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1 Introduction

1.1 Introduction to RiMEA

The results of the analysis of software **crowd:it** by **accu:rate GmbH** are summarized below. Test cases were developed by the RiMEA project *Richtlinie für mikroskopische Entfluchtungsanalysen* [RiM14].

2 Test 1 – Maintain the specified walking speed in a corridor

2.1 Test description

An agent in a 2m wide and 40m long corridor with a defined walking speed will cover the distance in the correct time period [RiM14].

Parameter	Value
Corridor length [m]	40
Corridor width [m]	2
No. of agents	100
Speed [m/s]	0.46 - 1.61 [Wei92]

Table 1: Test specifications [RiM14]

2.2 Simulation model

The corridor and walking speeds were modelled according to the specifications (see Table 1). One agent was generated per simulation run, eliminating the side-effects of other agents.

2.3 Documentation

Figure 2 confirms that in each of the 100 simulation runs, an agent does not exceed its prescribed speed.

The test verifies that agents can and do travel at predefined walking speeds, when specified.

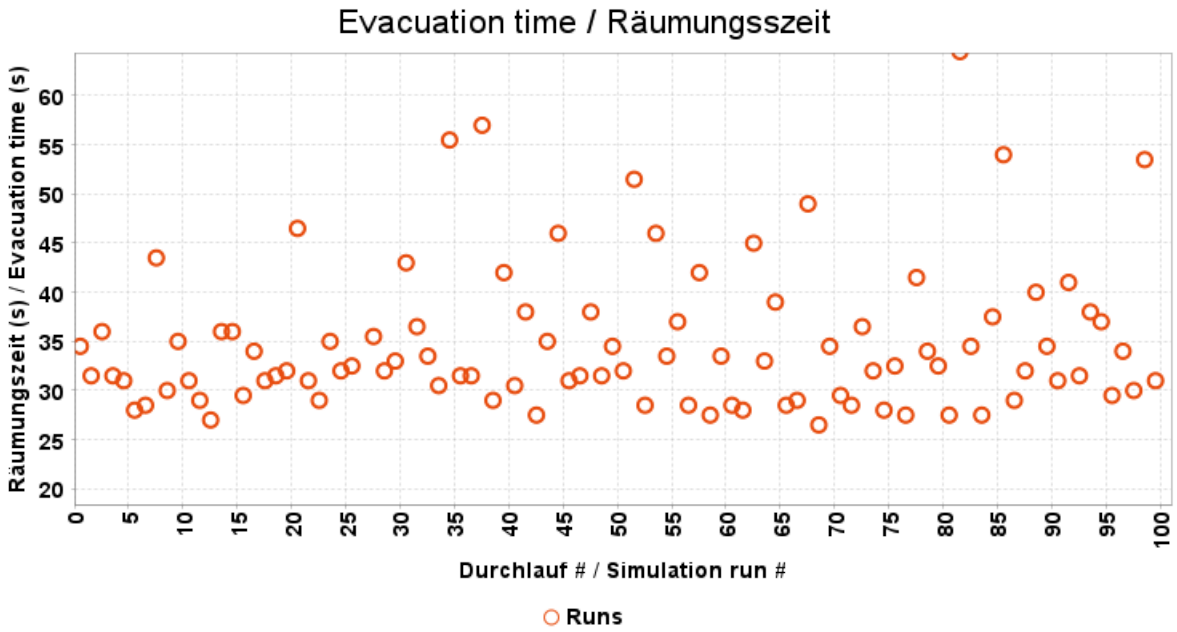


Figure 1: Agent travel time for each simulation run

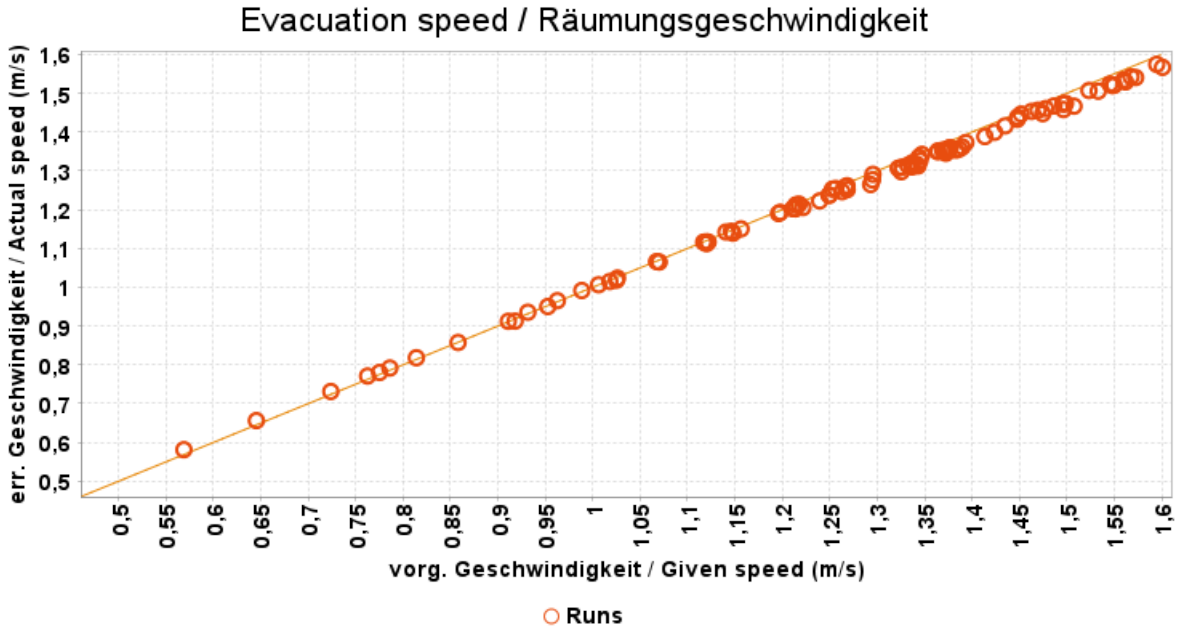


Figure 2: Comparison between prescribed travel time and actual travel time for each simulation run

3 Test 2 & 3 – Maintain the specified walking speed up and down stairs (Staircase Model)

3.1 Test description

An agent in a 2m wide and 10m long (measured along the slope) staircase with a defined walking speed will cover the distance in the correct time period [RiM14]. We amalgamate Tests 2 and 3 and consider Scaled Areas and the Staircase model separately. Here, first, the crowd:it staircase model.

Parameter	Value
Staircase length [m]	10
Staircase width [m]	2
No. of agents	100
Speed [km / h]	[Wei92]

Table 2: Test specifications [RiM14]

3.2 Simulation model

Staircases are modelled as in [GK15]. The scenario was modelled as prescribed in Table 2. Staircases were modelled with 26 treads of length: 260mm, 270mm, 280mm, 290mm and 300mm [DIN15].

3.3 Documentation

Figure 3 confirms that the staircase model decelerates agents by a degree that is dependent on the tread lengths of the respective staircase. Note: The staircase model decelerates agents non-uniformly. Those travelling faster are decelerated more [GK15].

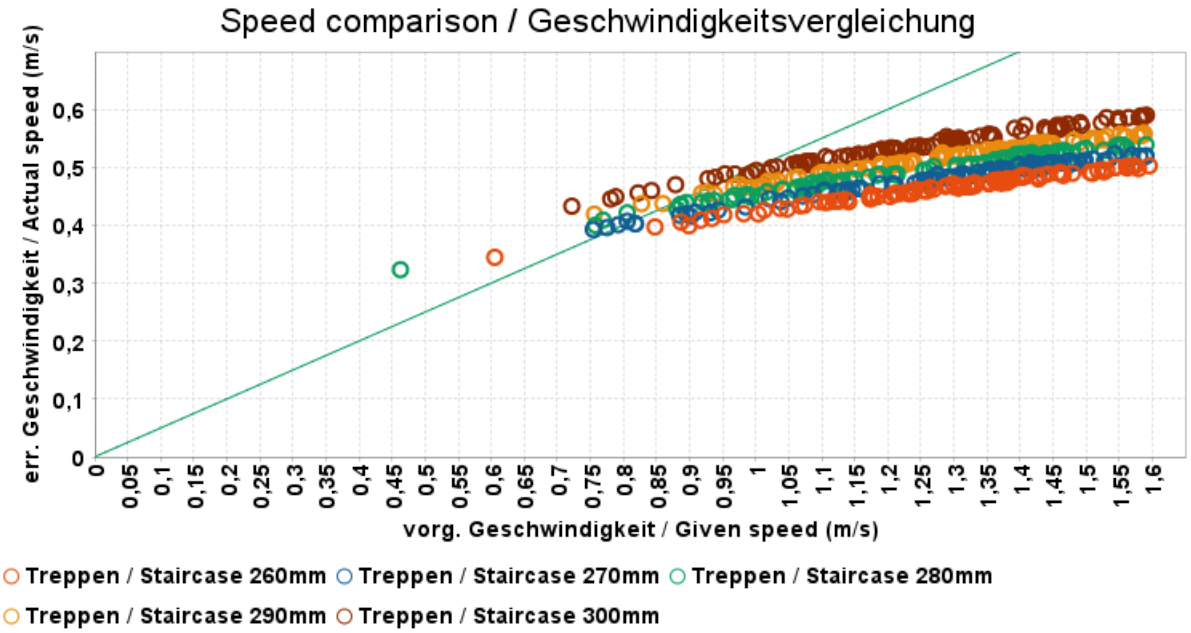


Figure 3: Agent speeds in comparison to their desired speeds for different stair types

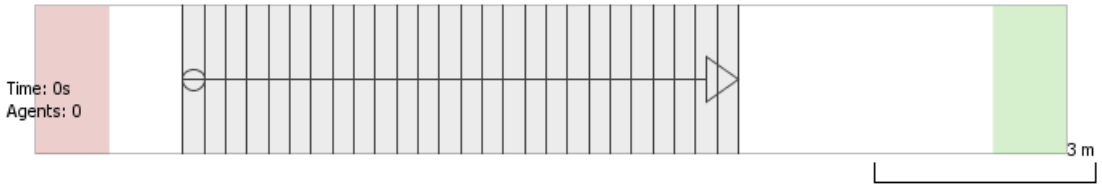


Figure 4: Screenshot of the simulation

4 Test 2 & 3 – Maintain the specified walking speed up and down stairs (Scaled Area)

4.1 Test description

An agent in a 2m wide and 10m long (measured along the slope) staircase with a defined walking speed will cover the distance in the correct time period. [RiM14]. Here, we consider Scaled Areas, which are areas in which agents are slowed by a predefined factor.

