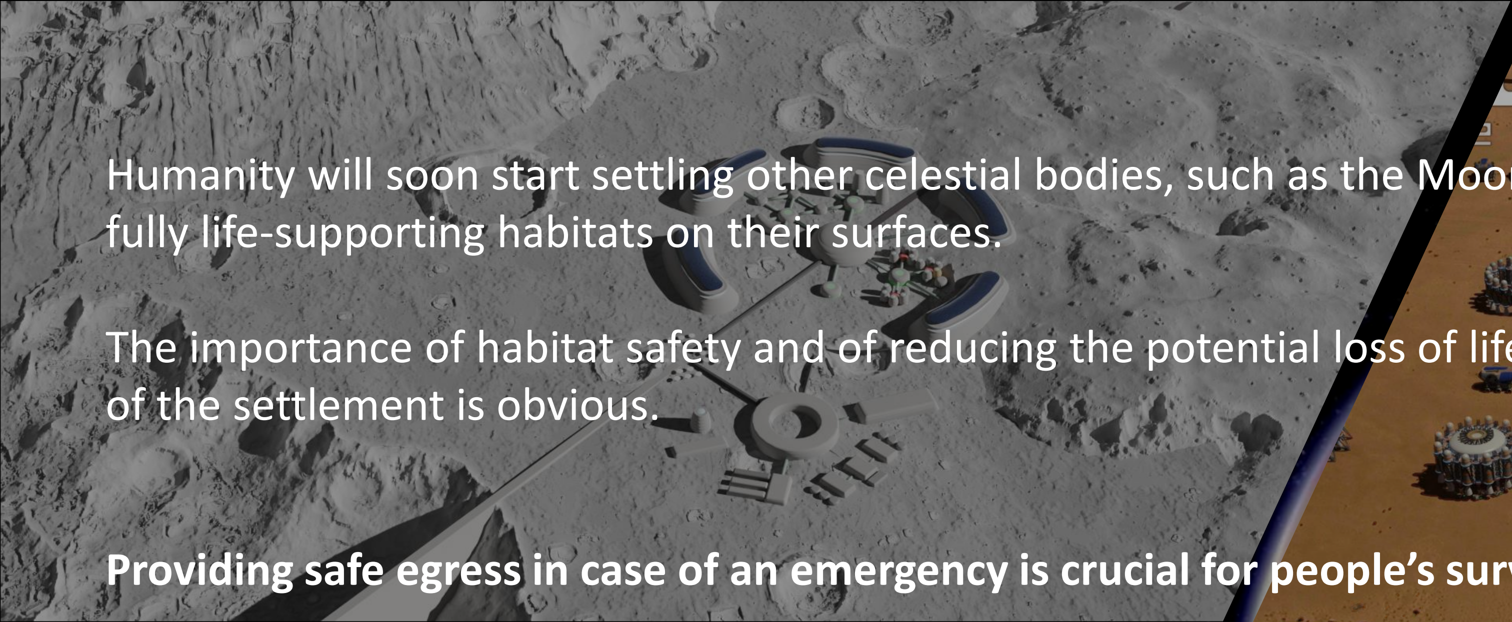
NEXUS AURORA

*Nexus Aurora is a global citizens science community contributing to permanent human space settlement*

Humanity will soon start settling other celestial bodies, such as the Moon and Mars, constructing fully life-supporting habitats on their surfaces.

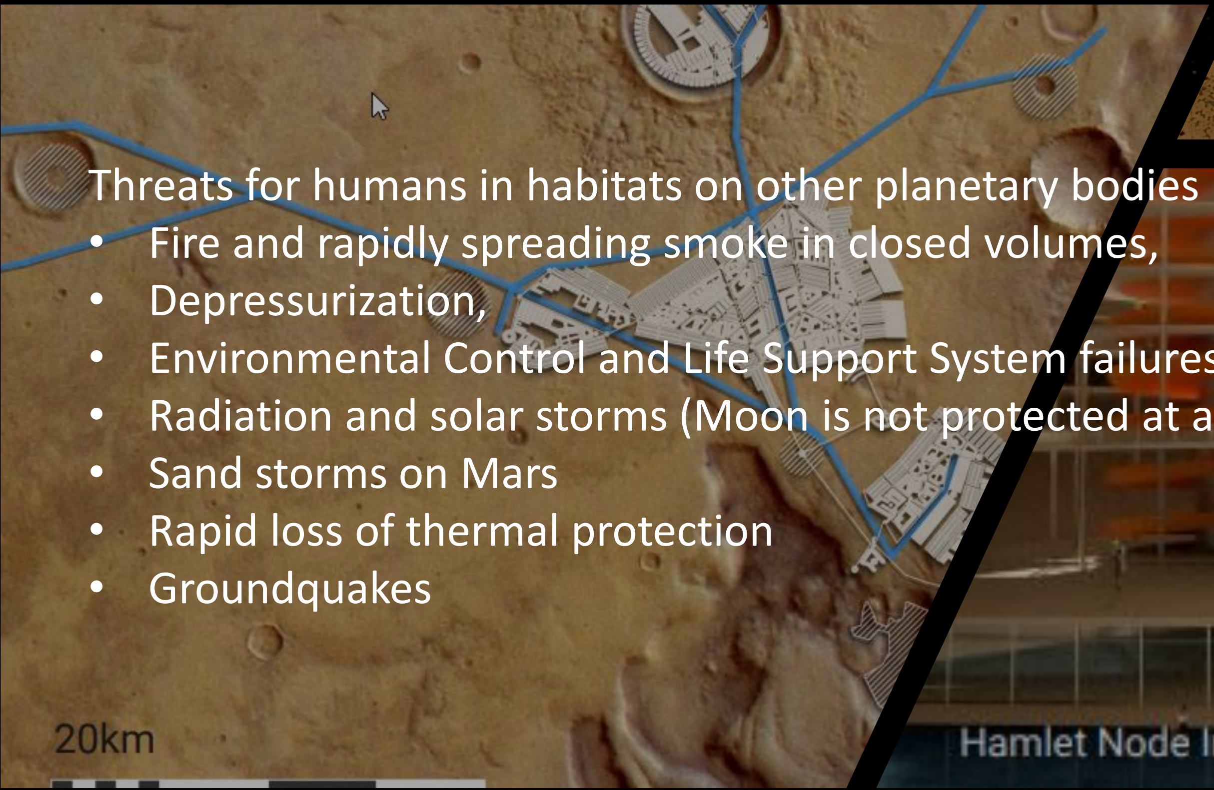
The importance of habitat safety and of reducing the potential loss of life during the occupation of the settlement is obvious.

