ANALYSIS OF EVACUATION IN MARTIAN CONDITIONS WITH AGENT-BASED SIMULATION SOFTWARE, ON THE EXAMPLE OF TWARDOWSKY MARS COLONY BIOME

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ABSTRACT

Settlement on Mars is closing every year. The construction of a base on the other planet, from a distant dream became, a technical reality. Next steps are also close ahead: a colony then a city, multiple cites and then possibly terraforming.

As any mistake, in the hostile environment, may result in life loss, any step must be taken wisely to provide safety for human being at every moment. This article follows the path of minimizing the risk and focuses on one of the most critical part of design priorities: mass evacuation and crowd forming in terms of reduced gravity.

INTRODUCTION

Safety of the people is a top technical priority in every building or device – in any place. All: structure, MEP systems and the layout should be focused on minimizing the risk of life loss.

Design of a base, or colony on other planet also should comply with this principle.

The layout of all safety egress communication (passages, corridors, staircases, lifts etc.) should not be changed or altered. The unchangeable layout of those elements is a bone system for the functional layout and all the decoration we see.

The drawback of such solution is that - once designed, the layout is frozen. Any change leads to re-examination of all safety measures – which is very expensive and time consuming (even in Earth's conditions).

One of the most important coefficients is evacuation time. Time – which people have to save their lives.

This article describes a research on Evacuation movement speed on Mars and a sample evacuation time count.

Depending on the threat (decompression, fire and smoke) additional means should be provided: smoke exhaust, additional air supply, sealed safety rooms, emergency teams access routes and action plan.

For the purpose of the investigation a fragment of Twardowsky Mars Colony was used.

Twardowsky won 2nd prize in 2019 competition organized by Mars Society

Let’s go back for a short while to 1centurury BC. This was a time when main architecture principles were formulated by Marcus Vitruvius Polio, a civil and military engineer and an, architect. In treatise *De architectura,* he defined a key triad of design directions:
Function, Structure, Aesthetics.

A triad, which is now followed by any architect in the world.

For Space architects the same rule applies: while function is a reflection of people needs and activities – in other terms: mission goals and aesthetic, reflecting all humanities, helps the colonists to mentally survive - the structure symbolizes all technical issues to realize both previously mentioned.

In real life none of those three may be developed alone – because it will become ...a bad design.

Author’s long-term goal is to develop design standards for base/colony and city on Mars, with main accent laid on peoples’ safety. Safety of the people is a top technical priority in every building or device – in any place. All: architecture, structure, mechanical electrical and plumbing (so called MEP) systems and technological solutions should be concentrated on minimizing the risk of life loss. So, design of a base, or colony or even a city, on other planet or moon also should comply with this principle.

The aim of this article is to present current research results on evacuation analysis as a part of the main goal.

Such analysis must be conducted on all stages of design process, as details may influence the evacuation time.

This simple example shows egress of the people in emergency situation:

- an early stage base (for 6-12 people) does not require significat analysis

- while base for more than 50 people must be a subject to deep study of evacuation process

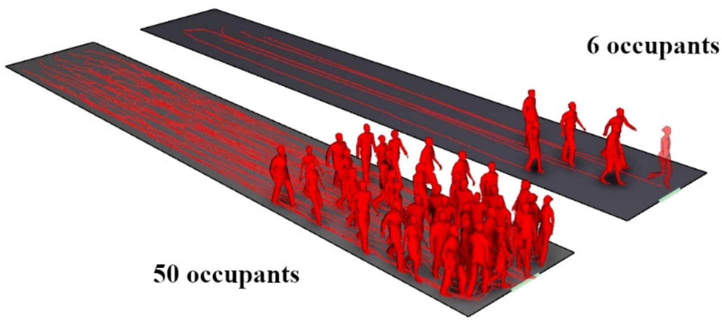

Fig.1.
Comparison of small and big amount of people evacuation

The research focused on a few directions:

- occupants’ movement speed in terms of reduced gravity
- layout of major building elements for evacuation: passages, corridors, staircases, airlocks, refugee rooms (so called safety zones)
- base population layout

PART 1 – SOFTWARE

To conduct evacuation simulation specialized software called Pathfinder was used (courtesy of Thunderhead Engineering: https://www.thunderheadeng.com/pathfinder/)

Pathfinder is an Agent based evacuation simulation software. Agent is a virtual representation of each occupant.

The result of such simulation is an animation showing fleeing agents. The key information for a designer is: the time in which all agents completely escape the scene or are located in refugee areas. This is called a successful evacuation.

Basing on the results – the time of successful evacuation –adjustments and corrections to building's elements must be made: number of staircases, width of the doors and corridors, or even airlocks capacity. After changes - the process must be rechecked, and through numerous simulation iterations - finally lead to safe design solution.

To conduct proper evacuation simulation, the software requires several types of data:

- Agent profiles - which are physical characteristics of occupants: incl. movement speed, locomotion properties on flat, sloppy surfaces and stairs/
- Geometry - a 3D scene, where all passages, staircases and doors are defined
- Scenario - Agents' layout in the scene (agents' starting points according to demography) and scenario for the simulation
- Behavior of each agent – behavioral scenario for agents: how do they move towards exits, wait for triggered action or even run in panic

PART 2 – AGENT PROFILES – MOVEMENT SPEED

Agent types are defined by Profiles.
Each Profile represents a group of Agents of identical features.
Profile types in the research were defined by gender and population age groups with particular movement data assigned. Part 4 of this article explains assumed population proportions in detail.

In each profile it is possible to randomize the agents' basic parameters (movement speed, locomotion properties on flat, sloppy surfaces and stairs). These are the key quantities that software requires for each Agent, in order to conduct the simulation.

While size of agent is identical to Earth - the movement speed, due to gravitational acceleration, changes significantly. Various scientific groups have conducted locomotion conditions research in terms of micro and reduced gravity. This study was based on results of research published in 2014 by Francesca Sylos-Labini, Francesco Lacquaniti and Yuri Ivanenko [1].