Parameter	Value
Staircase length [m]	10
Staircase width [m]	2
No. of agents	100
Speed [km / h]	[Wei92]

Table 3: Test specifications [RiM14]

4.2 Simulation model

Scaled Areas take the agent's desired walking speed as input, and reduce the agent's speed to a fraction of this input. Here we test factors: 0.5, 0.6 and 0.7. That is, the agent is slowed to $\frac{1}{2}$, $\frac{3}{5}$ and $\frac{7}{10}$ of its desired speed respectively.

4.3 Documentation

Figure 5 demonstrates the effectiveness of Scaled Areas on agent speed.

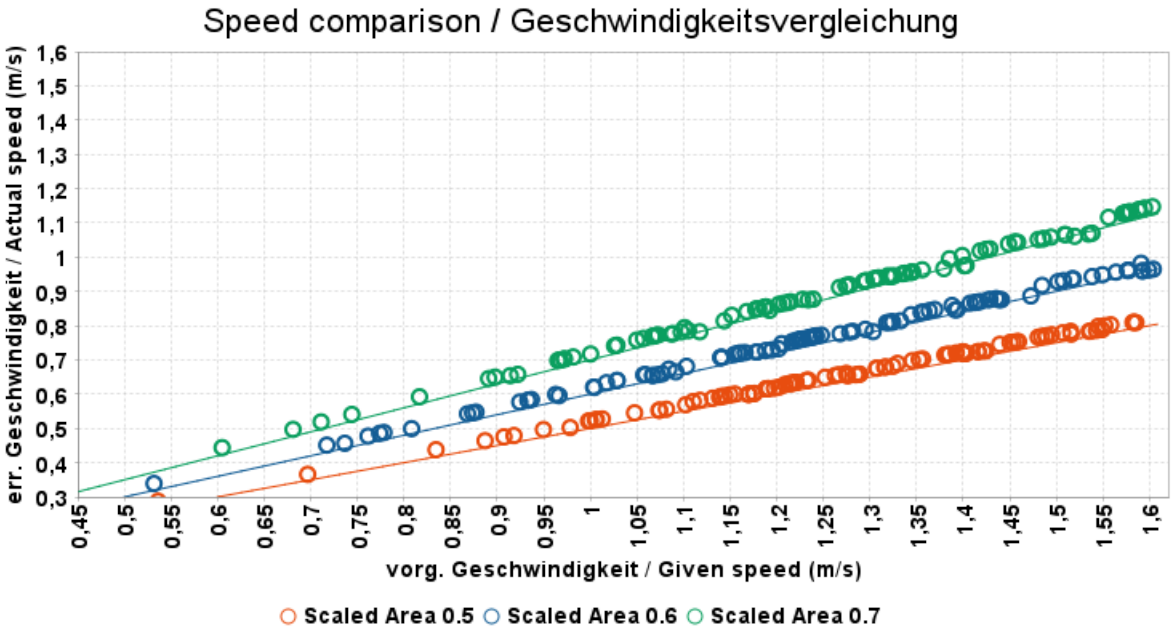


Figure 5: Agent speeds in comparison to their desired speeds for different Scaled Areas types

5 Test 4 – Measurement of the fundamental diagram

5.1 Test description

We test whether the effect of density on the speed of agents in the simulator matches that suggested by the fundamental diagrams. Given a corridor filled with varying numbers of agents, average speeds of the agents are measured within the prescribed areas and plotted against agent density to reproduce the fundamental diagrams.

Parameter	Value
Corridor length [m]	1000
Corridor width [m]	10
Measurement tile dimensions [m $\times$ m]	2×2
Time of measurement [s]	50
Agent density [Agent / m^2]	0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5

Table 4: Test specifications [RiM14]

5.2 Simulation model

The scenario was modelled according to the specifications (see Table 4). Several simulations were carried out with varying agent densities. The following measurements were carried out:

- Flux through the corridor (x-direction), measured via a tripwire in the middle of the corridor a 500 m
- Density inside a measurement tile of 10 x 10 m around the tripwire

Individual values are calculated as an averaging over all agents in each tile for each time-step.

5.3 Documentation

Density is calculated as follows: Agents are considered as soon as they cross the tile threshold and the proportion of their body crossing the threshold is what is included in the measurement.

For the average flux we count all passing pedestrians (from left to right) and average the count over 10 seconds. From that, the specific flow rate is determined (Pers / ms).

Thus, each data point shown in Figure 6 is an averaging of all values over the entire measurement period of 50 seconds (after a 10 second transient phase).

For comparison, the Weidmann curve [Wei92] is drawn over our data points:

$$v = 1.34 \cdot \rho \cdot (1 - e^{-1.913 \cdot (\frac{1}{\rho} - \frac{1}{5.4})}) \tag{1}$$

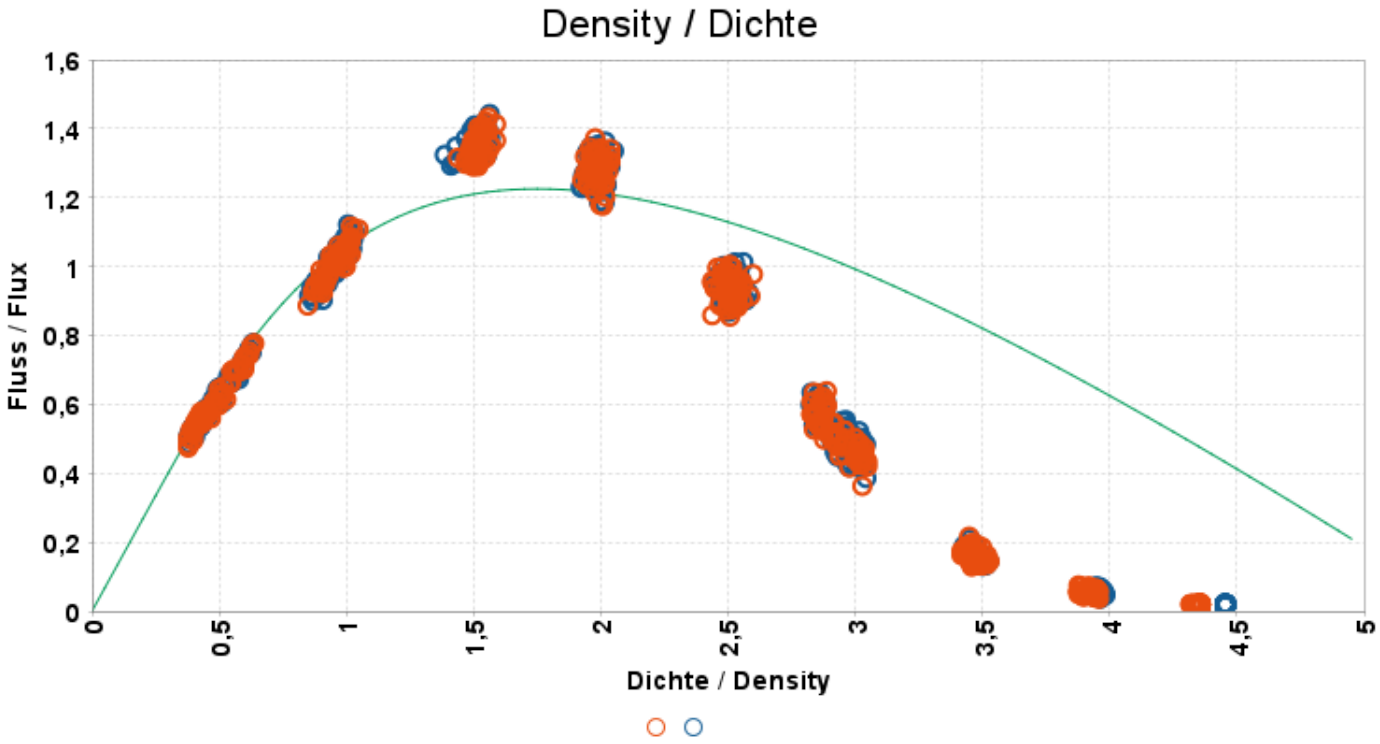


Figure 6: Fundamental diagram

Walking speeds decrease once density exceeds more than 2 persons per square meter. crowd:it can consider large densities and simulate the resulting agent deceleration correctly. The results of crowd:it follow the Weidmann curve. At high enough densities, the walking speeds of agents tend to zero.

6 Test 5 – Pre-movement times

6.1 Test description

Agents in an 8m wide and 10m long room (with a 1m wide exit) will start moving at the appropriate time, given a distribution of pre-movement times across all agents [RiM14].

Parameter	Value
No. of agents	100
No. of runs	10
Pre-movement time [s]	$U[1, 100]$
Room size [m $\times$ m]	8×5
Exit width [m]	1

Table 5: Test specifications [RiM14]

6.2 Simulation model

The room size and pre-movement times were modelled according to the specifications (see Table 5).

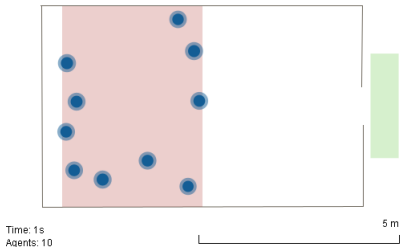


Figure 7: Screenshot of the scenario

6.3 Documentation

Figure 8 suggests uniformity in the agent pre-movement times, as prescribed by the model. To verify this is the case, a Kolmogorov-Smirnov test was carried out, which can be used to test whether a set of data fit a given distribution.