**Providing safe egress in case of an emergency is crucial for people's survival**



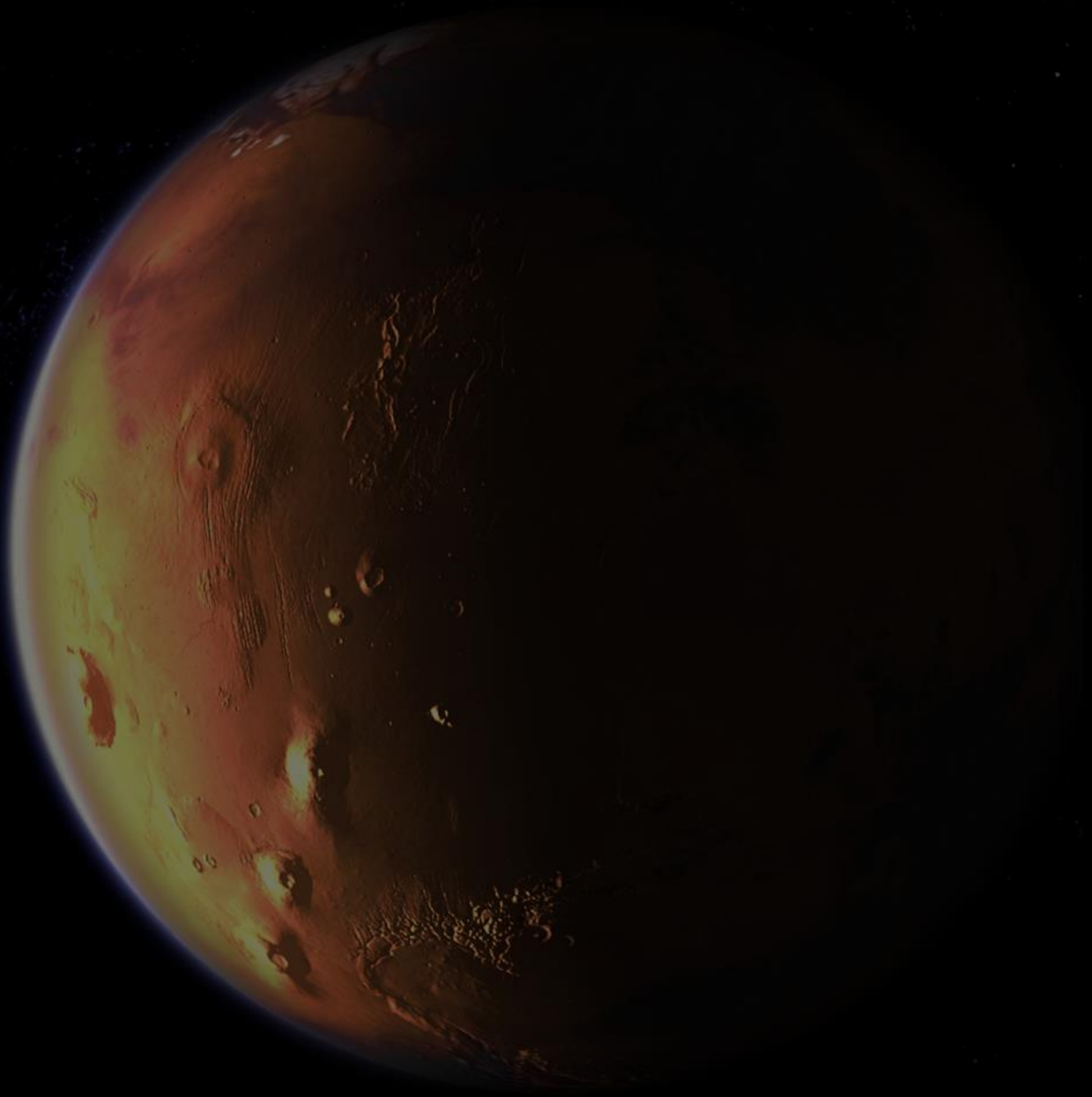
Threats for humans in habitats on other planetary bodies

- Fire and rapidly spreading smoke in closed volumes,
- Depressurization,
- Environmental Control and Life Support System failures
- Radiation and solar storms (Moon is not protected at all)
- Sand storms on Mars
- Rapid loss of thermal protection
- Groundquakes




## EVACUATION PROCESS DIFFERENCES

- Movement in terms of reduced gravity
- Hostile exterior
- Threats may lead to base extinction

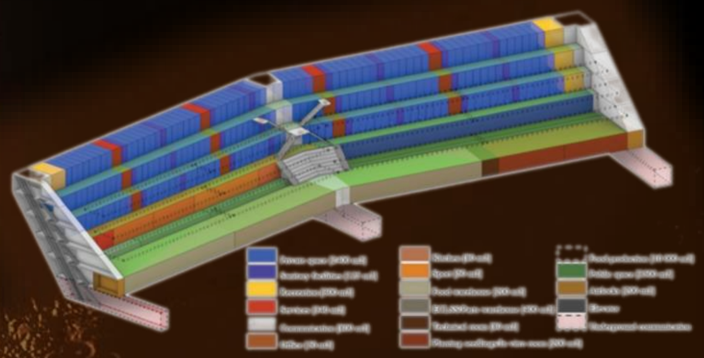


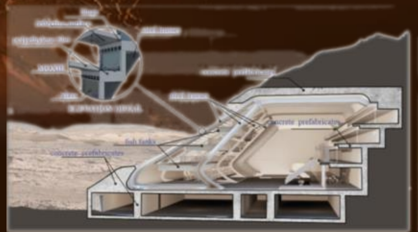
MAIN GOAL

**Required Safe Egress Times (RSET)**

Methodology is based on:

- spatial design guidelines,
- population typology definition
- human behavior
- human locomotion in conditions of reduced gravity,
- crowd formation and flow analysis in low gravity,
- simulation software programming





## STUDIES ALREADY CONDUCTED IN EARTH CONDITIONS

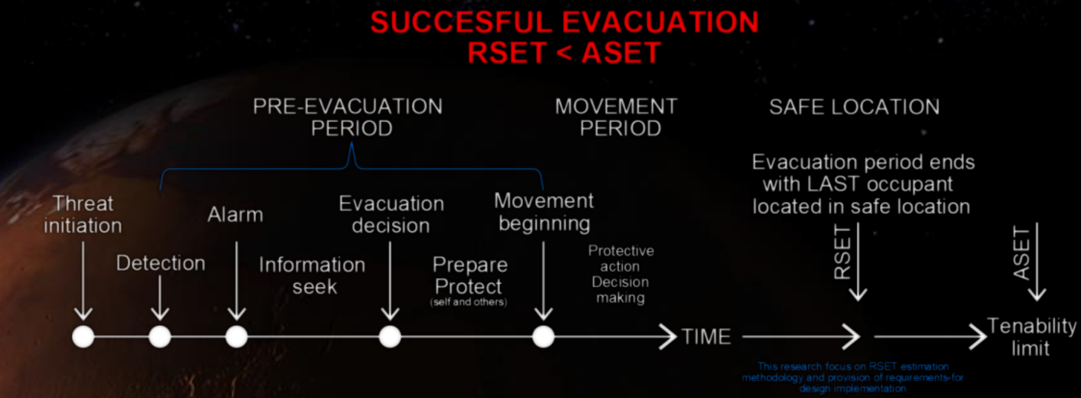
Human behavior for the research by SFPE, NFPA experience
Crowd formation and flow studies
Reduced gravity studies of a single human being by NASA, ESA and Universities

No crowd formation in reduced gravity conducted?