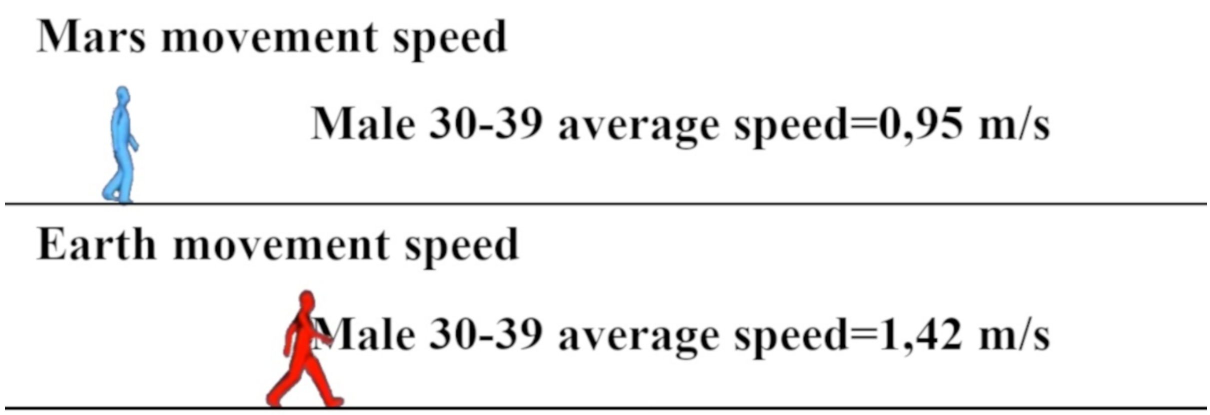

Fig.2.
Mars and Earth movement speed comparison

Transition methodology and software (Pathfinder) input data calculation.

To conduct proper simulation and calculate time for Mars base it is required to transform Earth velocities (obtained from statistical data for each gender and age group) into Martian ones. The transition is conducted via the formula:

$$V_{Mars} = \sqrt[2]{\frac{{V_{Earth}}^2}{G_{Mars}:G_{Earth}}} \qquad (1)$$

V_{Mars} – human speed on Mars
V_{Earth} – human speed on Earth
G_{Mars} - standard acceleration of free fall on Mars
G_{Earth} - standard acceleration of free fall on Earth

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for animation
of speed comparison

Additional data required by the Software (Pathfinder) are minimum, and maximum movement speed.

As each human being travels with slightly different speed - for more diverse representation - a randomization formula within Min and Max speeds is introduced basing on normal distribution of probability:

$$f(x) = \mu + \sigma x \qquad (2)$$

f(x) – resulting particular Agent's speed
μ - mean deviation
σ standard deviation
x is a random number from a standard normal distribution.

Additionally, the set of parameters are calculated and introduced into the software.

- Minimum speed is obtained by subtracting an average deviation from average WALKING speed
  $V_{min}=W_{alk\ velocity}- \sigma_{v\text{-}walking}$
- Maximum speed is obtained per analogia, by adding average deviation to RUNNING speed
  $V_{max}= R_{un\ velocity}+ \sigma_{v\text{-}running}$
- Mean value (μ) – average walking speed is taken.
  $V\ \mu = W_{alk\ velocity}$
- Standard Deviation (σ) - average of differences between age groups

Final conversion table is produced

Profiles		Vearth - WALK	Vearth - RUN	Vmars - WALK	Vmars-RUN	Data for Agent profiles - Pathfinder for Normal probability distribution				Comments
		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	1,4050	2,6941	0,8654	1,6595	0,8377	0,8932	1,6872	0,0277	%5 deviation used instead age range difference
Female*\	10 to 20	1,4150	2,6141	0,8716	1,6102	0,7484	0,9947	1,7333	0,1231	
Female	20 to 29	1,3400	2,2893	0,8254	1,4101	0,7940	0,8568	1,4415	0,0314	
Female	30 to 39	1,3400	2,1873	0,8254	1,3473	0,7036	0,8665	1,4691	0,1218	
Female	40 to 49	1,3900	2,5328	0,8562	1,5601	0,6439	0,8973	1,7724	0,2123	
Female	50 to 59	1,3100	1,9234	0,8069	1,1847	0,7274	0,8480	1,2643	0,0796	
Female	60 to 69	1,2400	1,7350	0,7638	1,0687	0,7145	0,8049	1,1180	0,0493	
Female	70 to 79	1,1300	1,6850	0,6960	1,0379	0,6285	0,7371	1,1054	0,0675	
Female*	80 to 89	0,9400	1,6557	0,5790	1,0199	0,5501	0,6201	1,0488	0,0290	%5 deviation used instead age range difference
Male	5 to 10	1,4500	3,1374	0,8931	1,9325	0,8276	0,9342	1,9981	0,0655	%5 deviation used instead age range difference
Male	10 to 20	1,4600	3,3402	0,8993	2,0574	0,6856	0,9404	2,2712	0,2137	
Male	20 to 29	1,3600	2,7462	0,8377	1,6915	0,7568	0,8788	1,7724	0,0809	
Male	30 to 39	1,4300	2,5536	0,8808	1,5729	0,8744	0,9219	1,5793	0,0064	
Male	40 to 49	1,4300	2,5328	0,8808	1,5601	0,8122	0,9219	1,6287	0,0686	
Male	50 to 59	1,4300	2,3099	0,8808	1,4228	0,7553	0,9219	1,5484	0,1256	
Male	60 to 69	1,3400	1,9922	0,8254	1,2271	0,7893	0,8665	1,2632	0,0361	
Male	70 to 79	1,2600	1,9550	0,7761	1,2042	0,6804	0,8172	1,2999	0,0957	
Male*	80 to 89	0,9700	1,9343	0,5975	1,1915	0,5676	0,6386	1,2213	0,0299	%5 deviation used instead age range difference
Both	Impaired Mobilty	0,3400	0,5400	0,2094	0,3326	0,1990	0,2505	0,3431	0,0105	%5 deviation used instead age range difference

Fig.3.
Movement speed data table

Notices:

- Gravity has a great influence on human speed movement. But it is not linear dependency between speed and gravity.
  The lower gravity the slower human being is walking
  The lower the gravity the smoother transition between walk and run occurs (and in the lower speed range).
- Due to walk/run transition speed and energy conservation during movement - it is unlikely that lopping, bouncing will be occurring on Mars (opposite to Moon – where kangaroo hopping is more probable way of the most energy efficient movement). [2]
- Bouncing in low gravity if happened, in crowd situation, may be dangerous to other people.
  So, it is possible, but on open areas, with density less than 1pers/2m2.
- No reduced gravity crowd movement simulation was ever conducted in reality (or no paper is available to public) – only single human being was examined.
- Profiles F/M 5-10 and 11-19y.o: data on children movement are taken from multiple sources – numbers are calculated as an average (rounded down) for each age-profiled group. For youngsters - the data taken was lacking gender division – to obtain this differentiation – average difference was taken from other sources and implemented on data. This of course does not reflect perfectly the movement speeds, but due to small quantity of agents with those profiles (F/M 5-10 and 11-19y.o.) – possible measurement error (up to 0,2 m/s) is negligible.