The p-value for a Kolmogorov-Smirnov test against the null hypothesis that the reaction times are evenly distributed is approximately 0.37. Therefore, crowd:it

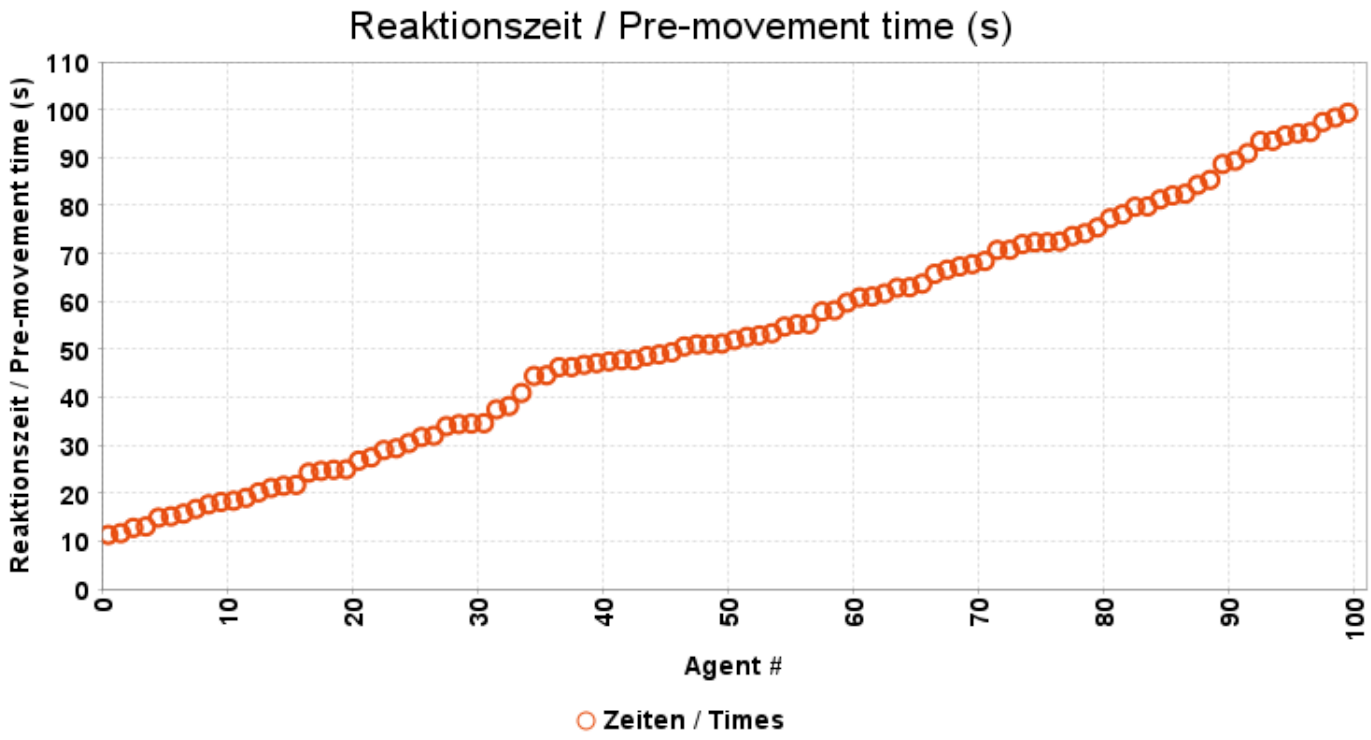


Figure 8: Pre-movement times

Parameter	Value
pValue	0.37

Table 6: Results

passes: it is possible to prescribe pre-movement times for agents, which are followed. (If the p-value were below 0.05, we would have a strong argument against the null hypothesis.)

7 Test 6 – Movement around a corner

7.1 Test description

Twenty agents moving towards a corner that turns to the left will successfully go around it without passing through walls [RiM14].

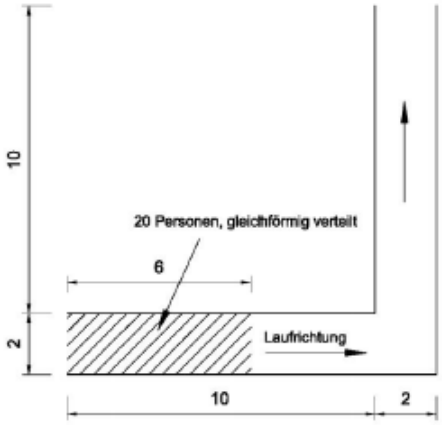


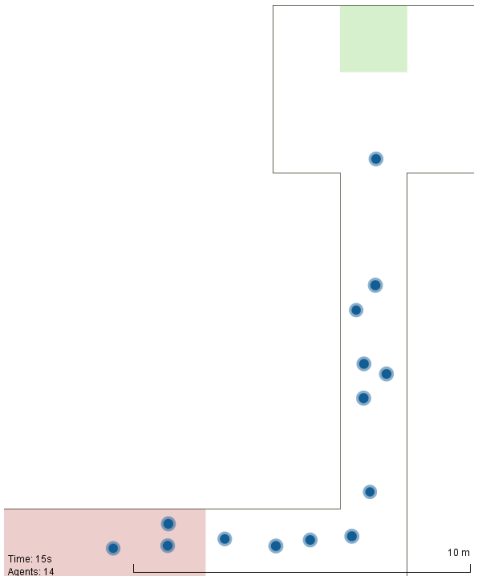
Figure 9: Construction of the scenario [m] [RiM14]

7.2 Simulation model

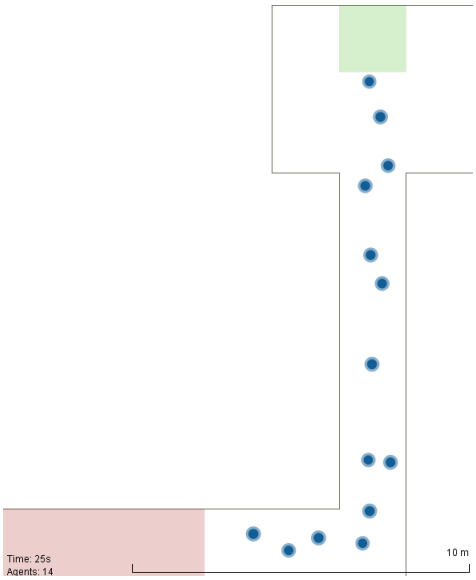
The corridor was modelled according to the specifications (see Figure 9). The origin for the agents is at the end of the corridor (green). Agents are generated over twenty seconds.

7.3 Documentation

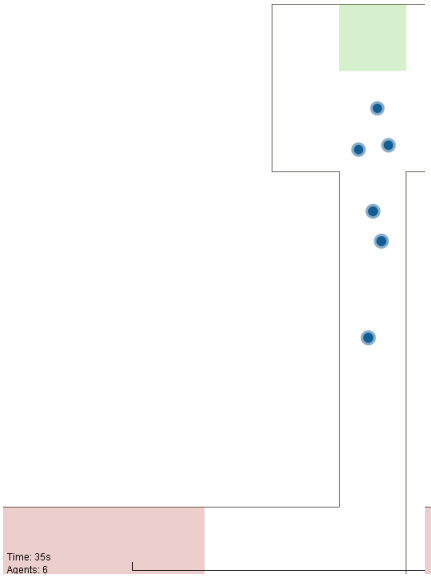
Figures 10a, 10b, 10c and 10d confirm that agents do not move through walls.



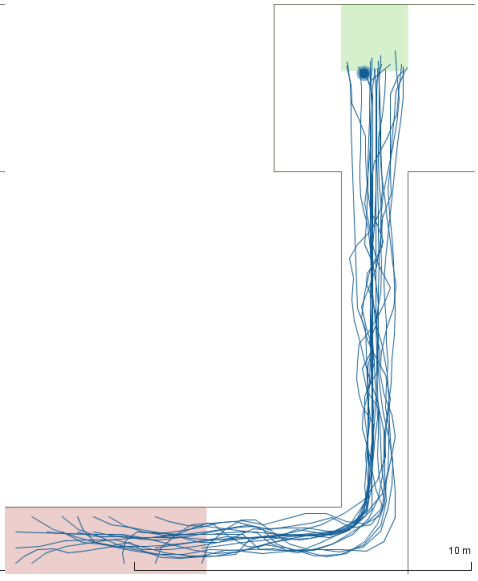
(a) Screenshot after 15 seconds



(b) Screenshot after 25 seconds



(c) Screenshot after 35 seconds



(d) Screenshot agents' trajectories

Figure 10: Screenshots of the simulation

8 Test 7 – Allocation of demographic parameters

8.1 Test description

The walking speeds of 50 agents were distributed according to Figure 11:

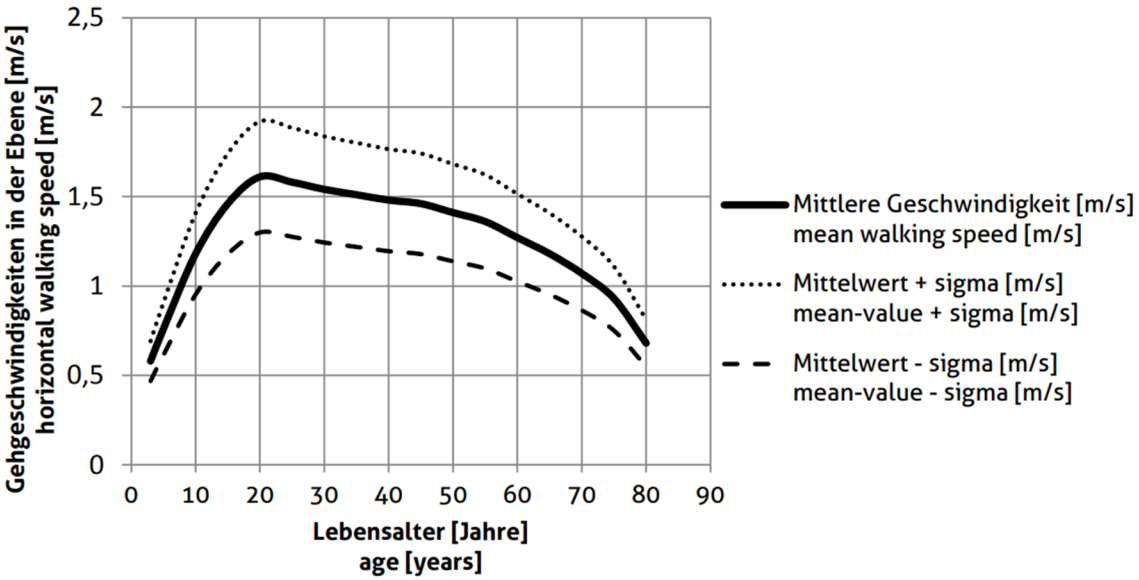


Figure 11: Horizontal walking speeds against agent age [Wei92]

Using these specifications, agents will walk with speeds compatible with Weidmann [Wei92].