Space agencies – the only regulatory body now
No normative frames are established

# BASIC ASSUMPTIONS

- Successful evacuation  = RSET < ASET
- Bouncing - inevitable
- No genetic or cybernetic modifications to gait
- Human behavior  - no alterations
- Each study assumes no engineering system suport
- RSET design goal set to 7-10 minutes
- The result model will act as a **benchmark** desing



# METHODOLOGY ELEMENTS

Movement conditions and speed

Habitat population

Emergency scenarios

Factors and considerations in human behavior

Parameters for the evacuation process

Implementation into simulation software

**RESULT for IMPLEMENTATION**

# MOVEMENT SPEED TRANSFOR MATION FORMULA

# MOVEMENT SPEED TRANSFORMATION FORMULA

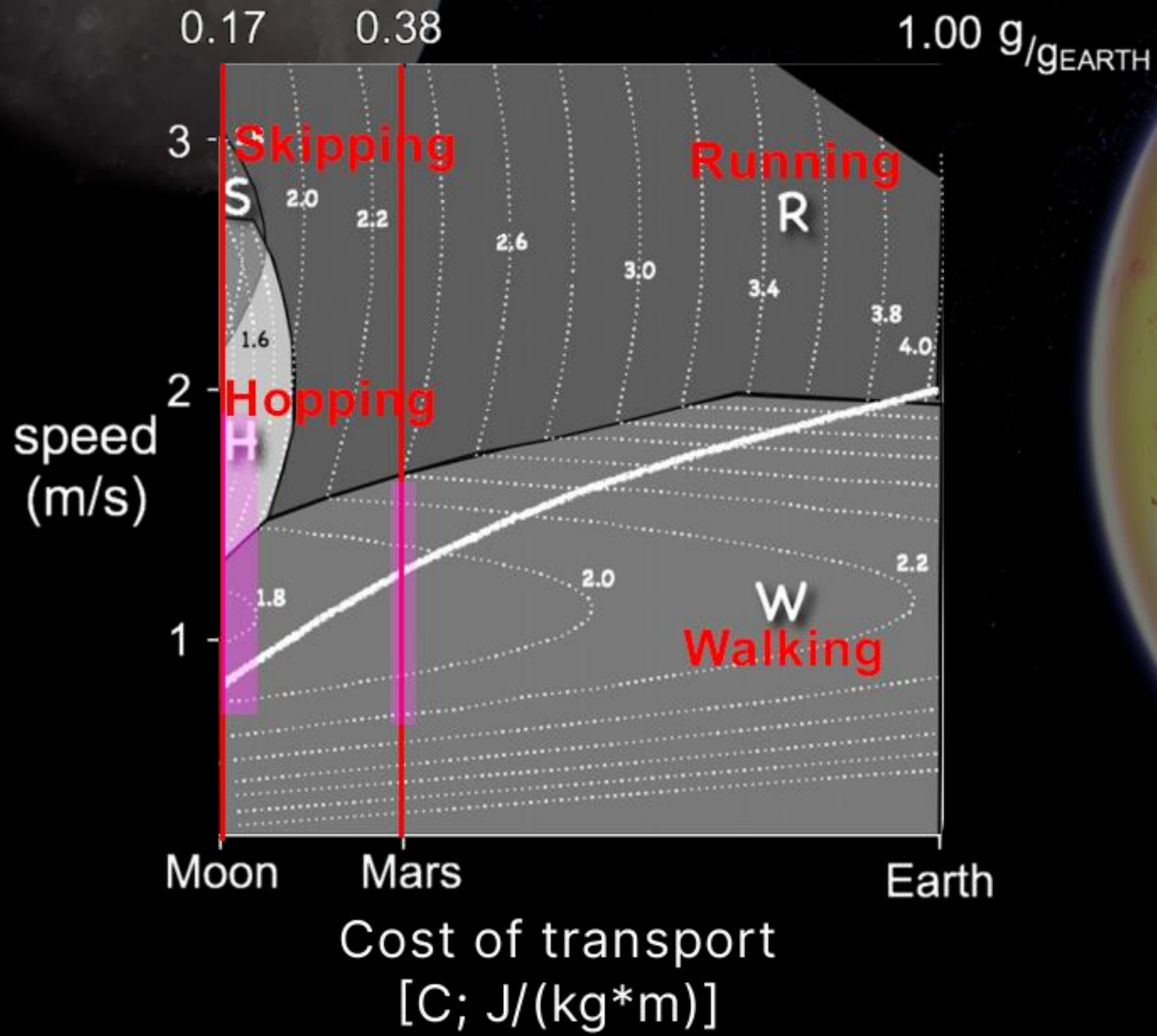
| Profiles | | Vearth - WALK | Vearth - RUN | Vmars - WALK | Vmars- RUN | Data for Agent profiles - Pathfinder for Normal probability distribution | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Average walk speed | Average run speed | Average walk speed (as per Conversion table) | Average run speed(as per Conversion table) | Min speed (Average walk - Std.Dev) | Mean - μ (Average Walk) | Max speed (Run+Std.Dev) | Std.Dev - σ (average of differences between age groups) |
| **GENDER** | **AGE RANGE** | **[m/s]** | **[m/s]** | **[m/s]** | **[m/s]** | **[m/s]** | **[m/s]** | **[m/s]** | **[m/s]** |
| Female* | 5 to 10 | 1,2470 | 2,5870 | 0,7681 | 1,5935 | 0,7353 | 0,7681 | 1,6263 | 0,0327 |
| Female* | 10 to 20 | 1,3186 | 2,6216 | 0,8122 | 1,6148 | 0,6919 | 0,8122 | 1,7352 | 0,1204 |
| Female | 20 to 29 | 1,3400 | 2,2893 | 0,8254 | 1,4101 | 0,6850 | 0,8254 | 1,5505 | 0,1404 |
| Female | 30 to 39 | 1,3400 | 2,1873 | 0,8254 | 1,3473 | 0,7637 | 0,8254 | 1,4090 | 0,0617 |
| Female | 40 to 49 | 1,3900 | 2,1389 | 0,8562 | 1,3175 | 0,7657 | 0,8562 | 1,4080 | 0,0905 |
| Female | 50 to 59 | 1,3100 | 1,9234 | 0,8069 | 1,1847 | 0,5546 | 0,8069 | 1,4370 | 0,2523 |
| Female* | 60 to 69 | 0,9400 | 1,7697 | 0,5790 | 1,0901 | 0,4238 | 0,5790 | 1,2452 | 0,1552 |
| Female* | 70 to 79 | 1,1300 | 1,5996 | 0,6960 | 0,9853 | 0,5963 | 0,6960 | 1,0850 | 0,0997 |
| Female* | 80 to 89 | 0,9400 | 1,4458 | 0,5790 | 0,8906 | 0,4731 | 0,5790 | 0,9964 | 0,1059 |
| Male* | 5 to 10 | 1,3181 | 2,8968 | 0,8119 | 1,7844 | 0,6461 | 0,8119 | 1,9501 | 0,1658 |
| Male* | 10 to 20 | 1,3720 | 3,3811 | 0,8451 | 2,0826 | 0,7858 | 0,8451 | 2,1420 | 0,0593 |
| Male | 20 to 29 | 1,3600 | 2,7462 | 0,8377 | 1,6915 | 0,5650 | 0,8377 | 1,9643 | 0,2727 |
| Male | 30 to 39 | 1,4300 | 2,5536 | 0,8808 | 1,5729 | 0,7935 | 0,8808 | 1,6602 | 0,0873 |
| Male | 40 to 49 | 1,4300 | 2,5328 | 0,8808 | 1,5601 | 0,8058 | 0,8808 | 1,6351 | 0,0750 |
| Male | 50 to 59 | 1,4300 | 2,3099 | 0,8808 | 1,4228 | 0,6842 | 0,8808 | 1,6194 | 0,1966 |
| Male* | 60 to 69 | 1,3400 | 1,9844 | 0,8254 | 1,2223 | 0,5969 | 0,8254 | 1,4508 | 0,2285 |
| Male* | 70 to 79 | 1,2600 | 1,7379 | 0,7761 | 1,0705 | 0,5198 | 0,7761 | 1,3268 | 0,2563 |
| Male* | 80 to 89 | 0,9700 | 1,5221 | 0,5975 | 0,9376 | 0,4417 | 0,5975 | 1,0933 | 0,1558 |
| Both* | Impaired Mobilty | 0,3400 | 0,5400 | 0,2094 | 0,3326 | 0,1990 | 0,2094 | 0,3431 | 0,0105 |