PART 3– GEOMETRY, 3D SCENE

General description

One of the key issues for software to conduct simulation is a 3D geometry.

Twardowsky Colony base [3] was chosen as it contains closed and open spaces, zones with high and low activity for tenants - all in one. Due its diversity in organization it is a good start to study multiple cases of emergency egress.

Twardowsky Base consists of 6 main living spaces: Biomes and technical/production areas. Total number of people (incl. Biome - Hotel) is 1200. For the purpose of this exercise - one whole Biome area was chosen due to its elaborated interior structure.

To provide adequate simulation conditions some additional elements were introduced:

Main alteration to the original design:

- Greenhouse access - provided via open staircases - leading to common space.
- Common space design is not repeating the views – the goal was to create some open space but with complicated shape, yet still capable to incorporate significant number of occupants. The original Design gives more natural design and soft impression.
- 3 airlocks were introduced at main access corridors. Airlock capacity was assumed: 1person per 0,28m2 (dense waiting area ratio). Each cycle takes around 50-60 seconds for technical reasons. Peoples movement is simulated by the Pathfinder.
- Diagonal lifts along main staircases were shifted and excluded from overall evacuation. It is assumed that their work during the evacuation is analogical to work of the lifts on Earth during such situations: lifts are travelling to main disembark floor and stay there, awaiting emergency team.
- Door width on main evacuation routes was assumed as 140 cm. Airlocks-160cm
- Refugee areas (Safety rooms) layout is introduced.
  The safety room capacity is calculated taking 1,9m2 per person (as per FEMA recommendation for shelters: 20 sq.f/person) including all amendments: place to sit or densely lay on the floor, common toilet (unisex with dimensions for impaired mobility persons), small storage space (food, water, fire extinguishing means). No MEP systems rooms are included.
  The total area is calculated taking 10% reserve of maximum evacuees directed to safety rooms.

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for animation of Twardowsky Base alterations

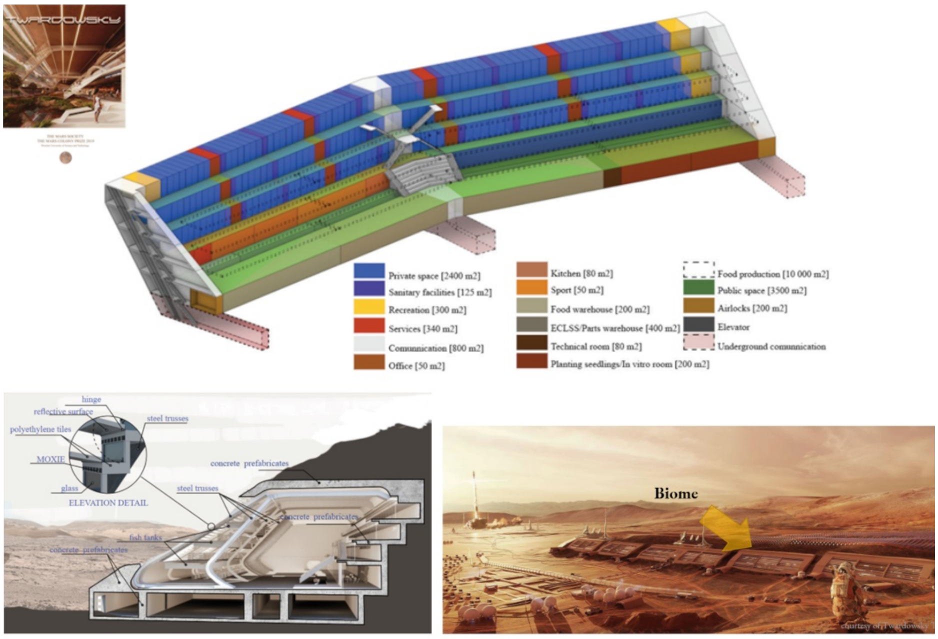


Fig.4.
Twardowsky Colony Base - original design

Pathfinder

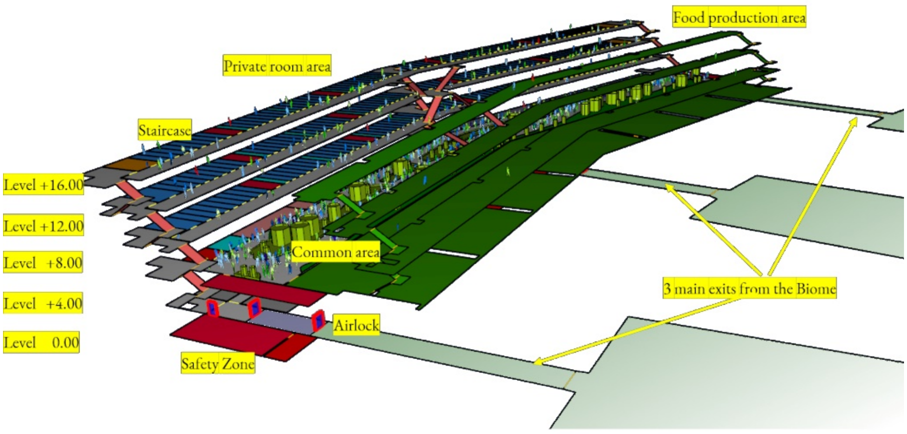


Fig.5.
Twardowsky Colony Base. Simulation model

<u>Refugee areas (Safety rooms)</u>

Safety room layout assumptions:

- Best if they are located all over the base – on every main functional floor or area.
- Emergency team easy access should be provided
- Escape distance should be no longer than 30m (as per analogia to Earth's 50m) from the staircase and 60m between safety rooms/ staircases or safety corridor exits, airlocks
- Violation of such may lead to crowd cumulation and longer overall escape time
    - Safety room features
    - should provide hermetic environment (permanent closure within defined time (for smoke prevention) or pressure drop (no lower than 750hPa).