8.2 Simulation model

The corridor (70m $\times$ 20m) and walking speeds were modelled according to the specifications (see Figure 12). Agents were generated over time, mitigating congestion. Agent speed distributions are described specifically in Table 7.

8.3 Documentation

Walking speeds are calculated by dividing the total distance travelled (over every time-step) by the total travel time.

Figure 13 demonstrates that crowd:it simulates agents correctly, according to the Weidmann documentation [Wei92].

Figure 12: Screenshot of the scenario

Age group	Number of agents	Min. [m/s]	Max. [m/s]
10-20	10	1.30	1.91
21-30	10	1.25	1.83
31-40	10	1.20	1.78
41-50	10	1.15	1.69
51-60	10	1.02	1.50
61-70	10	0.86	1.28

Table 7: Given Walking speed of each age group [RiM14]

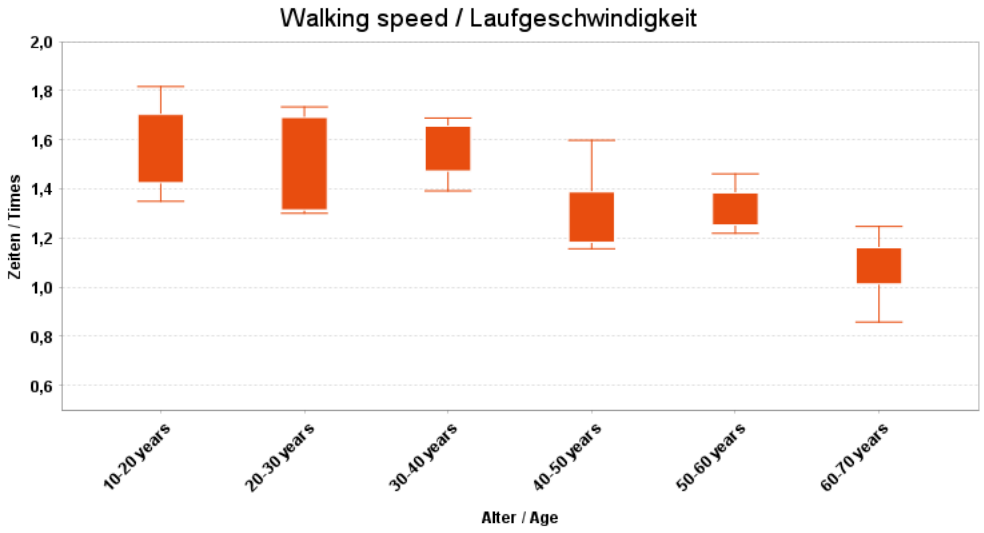


Figure 13: Walking speed of agents

9 Test 8 – Allocation of demographic parameters

9.1 Test description

A three-storey building will be evacuated and the corresponding time of evacuation analysed according to changes in agent parameters.

Changes in a parameter of interest will occur independently of all other parameters. Parameters can vary in two ways, either:

- a parameter is deterministically set.
- a parameter is non-deterministically set according to a predefined distribution.

9.2 Simulation model

The scenario is constructed as below [RiM14]: Note: The second floor distin-

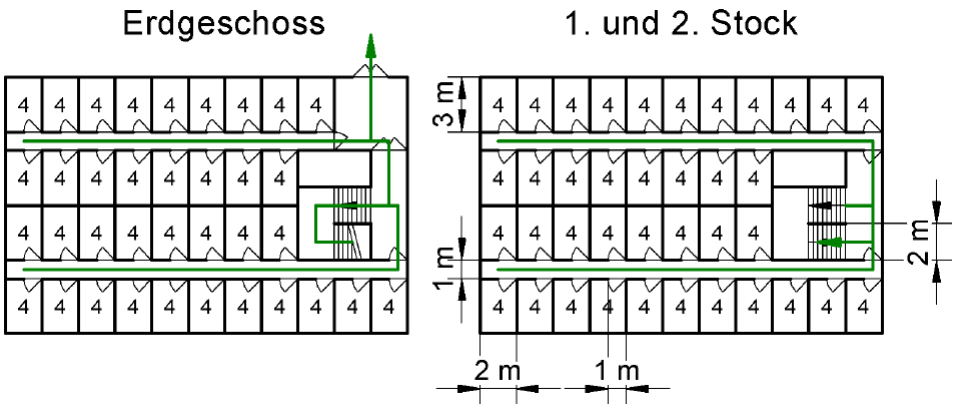


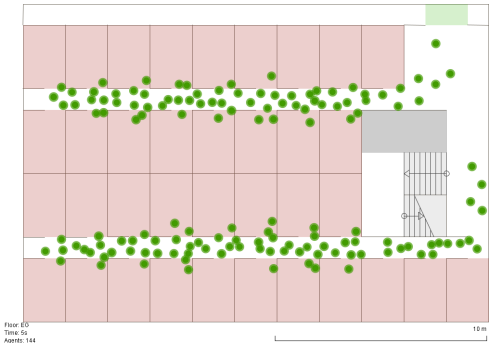
Figure 14: Construction of the scenario [m]

guishes itself from the first by providing no staircase upwards to the higher floor.

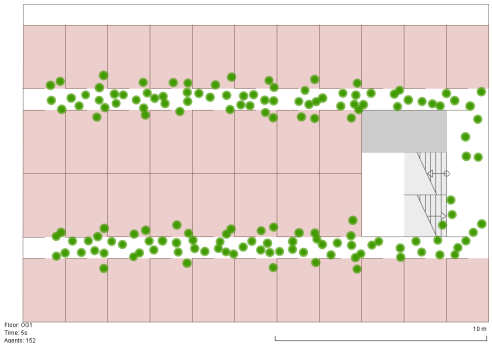
The **Standard** settings are as follows:

- Walking speed v: min: 0.46m/s, max: 1.61m/s, Standard deviation: 0.26
- **Perception radius**: 2.0m
- **Torso radius**: 0.2m
- **With Groups**: false
- **Stair-tread depth**: 0.25m

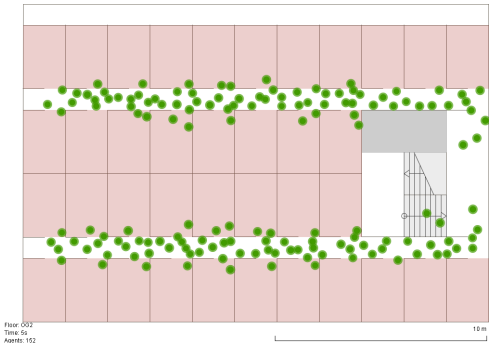
Perception radius describes the radius of the area within which an agent can



(a) Floor 0



(b) Floor 1



(c) Floor 2

Figure 15: Screenshot of the evacuation

perceive other agents (and consequently behave in a way that minimizes the possibility of collision with them).

v can be both determinsitic and non-deterministic. Both are considered here.

With groups considers agents who move in groups of two or three alongside agents who move alone. The distribution of these groups is as follows:

- Individuals: 34%
- Groups of two: 33%
- Groups of three: 33%

9.3 Documentation

Figure 16 provides an overview of evacuation times according to the respective parameter alteration.

The scenario with groups do not have a significant influence over the evacuation time.

The **Perception radius** and **Stair-tread depth** has little influence over the evacuation time.

Naturally, the smaller the **Torso radius**, i.e. the smaller the agents, the quicker agents exit the scenario.

The higher v the smaller evacuation times.

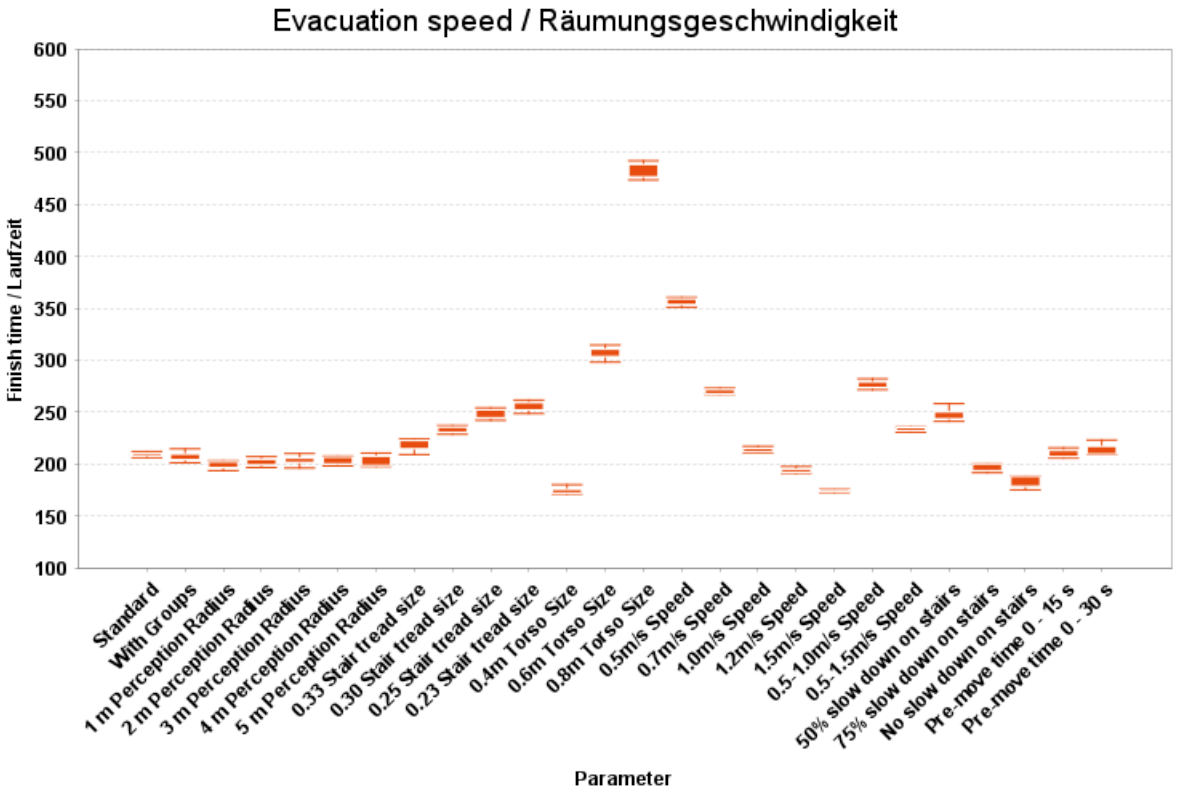


Figure 16: Evacuation times according to the varied agent parameter

This test demonstrates the influence over agent parameters within crowd:it. In this way, a personalized version of the software can be sought by the user.