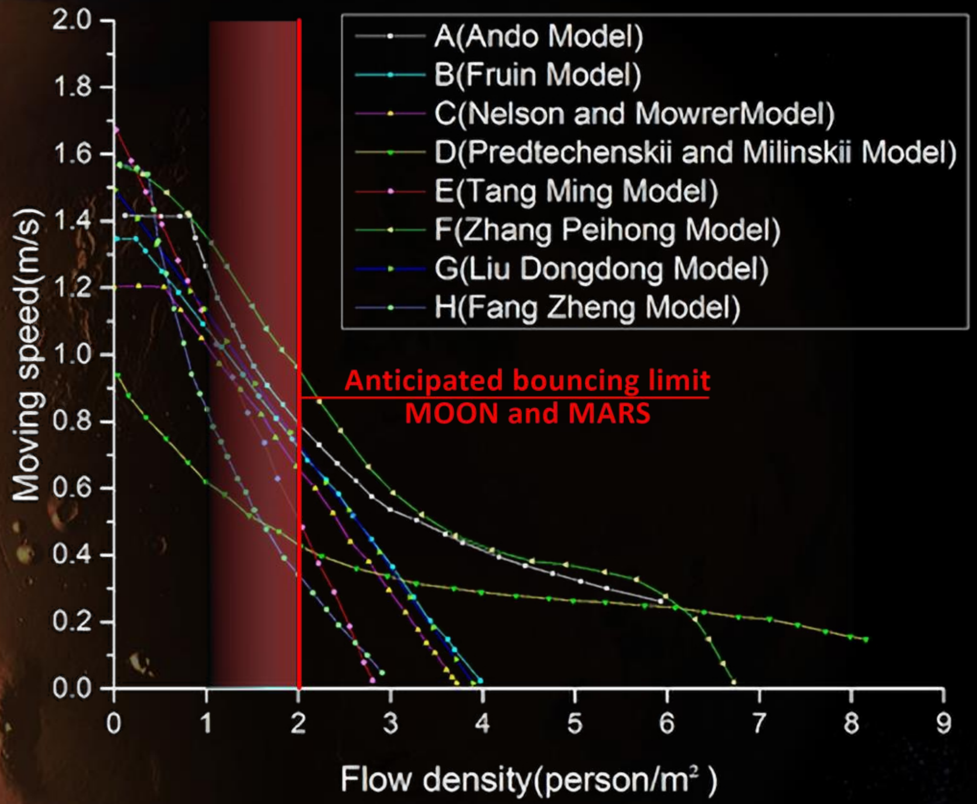
* Approximated Earth speed value

# MOVEMENT TYPES IN DIFFERENT GRAVITATIONAL ENVIRONMENTS

Most economical on Mars – Earth like

Moon movement – hopping

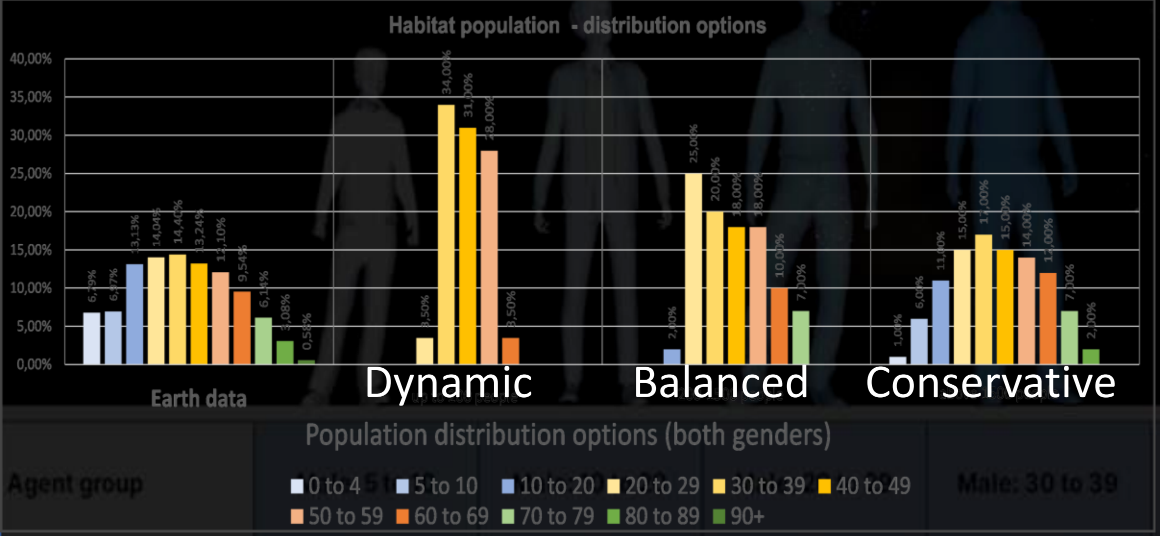


# POPULATION

## Habitat population - distribution options

| Age group | Earth data (UN stat) | | | Dynamic | | | Balanced | | | Conservative | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Female | Male | Both genders | Female | Male | Both genders | Female | Male | Both genders | Female | Male | Both genders |
| 0 to 4 | 3,30% | 3,49% | 6,79% | | | | | | | 0,50% | 0,50% | 1,00% |
| 5 to 10 | 3,39% | 3,58% | 6,97% | | | | | | | 3,00% | 3,00% | 6,00% |
| 10 to 20 | 6,39% | 6,73% | 13,13% | | | | 1,00% | 1,00% | 2,00% | 5,50% | 5,50% | 11,00% |
| 20 to 29 | 6,87% | 7,18% | 14,04% | 1,58% | 1,93% | 3,50% | 12,50% | 12,50% | 25,00% | 7,50% | 7,50% | 15,00% |
| 30 to 39 | 7,11% | 7,29% | 14,40% | 15,30% | 18,70% | 34,00% | 10,00% | 10,00% | 20,00% | 8,50% | 8,50% | 17,00% |
| 40 to 49 | 6,59% | 6,64% | 13,24% | 13,95% | 17,05% | 31,00% | 9,00% | 9,00% | 18,00% | 7,50% | 7,50% | 15,00% |
| 50 to 59 | 6,15% | 5,95% | 12,10% | 12,60% | 15,40% | 28,00% | 9,00% | 9,00% | 18,00% | 7,00% | 7,00% | 14,00% |
| 60 to 69 | 5,05% | 4,49% | 9,54% | 1,58% | 1,93% | 3,50% | 5,00% | 5,00% | 10,00% | 6,00% | 6,00% | 12,00% |
| 70 to 79 | 3,43% | 2,71% | 6,14% | | | | 3,50% | 3,50% | 7,00% | 3,50% | 3,50% | 7,00% |
| 80 to 89 | 1,91% | 1,17% | 3,08% | | | | | | | 1,00% | 1,00% | 2,00% |
| 90+ | 0,42% | 0,16% | 0,58% | | | | | | | | | |
| **Total** | **50,61%** | **49,39%** | **100,00%** | **45,00%** | **55,00%** | **100,00%** | **50,00%** | **50,00%** | **100,00%** | **50,00%** | **50,00%** | **100,00%** |




**Dynamic**

- science and survival-oriented bases
- only dynamic and fully healthy people are present in the population
- female / male proportions are 45/55 favoring physical labor
- Ages range from 30 to 60 years old balanced to favor groups 30-50 y.o
- The Martian habitat is populated with newcomers on a 2 year rotation basis of about 40-60%%,. The core crew required to run a base is expected to stay no less than 4 years
- The Moon assumes a one month stay

**Balanced**

- some people can have impaired mobility (elders),
- young people are present inthe habitat
- female / male proportion is balanced - 50/50
- range of people aged from 20 to 70 years old