- should provide radiation protection to Emergency exposure – limits given for occupational and public exposure as per USA Dept of Energy dose chart (20 mSv/year)
- doors must be capable of opening until permanent closure is ordered (pressure difference no more than 150Pa).
- doors must provide both: mechanical and hand opening and closure. It is possible to use slide doors under condition that sealed closure is provided.
- doors must be equipped with emergency hatch to provide further controlled evacuation via sleeves (60x60cm or more)
- in case of a distant location (more than 10 m) from open space areas that may provide work of emergency teams and vehicles - airlock must be provided (depth no less than 1,5m) - this case is to be provided on levels where no vehicle can be transported to
- all MEP systems must be independent and provide sealed cut-off from main systems in time no longer than permanent closure event.
- no transit of any auxiliary system is allowed via the room
- be well visible (lit signage) with easy access by any group of people (incl. impaired mobility ones). No threshold is allowed.
- 1 separated toilet 1,7x2m with independent collection system (which may be further on connected to sewage system via sealed flaps).

PART 4 – SCENARIOS

Scenarios are chosen to reflect non-standard situations, where long reaction time or mass gathering may slow down the evacuation process. Scenario also reflects a starting layout of all occupants.

Each scenario is tested on assumed evacuation time – for this research 420 seconds limit for successful evacuation is assumed.

To define a scenario a few steps are needed:

- Definition of the population in the colony –to reflect variety of the colony occupants
- Occupants layout in the scene - this is a definition of particular starting location in the scene of each occupant
- Behavior of each occupant defined – designates main goals of each occupant, like: escaping to airlocks, safety zones

PART 5 – SCENARIOS: POPULATION

Demography play a key role in Agents' profiles distribution. To obtain diversity in Agent profiles some population divisions were assumed.

This differentiation serves only the purpose of maximum mix of types of people to provide more reliable overall evacuation timing.

Main assumptions:

- 50/50 female/male proportion is taken
- Around 45% is in a mid-age group - to provide most efficient workforce
- Taking into consideration that colony is up and running for several years we can assume diversification of age groups

- Kids and youngsters as well as aged people are to be consider as a minor percent of the population due to specifics of the early stage of base growth. Kids and youngsters are assumed to be 1,5% of total population, while 70+ age groups are around 7%.
- Impaired mobility group may consist of older people, people with partial blindness or movement problems (caused by medical impairing or accidents). It is assumed that 0,5% of total population (randomly chosen out of age groups: 20to60 y.o.)
- As habitable module is not changing its capacity –a total, permanent residents' number is assumed to be 200 people.

No doubt, the start of the colony – means presence of very fit people. They will be trained and capable of efficient movement during emergency situations.

Although, it is better to introduce some less athletic groups, to provide margins for inaccuracy of total simulated evacuation time - and further to base architectural, structural and engineering solutions on such conclusions.
Taking into consideration guidelines from safety measures - modules would neither have to be redecorated nor adopted to all types of population profiles.
Additionally, safety measures - during colony development – must be updated on, at least, 5-6-year basis (considering space travel windows).

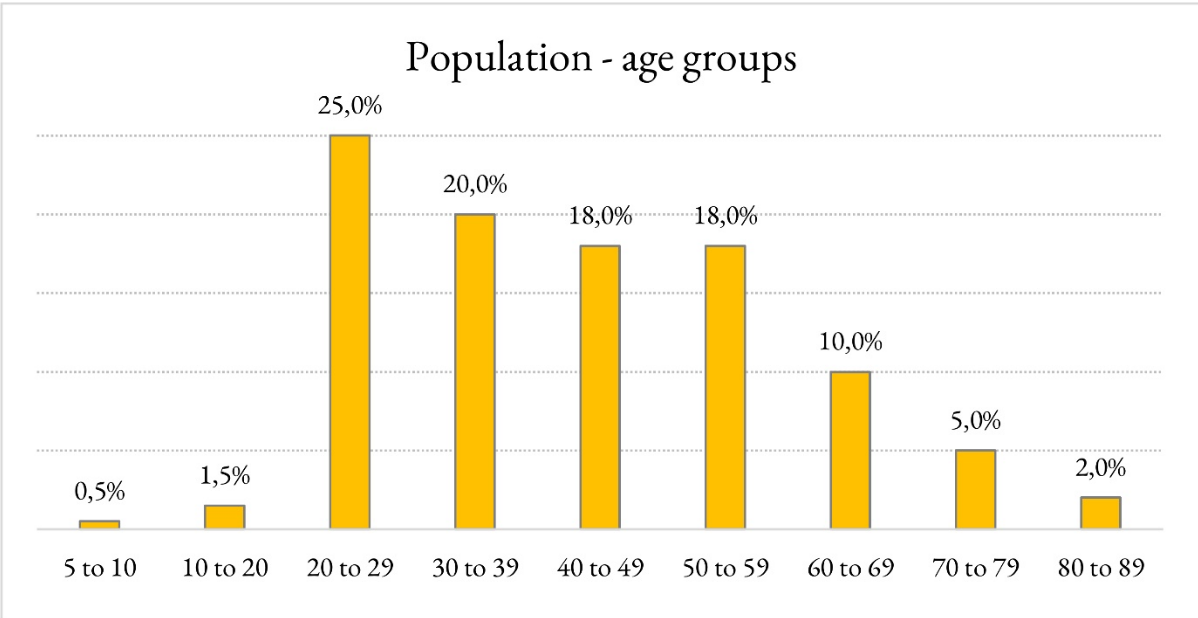


Fig.6.
Assumed percentage population age ranges

Twardowsky Colony base population count – Hotel shown separately
5 x Residential module + Hotel module = Total colony population
200 x 5 + 200 = 1200

Twardowsky Colony population in numbers

Permament habitants in residential module (Biome)		**Per module (Biome)**	**Total**
Percentage of population	Age group (both genders)	qty	qty
0,5%	5 to 10	1	5
1,5%	10 to 20	3	15
25,0%	20 to 29	50	250
20,0%	30 to 39	40	200
18,0%	40 to 49	36	180
18,0%	50 to 59	36	180
10,0%	60 to 69	20	100
5,0%	70 to 79	10	50
2,0%	80 to 89	4	20
100,00%	**Total**	**200**	**1000**
0,50%	Impaired mobility	1	5