10 Test 9 – Crowd of people leaving a large public space

10.1 Test description

Agents exiting a room with four doors exit more quickly than a room with only two doors [RiM14].

Parameter	Value
Corridor length [m]	30
Corridor width [m]	20
Exit width [m]	1
Distance between wall and origin [m]	2
No. of agents	1000
Speed [km / h]	[Wei92]
Reaction time distribution [s]	0

Table 8: Test specifications [RiM14]

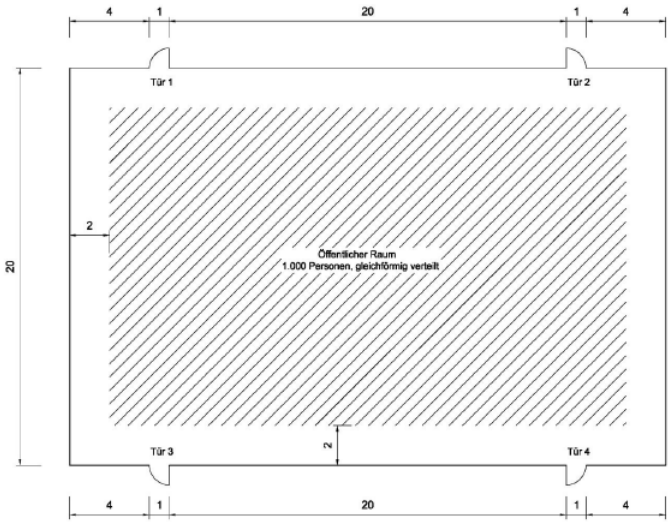
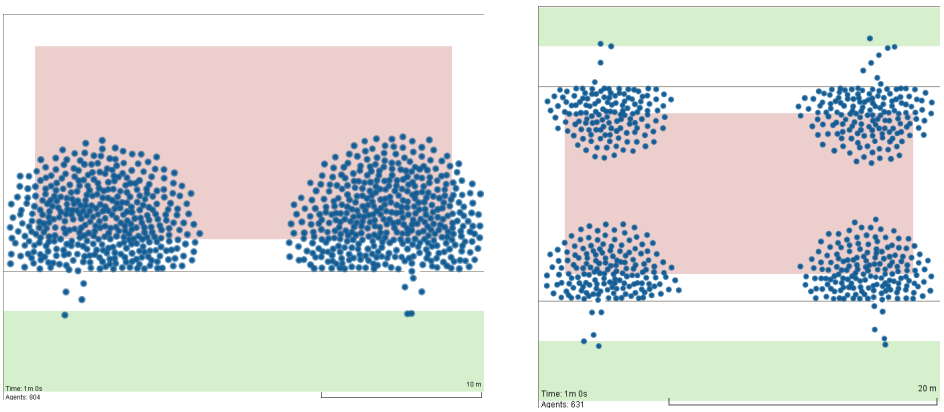


Figure 17: Scenario specifications [m]

The evacuation time between each scenario should be observed and compared. The expectation is that the scenario with four doors takes approximately twice as long to complete as the scenario with only two doors. [RiM14]

10.2 Simulation model

The room and walking speeds were modelled according to the specifications (see Table 8).



(a) Screenshot of the scenario with 2 doors

(b) Screenshot of the scenario with 4 doors

Figure 18: Screenshots of Test 9

10.3 Documentation

Scenario	Evacuation time [s]
4 doors, dynamic floor field calculation	143.45
2 doors, dynamic floor field calculation	281.20
4 doors, static floor field calculation	141.60
2 doors, static floor field calculation	284.90

Table 9: Test scenarios [RiM14]

With a dynamic floor field calculation, an evacuation of the room with 4 doors takes 52.0% the time of a scenario with 2 doors. Without a dynamic floor field calculation, an evacuation of the room with 4 doors takes 50.0% the time of a scenario with 2 doors.

For this test, both a dynamic and static floor field calculation was considered. The dynamic floor field calculation is computationally more effortful, however the agents can, using it, react to changing environments more appropriately.

The test confirms that the effect of having two doors instead of four does indeed approximately double the time of evacuation for crowd:it agents.

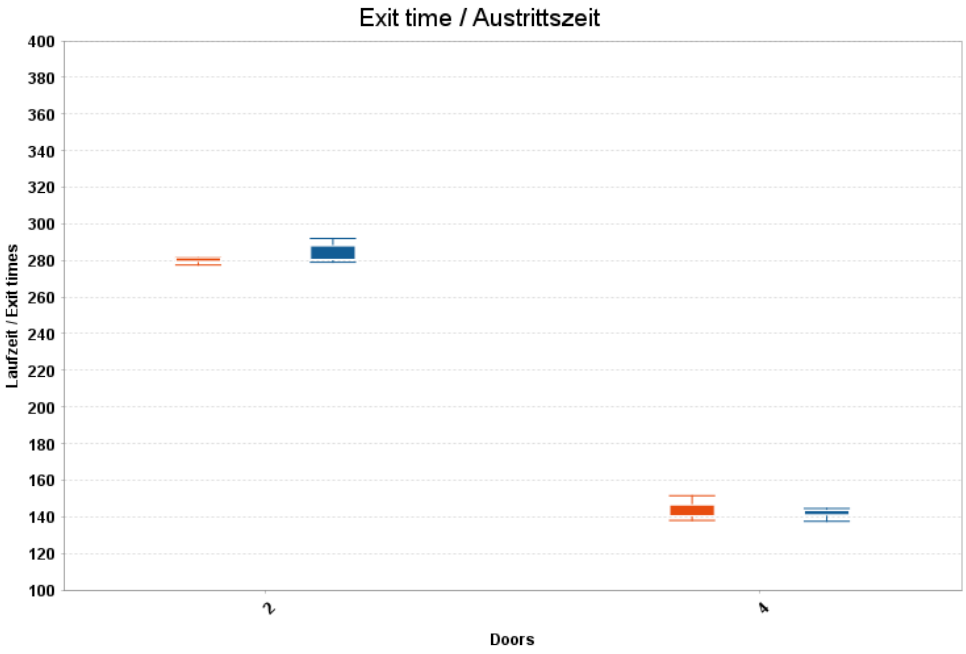


Figure 19: Run times for agents who used 2 or 4 doors. Blue is with a static flooding field. Orange is with a dynamic flooding field

11 Test 11 – Choice of escape route

11.1 Test description

Provided with a choice of two exits, agents will generally select the closer of the two, causing congestion.

Parameter	Value
No. of agents	1000
Pre-movement time [s]	0
Walking speed [m/s]	[Wei92]
Room size [m × m]	30 × 20
Exit width [m]	1
Distance between the walls and origin [m]	2

Table 10: Test specifications [RiM14]

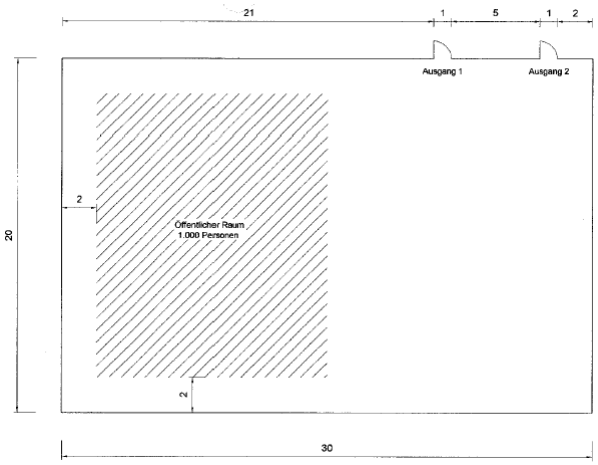
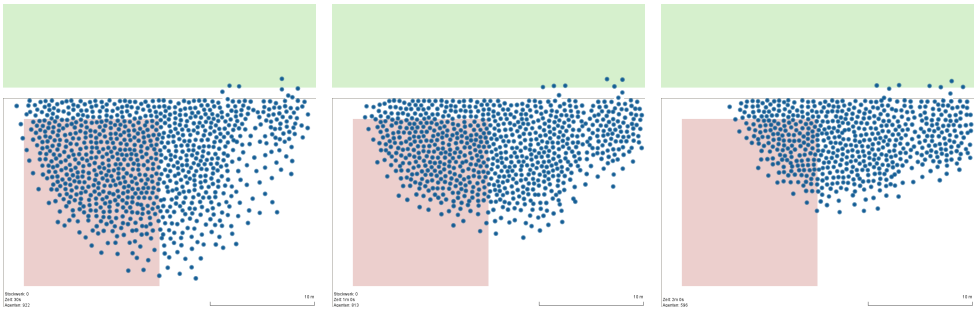


Figure 20: Construction of the scenario [m]

11.2 Simulation model

The scenario was modelled according to the specifications (see Table 10). In order to highlight the difference between a dynamic and static floor field, tests were carried out on both.



(a) Screenshot of the evacuation after 30 seconds

(b) Screenshot of the evacuation after 60 seconds

(c) Screenshot of the evacuation after 120 seconds

Figure 21: Screenshots of the evacuation

Exit	No. of agent using exit
1	522
2	477

Table 11: Results for dynamic decision making

Exit	No. of agent using exit
1	548
2	452

Table 12: Results for non-dynamic decision making

11.3 Documentation

With a dynamic floor field, agents make dynamic decisions when selecting an optimal route. That is, they select where to move next based on the current conditions. However, this feature is optional. When unused, agents select a route that would be optimal if no one else existed in the scenario.