- habitat is populated with newcomers on Mars on a 2-year basis (Moon assumed 1-month stay) - no more than 35%, the rest is a long-term habitants - 4-8 years
- mix of people is balanced to favor groups 30-50 y.o

**Conservative**

- elders, children are present in the habitat
- female / male proportion is balanced at 50/50
- Ages range from 5 to 80+ years old
- Population turn over rate is the same as for distribution 2.

# SCENARIOS

## MOST SIGNIFICANT SCENARIONS OF HABITAT LIFE COMBINED

# HUMAN BEHAVIOUR FACTORS AND CONSIDERATIONS BY SFPE

## *Habitat characteristics*

- Habitat type and main functionality (multifunctional bases should be described in detail and divided into major use areas)
- Area and population for each segregated section of the habitat
- Physical dimensions
- Geometry of enclosures
- Number and arrangement of means of egress
- Architectural characteristics/complexity
- Emergency information systems
- Fire protection systems
- Refuge areas
- EVA access
- Radiation protection areas
- Lighting and signage
- ECLSS subdivisions and redundancy strategy

## *Population characteristics*

- Population demographic typology (age/gender)
- Distribution of population in habitats
- Distribution of activities
- Individuals, solitary or grouped
- Familiarity of the occupants with the building
- Occupant alertness
- Physical/cognitive abilities
- Role/responsibilities of occupants during the normal use of the building and, in an emergency,
- Occupant awareness of location
- Involvement in the task currently performed
- Commitment to current task
- Focal point
- Prior fire/evacuation experience
- Culture

## *Evacuation strategies and procedures*

- Total, zoned, or staged evacuation
- Proportion of occupants trained or drilled in emergency procedures
- Provisions for those with access and functional needs,medical patients, impaired
- Frequency of training or drills
- Who is trained or drilled
- Ability to defend in place
- Relocation to refuge rooms, other safe areas,EVA locks
- Emergency team formation and time of arrival delay
- Use of external/internal vehicles for rescue

## *Environment during the emergency*

- Smoke and toxic gasses
- Hypoxia during a fire and separately during decompression
- High Radiation and convective heating from flames and smoke and low thermal loads from openings and failing structures (exposure to hostile environment)
- Reduced visibility of signage, egress route indication and alarms due to smoke.
- Availability of transportation,
- Duration and intensity of exposure to hazards