Guest habitants (hotel maximum)		**Total (per hotel module)**
Percentage of population	Age group (both genders)	qty
0,0%	5 to 10	
0,0%	10 to 20	
5,0%	20 to 29	10
25,0%	30 to 39	50
25,0%	40 to 49	50
30,0%	50 to 59	60
15,0%	60 to 69	30
0,0%	70 to 79	
0,0%	80 to 89	
100,00%	**Total**	**200**
0,50%	Impaired mobility	1

Fig.7.
Table:Assumed population - peoples' numbers

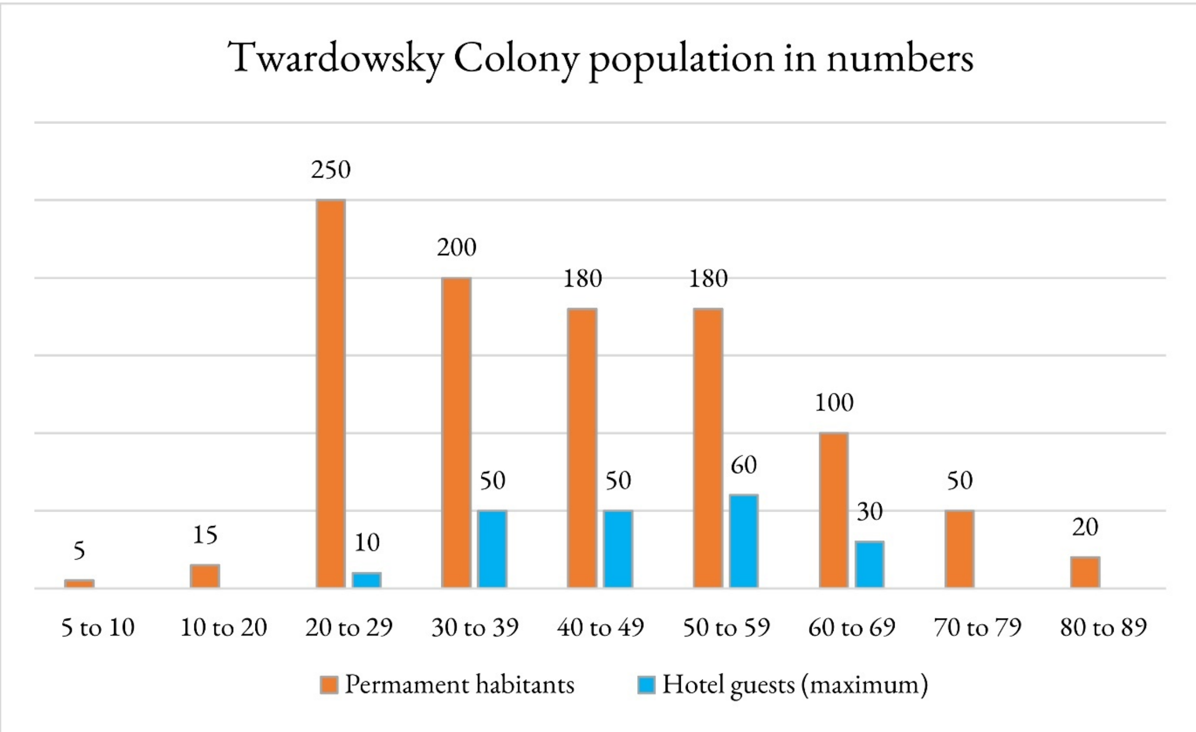
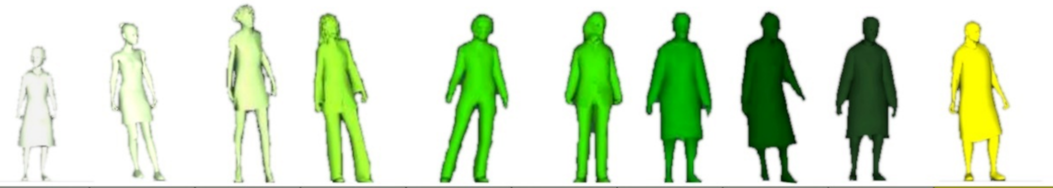


Fig.8.
Chart:Assumed population - peoples' numbers

Taking together data from tables (Fig.3., Fig.6. and Fig.7) a population summary table can be provided:



Agent group	Female: 5 to 10	Female: 10 to 20	Female: 20 to 29	Female: 30 to 39	Female: 40 to 49	Female: 50 to 59	Female: 60 to 69	Female: 70 to 79	Female: 80 to 89	Both: Impaired Mobilty
Percentage of population	0,25%	0,75%	12,50%	10,00%	9,00%	9,00%	5,00%	2,50%	1,00%	0,50%
Vmars Walk [m/s]	0,87	0,87	0,83	0,83	0,86	0,81	0,76	0,70	0,58	0,21
Vmars Run [m/s]	1,66	1,61	1,41	1,35	1,56	1,18	1,07	1,04	1,02	0,33

Agent group	Male: 5 to 10	Male: 10 to 20	Male: 20 to 29	Male: 30 to 39	Male: 40 to 49	Male: 50 to 59	Male: 60 to 69	Male: 70 to 79	Male: 80 to 89	Earth reference Agent (male 30y.o)
Percentage of population	0,25%	0,75%	12,50%	10,00%	9,00%	9,00%	5,00%	2,50%	1,00%	-
Vmars Walk [m/s]	0,89	0,90	0,84	0,88	0,88	0,88	0,83	0,78	0,60	1,43
Vmars Run [m/s]	1,93	2,06	1,69	1,57	1,56	1,42	1,23	1,20	1,19	2,55

Fig.9.
Profiles summary

PART 6 – SCENARIOS: OCCUPANTS' LAYOUT

This part of the article covers a subject of the layout of occupants according to functional layout of the base, chosen scenario according to population density, diversification of profiles. This is a starting set up for conducting the simulation.