Figures 21a, 21b and 21c demonstrate the results of a dynamic floor field. As is clear, when dynamic decision making is selected, fewer agents choose the left-most exit, as they recognise that this is crowded and seek a less crowded route.

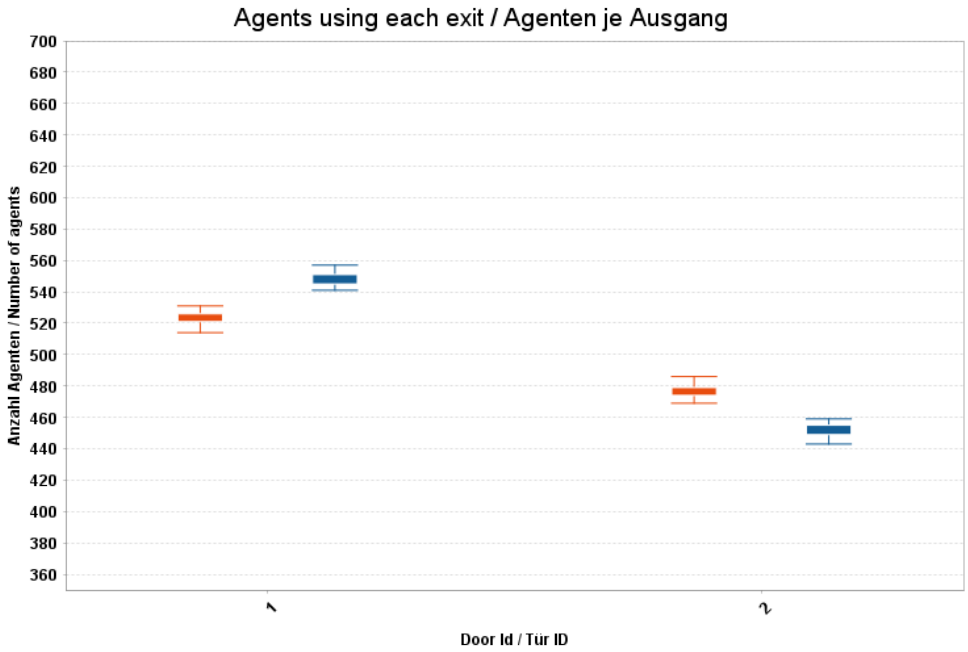


Figure 22: Number of agents who have used door 1 and 2. Blue is with a static floor field. Orange is with a dynamic floor field.

12 Test 12 – Effect of bottlenecks

12.1 Test description

Given a room that is connected to another room via a corridor, congestion will occur only in the room that contains an agent origin [RiM14].

Parameter	Value
No. of agents	150
Pre-movement time [s]	0
Corridor size [m × m]	1×5
Walking speed [m/s]	[Wei92]

Table 13: Test specfications [RiM14]

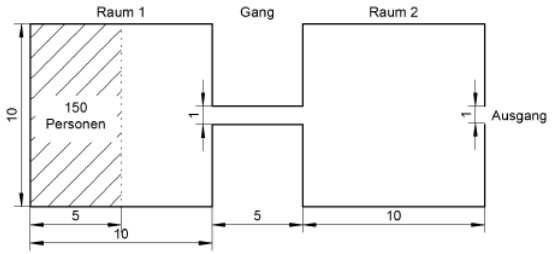


Figure 23: Construction of the scenario [m]

12.2 Simulation model

The rooms, corridor and walking speeds were modelled according to the specifications (see Table 13). The destination was set outside of the room.

12.3 Documentation

The screenshots in Figures 25a through 25d demonstrate that the correct behaviour was observed: due to the narrowness of the corridor, the flow rate of agents into the second room is much smaller than it otherwise might be, causing congestion in the first room. (In the heatmap, the red and black signifies the reduced walking speed of the agents.)

After exiting the corridor, agents walk freely to the exit, given the reduced flow-rate of agents into the second room. This matches the expectations of the test [RiM14].

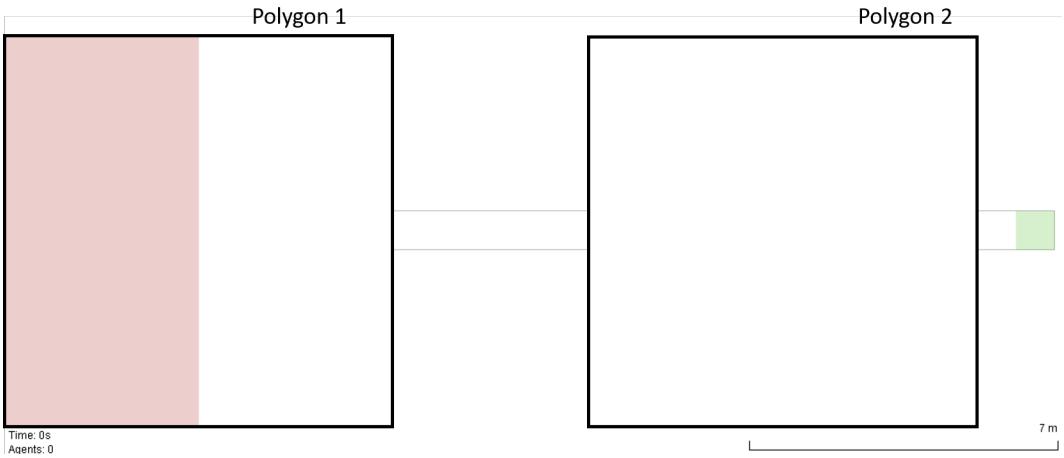
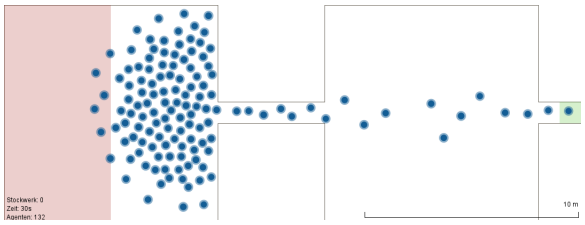


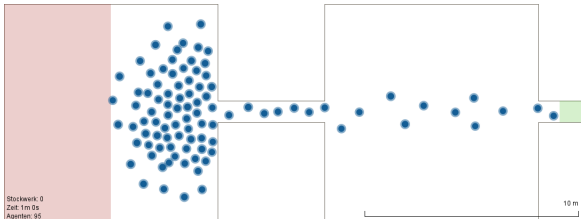
Figure 24: Screenshot at the beginning of the scenario

Polygon	Time inside the polygon [s]
1 (before the corridor)	67.34
2 (before the exit)	9.50

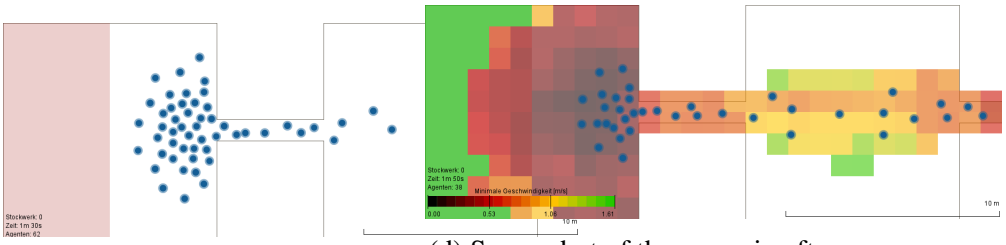
Table 14: Results



(a) Screenshot of the scenario after 30 seconds



(b) Screenshot of the scenario after 60 seconds



(c) Screenshot of the scenario after 90 seconds

(d) Screenshot of the scenario after 110 seconds with a (mean)velocity heatmap

Figure 25: Screenshots of the scenario

13 Test 13 – Congestion in front of a flight of stairs

13.1 Test description

Given a room connected to a staircase passageway (see Figure 26), congestion will occur at the room's exit as agents have restricted space to exit. Meanwhile, at the foot of the stairs a small queue will form that grows over time as the flow via the stairs is smaller than it is through the corridor [RiM14].

Parameter	Value
No. of agents	150
Pre-movement time [s]	0
Corridor size [m × m]	2 × 12
Walking speeds [m/s]	[Wei92]

Table 15: Test specifications [RiM14]

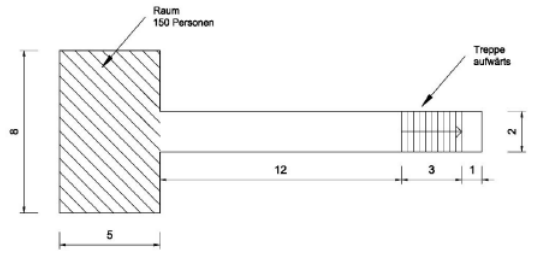


Figure 26: Construction of the scenario [m]

13.2 Simulation model

The corridor and walking speeds were modelled according to the specifications (see Table 15).

13.3 Documentation

The screenshots in Figures 28a through 28e demonstrate that the correct behaviour was observed: due to the narrowness of the exit, congestion forms in the room. There is a reduction in walking speed on the stairs (most clearly seen on the heatmap), however this does not have a large impact on the walking speed of agents in front of the staircase.