# PARAMETERS FOR EVACUATION PROCESS

## *Delay times*

- The delay times must consider the following items, taken from SFPE guidelines [2] and other items of note:
- **population demographic typology** (age/gender) – influences on pre-evacuation time, and displacement time – see section 4
- **alertness** - reaction time due to location and activity conducted (eg.: people during working hours will react sooner than residents during sleeping hours), including the influence of prior emergency/evacuation experience and training
- **physical/cognitive abilities**, including mental and physical health, impairments
- **role/responsibilities** (trained / untrained staff and number of people per population) including critical systems shutdown and protection
- **location**: awareness of the place evacuees find themselves to be considered in various degrees of size (for each scenario): from the immediate surroundings in which a given person moves during their main daily activities, to awareness of the location in the district, habitat (correct navigation plays a huge role here)
- **focal points**: significant, visible areas with quick access and trained staff, such as stages, main squares, public buildings, etc) play a significant role in public spaces of future habitats, as they help orientate and navigate the crowd
- **commitment to current task**, this may delay the evacuation, especially during working hours when specialized and valuable instruments are used or important data is stored

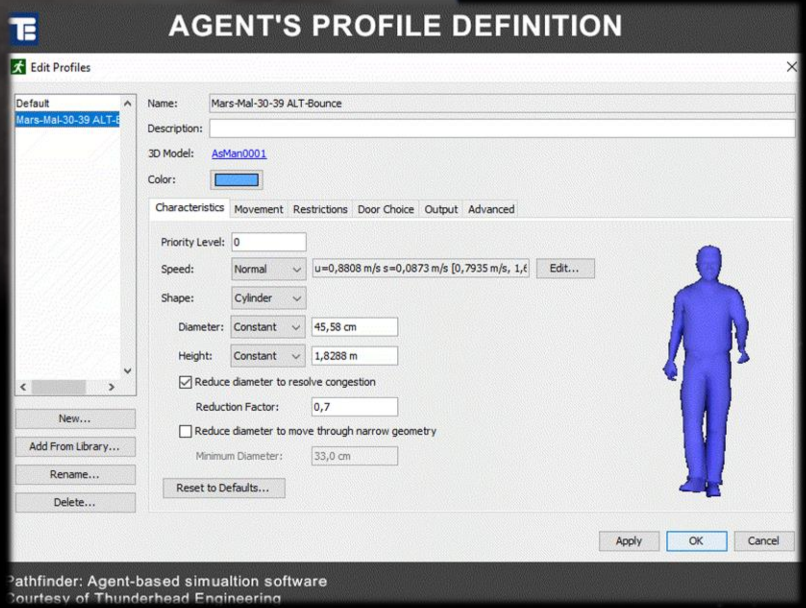
## *Evacuation strategy/procedures*

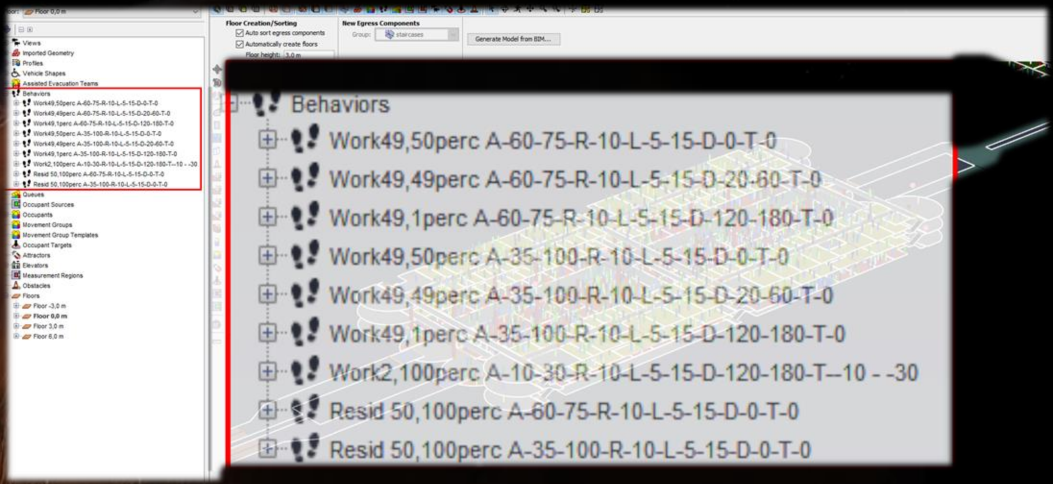
- Total, zoned or staged evacuation – which depend on the size of the emergency zone and the number of people. The larger the area, the more announcement zones are needed, with additional delay times for each zone. Delay times should be established with iterated simulations.
- provisions for those with access and functional needs – infirm, impaired (less or not possible in Distribution 1 habitats, but to be considered for distributions 2 and 3)
- who is trained or drilled
- frequency of training or drills may lead to a high level of practice but on the other hand it may be a cause of indifference to alarm signals
- emergency team formation and arrival time: Emergency teams are provided with a personal announcement/message at the beginning of pre-evacuation time (after Detection phase). An emergency team should be formed in another safety zone prior to any evacuation start. Considering the size of the habitat, it may be an EVA bay with emergency equipment or a fully equipped emergency station (with external environment access)and airlocks to the area under emergency.
- other factors such as defend-in place are not considered, as the worst-case scenario should assume maximum crowd load on all available communication paths.

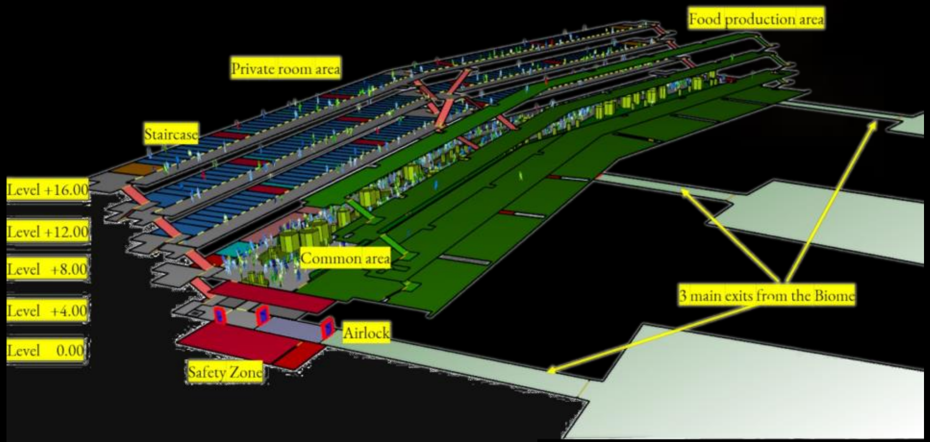
**SAMPLE OF ADDITIONAL PARAMETERIZATION OF EVACUATION PROCESS DELAY TIMES FOR HABITATS 115, 1000 AND 10 000 PEOPLE**