<u>Scenarios</u>

Scenarios are chosen to reflect non-standard situations, where long reaction time or mass gathering may slow down the evacuation process. Therefore, two scenarios were chosen: Late evening, Weekend day

<u>Scenarios main goals:</u>

- Each scenario is tested on assumed evacuation time.
  For the purpose of the simulation - it is assumed that evacuation time should be no longer than
  420 seconds, (countries require different evacuation times from 7 to 10 minutes –so 7 minutes (420 s) was taken as a basis)
- Evacuation is assumed to be **successful**, when, in given time limit, **all agents are placed in secured areas**: airlocks and corridors leading to other parts of the base and hermetic safety zones.
- Each Agent which is not evacuated in time limit indicates the necessity of change of the design. So, via scene alterations (more safety zones, wider doors, corridors, staircase runs, enlarged airlocks' capacity) and numerous iterations of the simulation of each scenario, successful evacuation time must be reached.

- In this article - it is not yet tested the time limit. It is only an assumption based on global standards. Time limit must be investigated further as it depends on possible emergency situations like fire, decompression, ground quake.

<u>Late evening/early night - description</u>

- all private rooms are occupied (people are sleeping – reaction time for public announcement is longer),
- some of the tenants are conducting sports activities or having a late supper.
- Number of occupants: 200 tenants + 20 guests = 220 (plus some Earth speed reference agents)

<u>Weekend day with local event for the Colony – description</u>

- 10% of the Colony is at work during the day off (incl. 10% out of 200 permanent tenants of analyzed residential module)
- 25% of private rooms are occupied,
- 65% of tenants take the gallery passages
- guests (3/4 of the rest of the Colony population) are filling the common space area within the most crowded zone in the middle.
- Number of occupants: 180 tenants + 675 guests = 855 (plus some Earth speed reference agents)

Summary tables: detailed occupants' layout for both scenarios – considering population profiles and scenarios.

Late evening scenario - population layout

Level	Female: 5-10	Female: 10-20	Female: 20-29	Female: 30-39	Female: 40-49	Female: 50-59	Female: 60-69	Female: 70-79	Female: 80-89	Male: 5-10	Male: 10-20	Male: 20-29	Male: 30-39	Male: 40-49	Male: 50-59	Male: 60-69	Male: 70-79	Male: 80-89	Both: Impaired Mobility	Total
0 – storages, airlocks												2								**2**
+4.00			5	4	4	4	2	1				3	4	4	4	2	1			**38**
+8.00			8	6	5	5	2	2				8	6	5	5	2	2	1		**57**
+12.00		1	7	6	5	5	3	1	1		1	7	5	5	4	3	1	1	1	**57**
+16.00			8	5	5	5	2	2	1	1	1	8	6	5	5	2	2			**58**
Greenhouse			1	1	1	1						1	1	1	1					**8**
Total agents	**0**	**1**	**29**	**22**	**20**	**20**	**9**	**6**	**2**	**1**	**2**	**29**	**22**	**20**	**19**	**9**	**6**	**2**	**1**	**220**

Weekend day-event scenario - population layout

Level	Female: 5-10	Female: 10-20	Female: 20-29	Female: 30-39	Female: 40-49	Female: 50-59	Female: 60-69	Female: 70-79	Female: 80-89	Male: 5-10	Male: 10-20	Male: 20-29	Male: 30-39	Male: 40-49	Male: 50-59	Male: 60-69	Male: 70-79	Male: 80-89	Both: Impaired Mobility	Total
0 – storages, airlocks			1									1								**2**
+4.00	1	3	85	67	60	60	33	17	6	1	2	85	67	61	60	33	17	6	1	**665**
+8.00		1	6	7	5	5	3	1	1		1	7	7	5	6	3	1	1		**60**
+12.00	1		7	7	5	5	3	1	1		1	6	7	5	5	3	1	1	1	**60**
+16.00		1	7	6	6	5	3	1	1	1	1	7	6	5	5	3	1	1		**60**
Greenhouse			1	1	1	1						1	1	1	1					**8**
Total agents	**2**	**5**	**107**	**88**	**77**	**76**	**42**	**20**	**9**	**2**	**5**	**107**	**88**	**77**	**77**	**42**	**20**	**9**	**2**	**855**

Fig.10.
Detailed Occupants' layout for both scenarios – considering population profiles and scenarios

PART 7 – SCENARIOS: BEHAVIOR

Behavior of each occupant is to be defined. The main goal of each agent: is the successful evacuation. They will try to reach any exit or safety zone.

But there are parameters and assumptions that need to be defined to provide proper scenario realization:

- People on Mars are not subject to genetic and cybernetic changes therefore a normal motorics and energy conservation typical for Martian movement is assumed. With the same reason: bouncing movement is excluded from simulation as well.
- Panic behavior is excluded due to training
- Each agent heads towards any possible exit from the premise (no emergency service is provided during the simulation)
- Relaxing/sleeping people react in 60-90 seconds after public announcement
- These who are awake or can understand better the situation (they are in common space after all) – react quicker within 10 to 25 seconds
- These, who will not meet 300 seconds time of successful evacuation, will flee into closest safety room. (note that total time for evacuation is 420 seconds)

Via numerous simulation approaches, it is already understood that: knowing the timing for work of airlocks and possible crowd forming in exit areas –these evacuees with egress time above **300 seconds must run into safety zones to meet the overall time goal.**

PART 8 – SIMULATION

<u>Summary</u>

To conduct evacuation simulation, it is required to combine several initial data:

- Agent's profiles
  - Agent profiles significantly depend on movement velocity.
  - Profiles are divided by age groups - representing diverse population – which for software means different speed ranges
- Scenarios, which are chosen to reflect non-standard situations and must be constructed based on:
  - population in the colony
  - Occupants layout in the scene
  - Behavior of each occupant
- 3D Scene