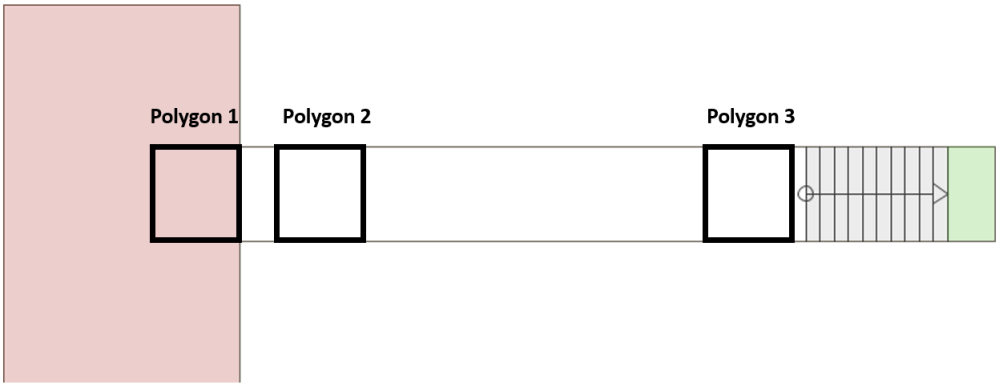
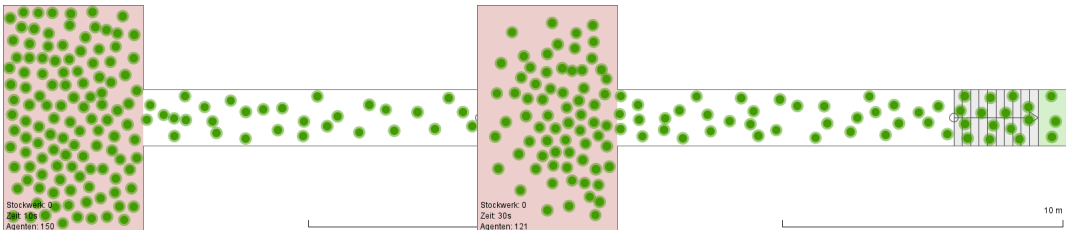
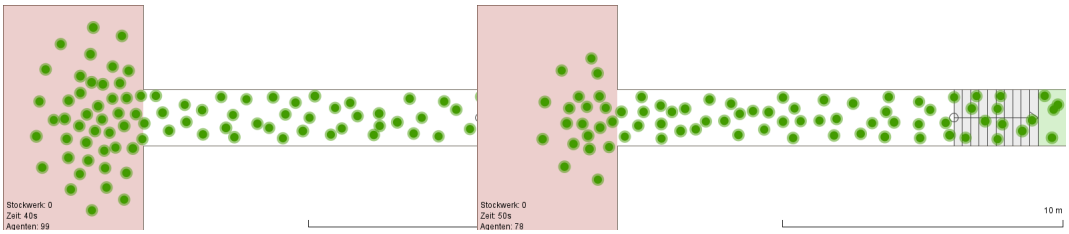


Figure 27: Screenshot at the beginning of the scenario (the polygons are not to scale)



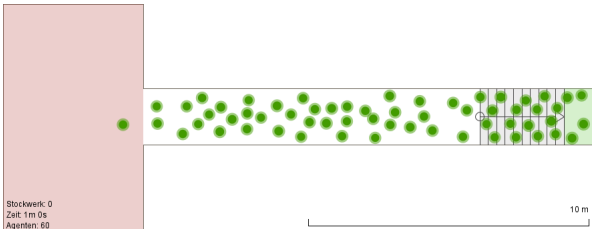
(a) Screenshot of the scenario after 10 seconds

(b) Screenshot of the scenario after 20 seconds



(c) Screenshot of the scenario after 30 seconds

(d) Screenshot of the scenario after 50 seconds



(e) Screenshot of the scenario after 60 seconds with a heatmap

Figure 28: Screenshots of the scenario

To validate the supposed congestions, three evaluation polygons (see Figure 27) were placed in the the scenario to ascertain how much agents were slowed in each of the three areas. The results are shown in Table 16.

Polygon	Time in the polygon Δt [s]
Polygon 1	67.34
Polygon 2	9.5
Polygon 3	4.82

Table 16: Results

14 Test 14 – Choice of route

14.1 Test description

Agents are placed in a scenario that contains a destination at the end of a corridor. There are two routes to this destination: around a long U-shaped corridor, and up and down a set of stairs that take agents directly to the destination. Agents should select reasonable routes given their prescribed behavioural heuristic [RiM14].

14.2 Simulation model

The scenario was set-up according to Figure 29.

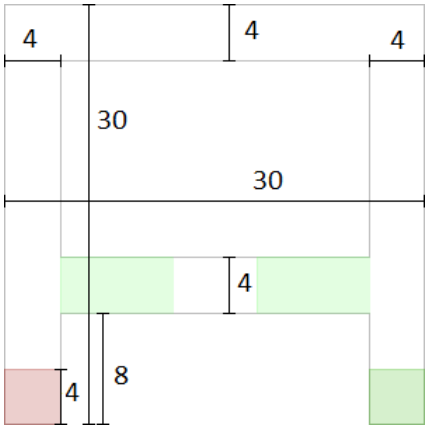


Figure 29: Construction of the scenario [m]

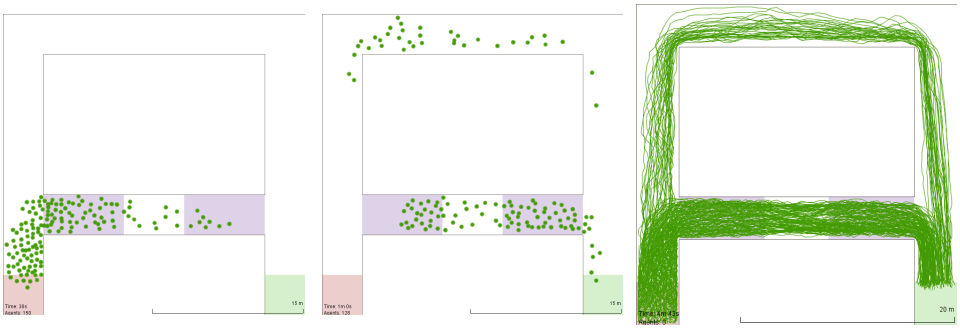
Agents are generated in the origin over the first ten seconds. In each case, agents are provided one of two behavioural tendencies: take the shortest route or take the fastest route.

Parameter	Value
No. of agents	150
Pre-movement distributions [s]	0
Walking speed [m/s]	[Wei92]
Deceleration factor (for stairs)	0.4

Table 17: Test specification [RiM14]

14.3 Documentation

The first scenario considers agents who opt for the fastest route. This causes some agents to walk around the longer corridor, due to the mass of agents on the stairs. See Figures 30a, 30b and 30c.



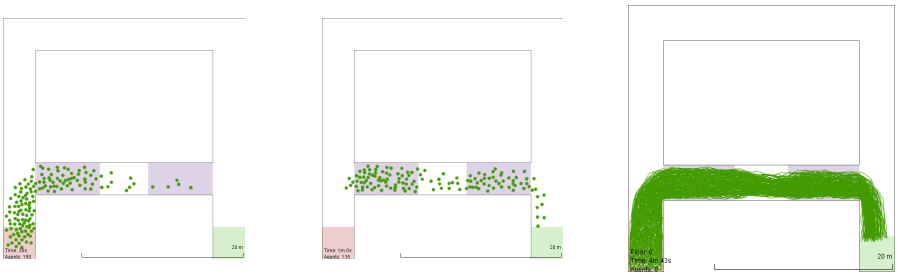
(a) Screenshot of the simulation after 30 seconds

(b) Screenshot of the simulation after 60 seconds

(c) Screenshot of the simulation with traced agent paths

Figure 30: Screenshots of the simulation

The second scenario considers agents who opt for the shortest route. This causes no agent to walk around the longer corridor. See Figures 31a, 31b and 31c.



(a) Screenshot of the simulation after 30 seconds

(b) Screenshot of the simulation after 60 seconds

(c) Screenshot of the simulation with traced agent paths

Figure 31: Screenshots of the simulation

In crowd:it behavioural heuristics can be set. If a "fastest route" heuristic is set, agents react to congestion and take a longer route if it means avoiding other agents. If a "shortest route" heuritistic is set, agents ignore the slowing effect of congestion and take the shortest route regardless of the crowd.

Path	Statistic	No. of agents
shorter route	min.	114
shorter route	max.	124
shorter route	avg.	119
longer route	min.	26
longer route	max.	36
longer route	avg.	30

Table 18: Results for the "Fastest Path Heuristic"

Path	Statistic	No. of agents
shorter route	min.	150
shorter route	max.	150
shorter route	avg.	150
longer route	min.	0
longer route	max.	0
longer route	avg.	0

Table 19: Results for the "Shortest Path Heuristic"

15 Test 15 – Movement of a large crowd of pedestrians around a corner

15.1 Test description

Agents will not be so affected by a corner that they are slowed too much, nor will they be so unaffected that a corner has no effect on agent evacuation times.

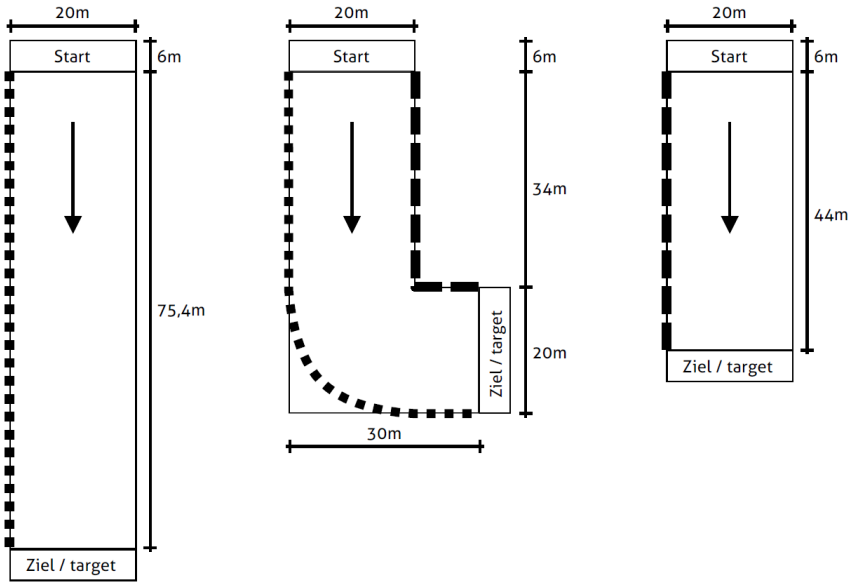


Figure 32: Test geometry specifications [RiM14]

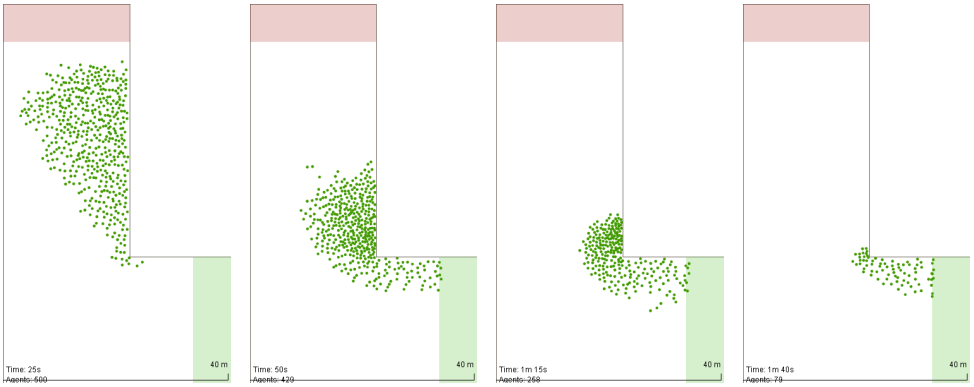
The expectation is that the shortest evacuation time occurs for the scenario with the shortest, straight corridor; the longest evacuation time occurs for the scenario with the longest, straight corridor; and the scenario with a corner has an evacuation time lying between these othe two evacuation times.