| Scenario | 115 occupants | | | 1000 occupants | | | 10 000 occupants | | |
|---|---|---|---|---|---|---|---|---|---|
| Delay type | Worktime | Sleeping | Gathering | Worktime | Sleeping | Gathering | Worktime | Sleeping | Gathering |
| Population characteristics | | | | | | | | | |
| Demographic distributions | Distribution 1: Dynamic society | | | Distribution 2: Balanced | | | Distribution 3:Conservative | | |
| Alertness delaying factors(s) (see drill and training) | 75%:60-75 5%:10-30 | 75%:60-120 25%: 10-30 | 75%:35-100 25%: 10-30 | 47%:60-75, 48%:35-100 5%: 10-30 | 95%:60-120 deep sleepers alcohol use: 200 to 360 5%: 10-30 | 95%: 35-100 5%:10-30 | 49%: 60-75 49%:35-100 2%: 10-30 | 98%:60-120, deep sleepers alcohol use: 200 to 360 2%:10-30 | 98%: 35-100 2%: 10-30 |
| SFPE ref. Table And notes | 64.8 industrial | 64.13 | 64.7 merc. | 64.8 industrial | 64.13 Notes 1,2 | 64.7 merc. | Table 64.8 industrial | 64.13 Note 1 | 64.7 merc. Note 2 |
| | | | | 1-sleeping data, EuroStat reduced by 50% 2-Heavy drinking (weekly basis) F:0,8% M 3,6% | | | 1-sleeping , Eurostat Heavy drinking (weekly basis) F:1,6%, M 7,2%) 2- few people are considered credible source of information therefore reaction time is almost as low as sleeping hours. | | |
| Impairments | no impaired profile to be used | | | use 1 impaired profile, 0,5% in wheelchairs | | | at least 2 different profiles for impaired, 1% in wheelchairs, 0,74% deaf-blind | | |
| Role and res-ponsibilities | none | none | none | none | none | none | for disorientation/ misinformation add: | | |
| | | | | | | | 10s | 20s | 5s |
| Location | common places - no additional cost in delay due to high/moderate location awareness | | | common spaces: additional cost in delay due to high/moderate location awareness | | | Addition for location awareness on next district entrance | | |
| | | | | none | 5-15 s | none | 5-15 s | 10-20 s | 5-15 s |
| Commit. to task | See trained and drilled procedures | | | See trained and drilled procedures | | | See trained and drilled procedures | | |
| Focal point | none | none | none | none | none | red.:20-30s | | | Red: 20-30s |
| Prior fire/evac experience | See above - lertness | See above - Alertness | See above - Alertness | See above - Alertness | See above - Alertness | See above - Alertness | See above - Alertness | See above - Alertness | See above - Alertness |
| Evacuation strategy/procedures | | | | | | | | | |
| Total, zoned or staged evacuation | no zoning delays | | | zoning delays to be elaborated as an emergency scenarios strategy, simulation assumes that all systems have failed | | | zoning delays to be elaborated as an emergency scenarios strategy, simulation assumes that all systems have failed | | |
| All or few occupants trained or drilled in procedures | 1-Delay to stop experiments 2-critical shutdowns | | | 1-Delay to stop experiments 2-critical shutdowns 3-Production areas EVA bays shutdown | | | 1-Delay to stop experiments 2-critical shutdowns 3-Production areas EVA bays shutdown | | |
| | 1:20-60 s for all. 2: 120-180 for one occupant | 1: none 2:30-120 s for one occupant | 1:none 2:120-180s for one occupant per room | 1:20-60s,all 2: 120-180s for 2% of occupants 3: 120-240s, all attendees | 1-None 2- 60-180s for one occupant per habitable area/floor | 1- None 2- 120-180s for 2% of attendees | 1: 20-60s,all 2: 120-180 for 2% of occupants 3: 120-240s, all attendees | 1:none 2: 60-180s for one occupant per habitable area/floor | 1-None 2- 12-180s for 2% of attendees per module |
| • Provisions for occupants with access and functional needs | no assistance | | | no assist. | no assist. | All, note 1 | All, note 1 | All, note 1 | All, note 1 |
| | No disabled, incarcerated or impared occupants | | | 1- wheelchairs are to be assisted with 1 additional person. Visual and hearing imparity is to be considered as typical evacuees (help during the evacuation by neighboring people is assumed) | | | 1- wheelchairs are to be assisted with 1 additional person. Visual and hearing imparity is to be considered as typical evacuees (help during the evacuation by neighboring people is assumed) | | |
| training/drills frequency | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Who is trained or drilled | 0 | | | not more than 5% of inhabitants will have reduced delay time by 10-30 second due to training | | | not more than 2% of inhabitants will have reduced delay time by 10-30 second due to training | | |
| Emergency team formation and arrival time | 60-75 s + simulation arrival time | | | 60-75 s + simulation arrival time | | | 60-75 s + simulation arrival time | | |

# SOFTWARE IMPLEMENTATION



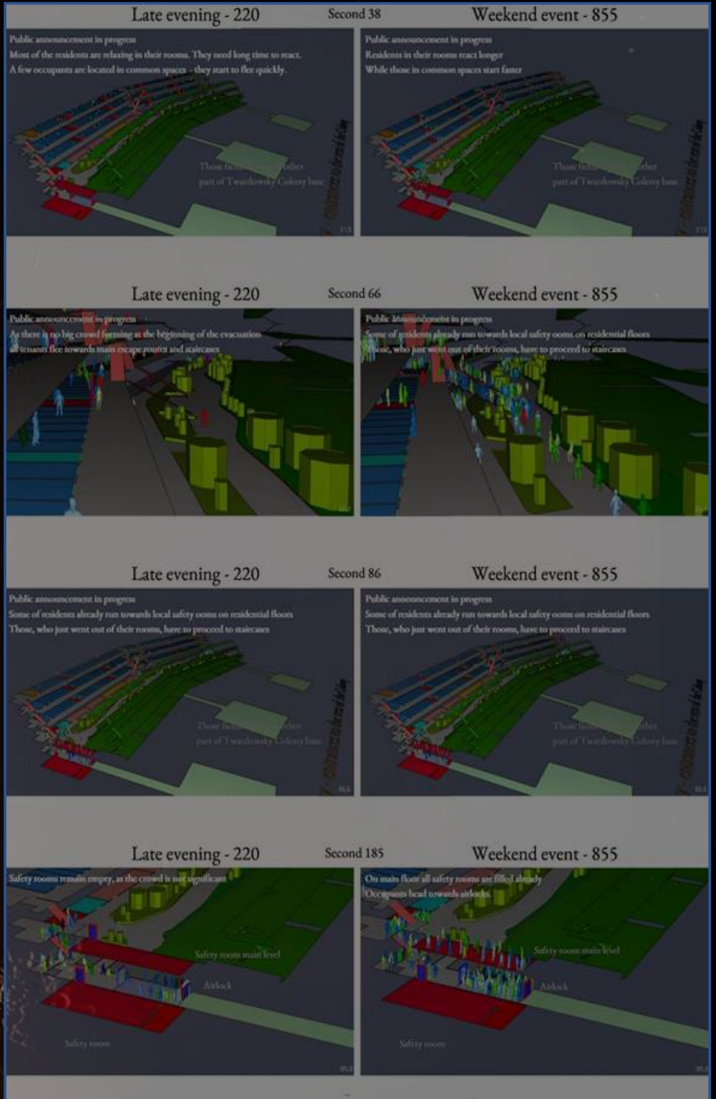




# RESULTS IMPLEMENTATION

Sample guidelines are provided as an illustration of the methodology result.