<u>The simulation</u>

Late evening scenario

QR Code
Scan, Click or Tap for animation

Weekend event scenario

QR Code
Scan, Click or Tap for animation

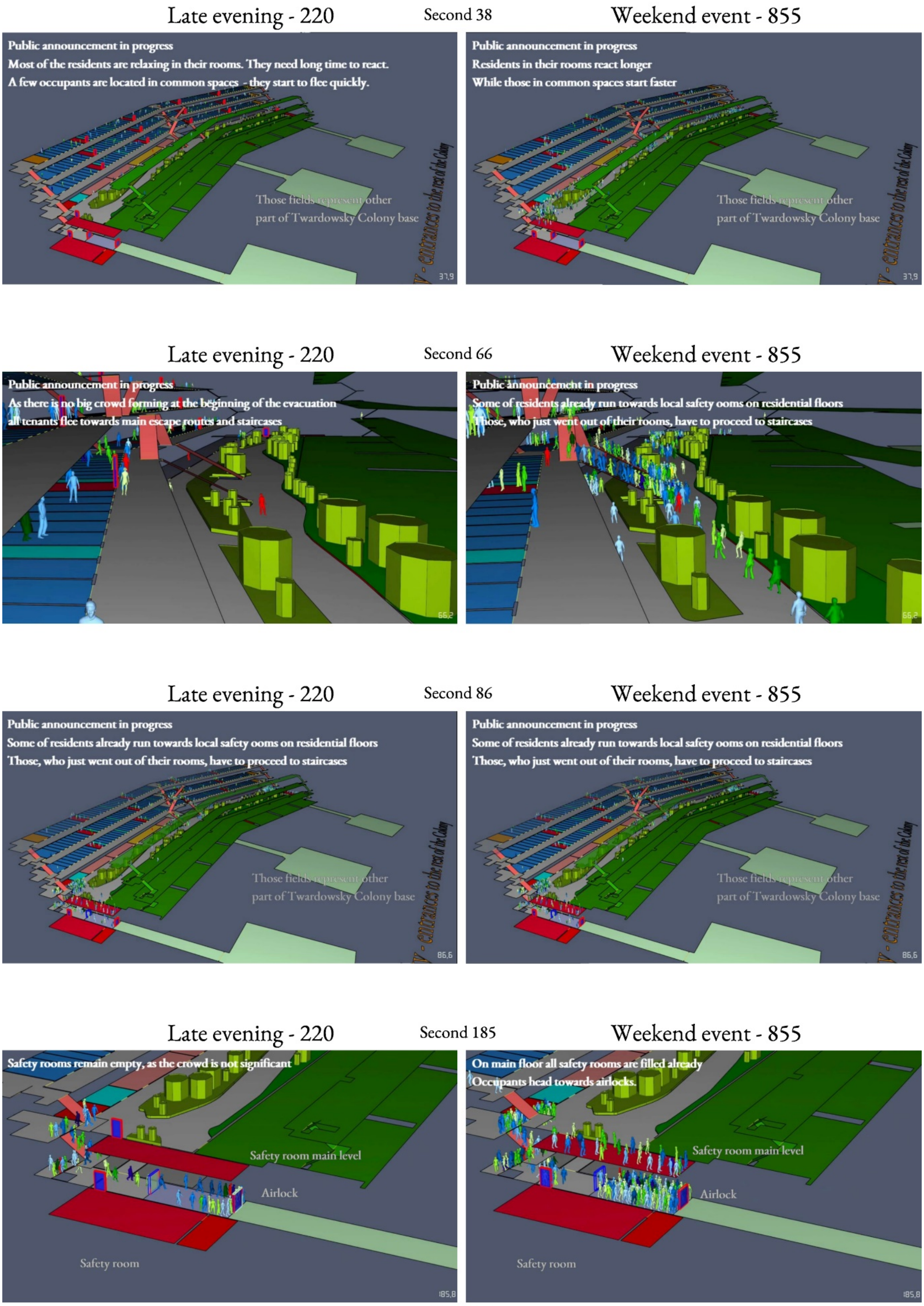


Fig.11A.
Animation - Simulation result

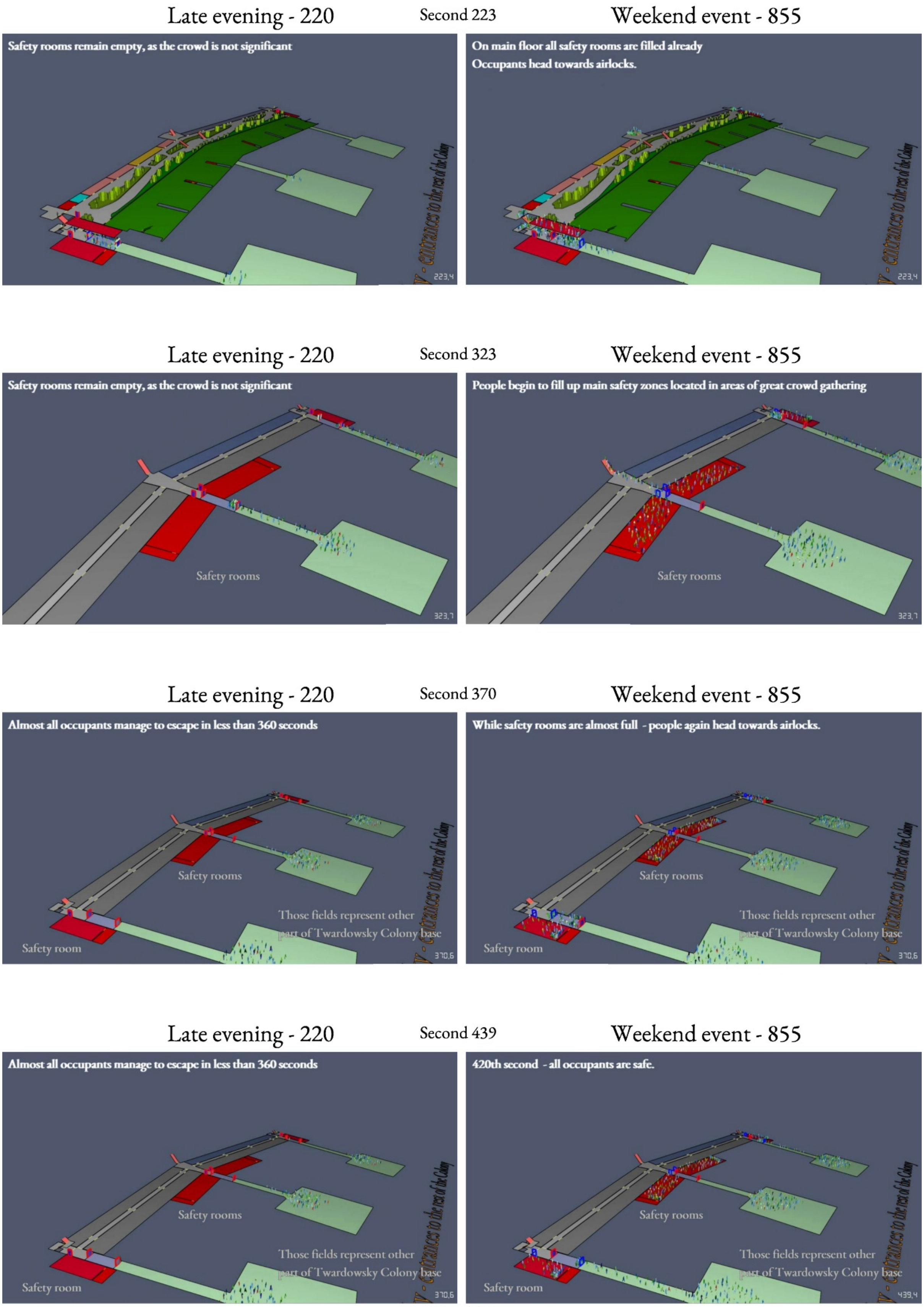


Fig.11B

Animation - Simulation result

Notices and conclusions

Late evening scenario conclusions– total evacuation time is around 360 seconds:

- Even a long delay of evacuation start (reaction to public announcement), does not cause significant obstruction.
- Number of evacuees was small enough, so there were no significant crowd jams causing people to enlengthen their evacuation time.
- Around 358 second of the simulation – an Airlock door closes after last of the evacuee and evacuation may be considered successful
- Total evacuation time is less than 6 minutes, even considering Martian conditions of slower-than-Earth-movement speeds.
- None of the Agents was forced to proceed to safety zone.
- Door widths and staircase runs widths (1,4m) are sufficient for everyday activities and evacuation purposes for 110% of constant tenants count of each Biome.
- This scenario simulations results show **no necessity** of any additional SAFETY ZONES.

Weekend day-event scenario conclusions - total evacuation time is around 419 seconds:

- Airlocks were not upgraded or altered – they are the same as in Late Evening scenario.
- More than a half of evacuees are required to go to safety rooms.
- Around 250 second of the simulation- first wave of evacuees went out through airlocks.
  Next occupants are waiting for airlock re-pressurization - crowd jams are created near the entrances.
  Therefore, safety zones are opened to receive people.
- It is assumed that due to training - some occupants head towards smaller SAFETY ZONES, which fill up in less than a minute, while 2 bigger ones (at the most crowded space) - require around 110 seconds.
- At 400th second of the simulation - almost everybody is safe.
  There is only one impaired mobility Agent who finalizes the evacuation in 419th second entering safety zone.
  If there will be help in quicker movement for Impaired mobility people - it is possible to reduce total evacuation time. Training for every single occupant is necessary.

Global notices and conclusions:

- Airlock system causes significant delays in evacuation due to crowd congestions, but it is necessary to cutoff the rest of the base.
- In front of airlock there should be a room of minimum person capacity of double of the airlock itself
- Staircases must be hermetically separated from other premises; enclosing construction elements must be minimum REI120. Doors - minimum 60 EIS
- For sake of saving the rest of the base, major functional blocks must be constructed separately from one another
- It is assumed that safe conditions, including work of smoke exhaust and air-supply systems, must support the minimum life conditions by 7 minutes – 420 seconds. Although it does not mean that MEP systems may stop working in this time: they should be working at minimum 1h at full capacity (smoke exhaust and pressure compensation)