15.2 Simulation model

Agent walking speed is distributed according to [Wei92]. No pre-movement time was included. The scenario's geometry was modelled according to Figure 32.

15.3 Documentation

Figures 33a through 35e display the behaviour of agents in each scenario.



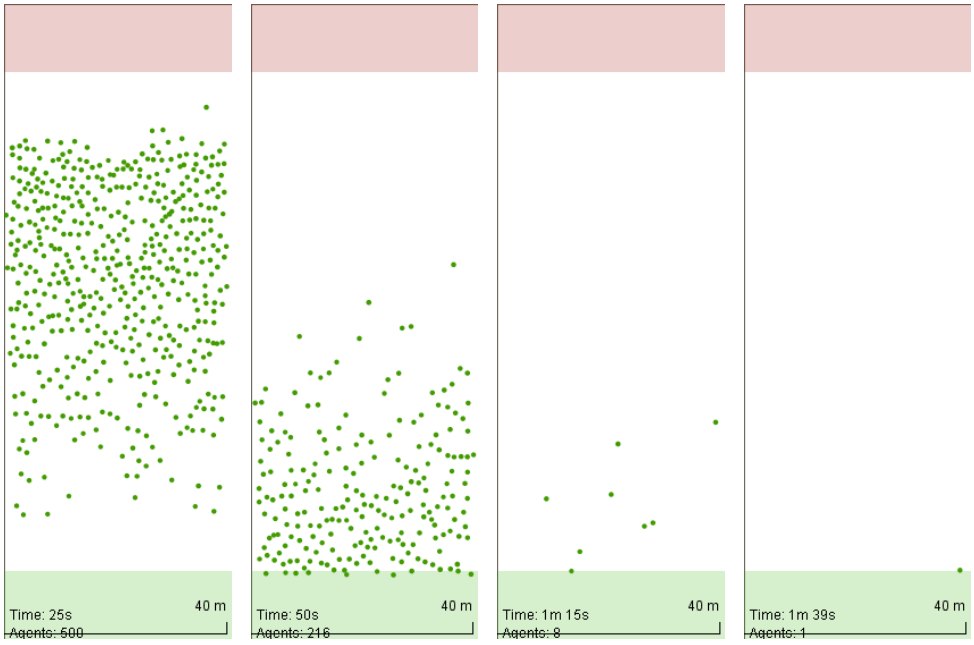
(a) Screenshot of the simulation after 25 seconds

(b) Screenshot of the simulation after 50 seconds

(c) Screenshot of the simulation after 75 seconds

(d) Screenshot of the simulation after 100 seconds

Figure 33: Screenshots of the cornered corridor scenario



(a) Screenshot of the simulation after 25 seconds

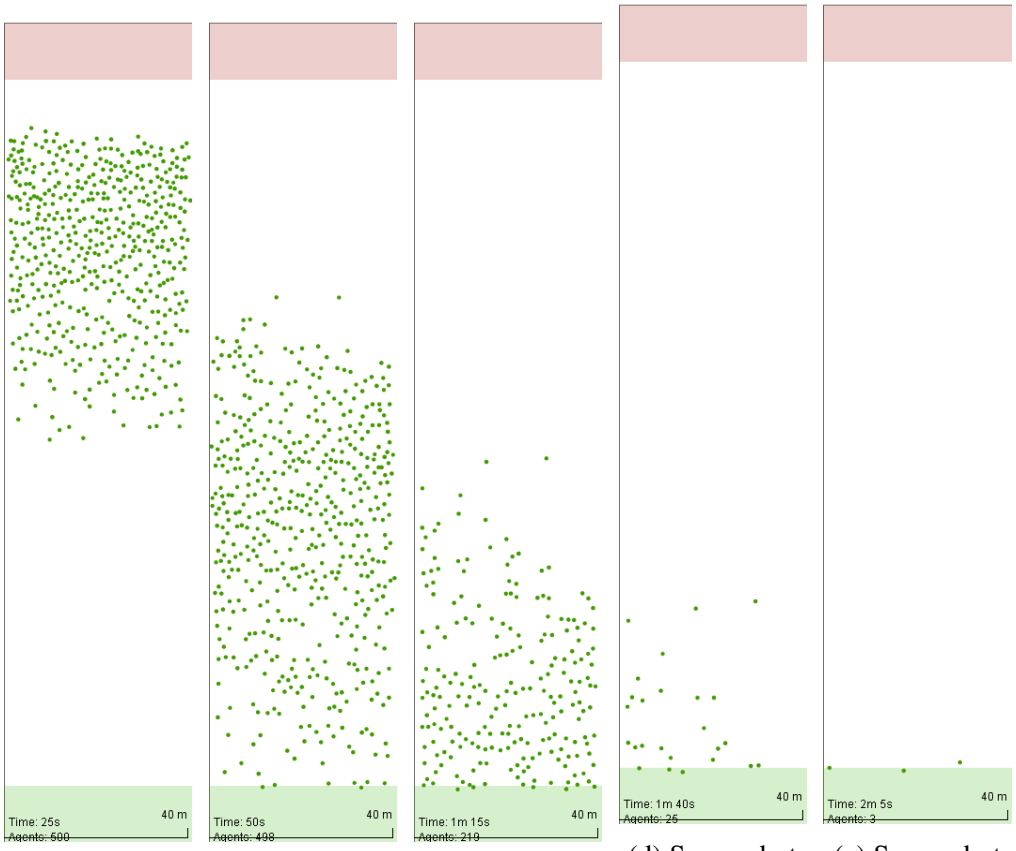
(b) Screenshot of the simulation after 50 seconds

(c) Screenshot of the simulation after 75 seconds

(d) Screenshot of the simulation after 100 seconds

Figure 34: Screenshots of the short, straight corridor scenario

Figure 36 shows the evacuation time for each agent per scenario. crowd:it adheres to the expection. The short, straight corridor is the fastest, the longest corridor



(a) Screenshot of the simulation after 25 seconds

(b) Screenshot of the simulation after 50 seconds

(c) Screenshot of the simulation after 75 seconds

(d) Screenshot of the simulation after 100 seconds

(e) Screenshot of the simulation after 125 seconds

Figure 35: Screenshots of the long, straight corridor scenario

takes the longest, the corner scenario times lie in between.

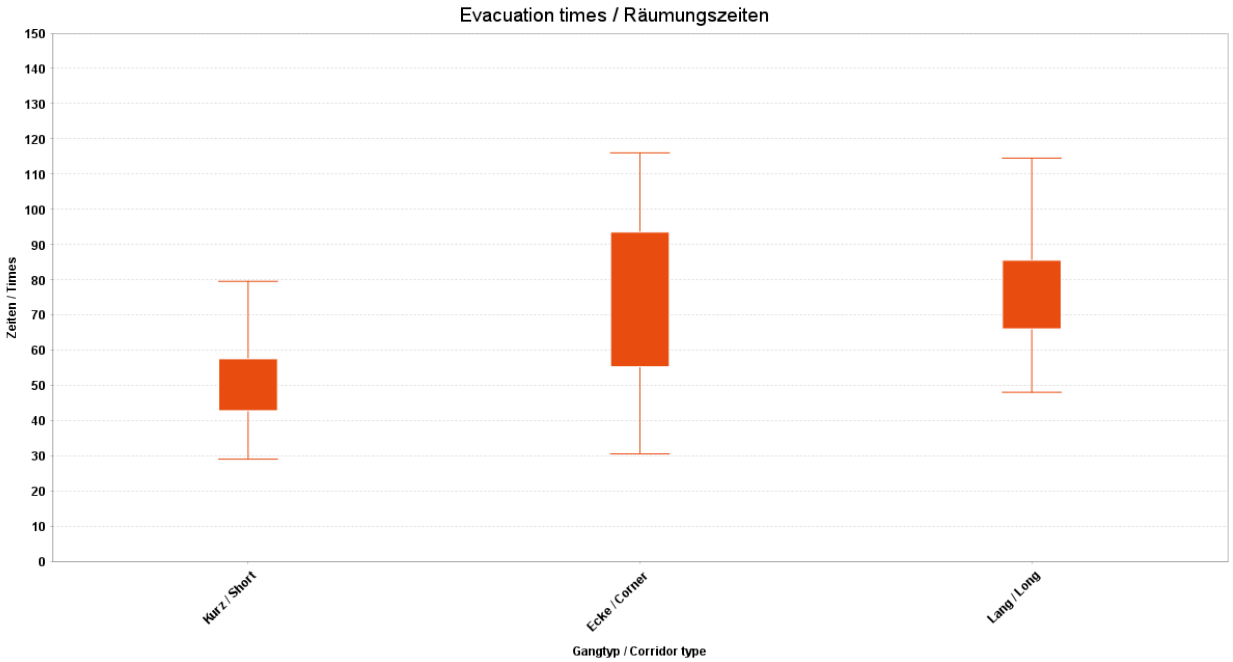


Figure 36: Evacuation times

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[GK15] Felix Dietrich Gerta Köster, Daniel Lehmberg. Is slowing down enough to model movement on stairs? *Traffic and Granular Flow*, Nootdorp:27 – 30, 2015.

[RiM14] RiMEA. *Richtlinie für mikroskopische Entfluchtungsanalysen*, volume 3.0 (Entwurf). Rimea e.V., 2014.

[Wei92] Ulrich Weidmann. *Transporttechnik der Fußgänger*. IVT, 1992.