- Use loop design: horizontal and vertical dead ends must be short, no longer than 15m, or avoided altogether.
- consider possible bouncing and inertia of movement: due to the high risk of collisions, and subsequent injuries, main passages and communication corridors should not turn with sharp 90 degree angles but have wide turns and large viewing angles
- divide the habitat: based on main functional zoning with partitions rated for fire, pressure and ECLSS independence. Make areas fully resistant to external conditions and ensure the isolation of the emergency event. Physical separation and distancing is required.
- provide refuge rooms
- provide compartments accessed via airlocks with the following characteristics:
- an emergency power systems for quick airlock pressurization.
- sliding doors that can be opened with a single person-force
- non flammable finishes
- introduce empty corridor policy: all corridors and passages should be left empty. In common areas, there must be free passages between interior elements - best if the communication lines are straight and lead directly to the door area.
- Provide well-trained staff: ensure constant updates on their location.
- Notify emergency rescue teams: in case of the detection of a hazard (beginning of pre-evacuation period), with consecutive cancellation in case of a false alarm.
- Secure EVA bays: provide these with external access for emergency vehicles and internal access through airlocks to separated areas. Eventually provide them with emergency suits, once these are developed.
-
- Refuge room layout:
- Locate refuge rooms on every main functional floor or area: in proximity to external walls for further rescue, when required by the simulation.
- Provide emergency teams access: there should be multiple access paths via an external airlock.




*Animation - Simulation result* 1

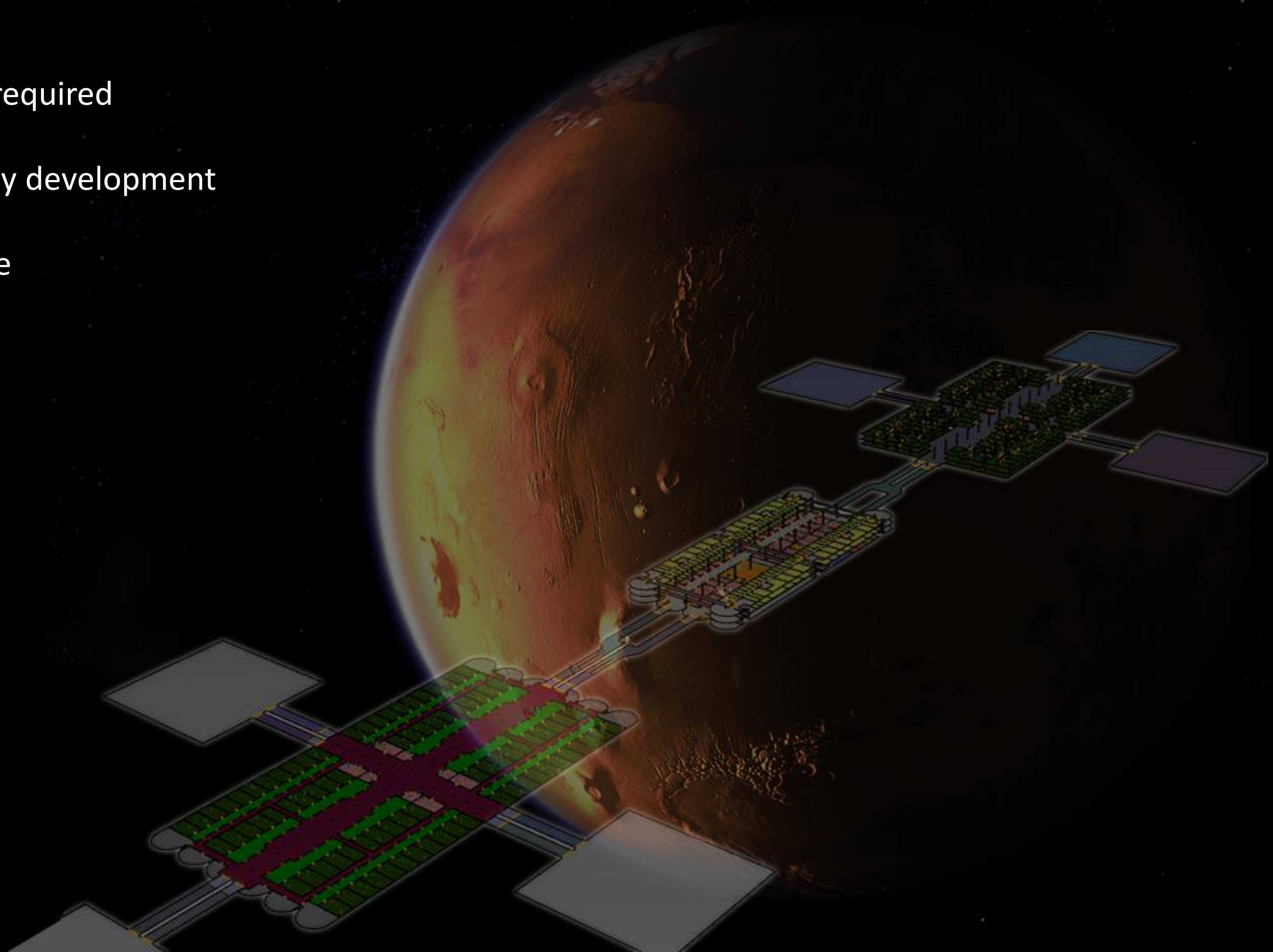
# POSSIBLE IMPACT

- Raises awareness
- Essential in habitat design
- Habitat emergency strategy planning
- Technical Guidelines
- Analog mission on earth help
- Astronaut and future colonists  training

- Real crowd formation experiments in parabolic flight conditions
- Earth-based design for arcologies or hostile environments settlements (excluding low gravity conditions)

# CONCLUSION

- Multidisciplinary approach required
- Tracking changes over colony development
- Agent-based simulations use
- Part of risk assessment
- Design development
- Mission planning



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## THANK YOU

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