- Airlocks: maximum open corridor distance is established: 30m from staircase exit
- It is required that each part of base is equipped with people counters. Best if they are located in every entrance to each functional floor.
    - System must constantly monitor and warn on any excessive number of people.
    - They should be designed to hold at least the population typically present in the area.
    - People above this number must not enter the module (Biome) or should be equipped with additional equipment for breathing and further, surviving the decompression
- In zones provided for more people than standard quantity - at least 50% occupant capacity must be provided.
- Before designing safety zones - proper evacuation calculation must be made to obtain locations of possible crowd jams – which slow down overall evacuation.
    - safety zones are required in any case - due to possible blockage of evacuation ways and unexpected circumstances.
    - They should be evenly distributed on all functional floors – providing minimum 15% of maximum occupant capacity
    - Additional safety zones must be provided near possible crowd jam areas - providing 35-40% of capacity.
- It is possible to provide such safety measures just for one module for public gathering, while other ones must be restricted on people number – airlocks are mandatory, but number and area of safety rooms can be calculated for each module residents + 10% of reserve
- With additional hermetic areas - design of Twardowsky base is providing safe evacuation in peoples count up to ~860 of each Biome assuming airlocks and safety rooms presence
- Safety zones should comply with standards listed Part 3 of this article.
- Those guidelines and numbers are provided exclusively for Twardowsky base. Other designs require additional detailed analyses on capacities required for each zone.

- Nonetheless it should be a design standard - to provide small safety zones distributed evenly all over living spaces.
- Providing proper safety measures (airlocks, safety zones) and evacuation routes in the beginning of the design, and making them highly modular, it is possible to obtain free space for FLEXIBLE functional layout, which may be changed during the lifetime of a building. This may reduce cost of redecoration and adaptation in the future.

QR CODES SUMMARY

Mars Society Convention 2020 Presentation	Agent movement speed calculation	Twardowsky base alterations	Late evening scenario animation	Weekend event scenario animation

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ACKNOWLEDGEMENTS

This research would not have been possible with a great support of:

- **Francesca Sylos-Labini**
- Twardowsky Team:
  Amanda Solaniuk, Anna Wójcik, Joanna Kuźma, Natalia Ćwilichowska, Katarzyna Lis, Sławek Malkowski, Dariusz Szczotkowski, Szymon Łój, Orest Savystskyi, Dominik Liśkiewicz, Wojciech Fikus, Jakub Nalewaj, Anna Jurga, Leszek Orzechowski, Bartosz Drozd, Paweł Górniak, Krzysztof Ratajczak, Paweł Piszko, Maciej Piorun, Gordon Wasilewski, Paweł Rudzki
- Thunderhead Engineering Team:
  Noah Hastings, Kyle Perkuhn
- Mars Society Poland

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