Development of Physical and Psychological States Graphs of People and Their Software Implementation in the Tasks of Evacuation Modelling

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Abstract: The purpose of the presented in the article results is to increase the realism of the people evacuation modeling in case of emergency situation. Models that exist today do not describe in detail physical and psychological states of the characters during the simulation. This article presents the results of the development of people physical and psychological states graphs in the conditions of evacuation. All graphs are presented as extended final state machines. On the basis of the developed finite state machines the description of state transitions was carried out and algorithms were built This work was carried out as part of the development of a comprehensive 3D model of the people evacuation processes of in emergency situations in particular fires. A software implementation in the *Unreal Engine* program of these states was performed. Examples of the behavior of characters in various psychological and physical states are also presented.

1 INTRODUCTION

To date, methods of modeling various processes are actively developing. Modern modeling methods and tools allow us to study both technical and social processes.

In particular, there is a large number of works aimed at modeling the processes of evacuation of people in emergency situations [1-12]. Depending on the approach there are 4 types of models: the molecular approach [1,2], the route-based approach [3,4], the group-based approach [5-7] and the agent-based approach [8-10]. The most promising models are those built using an agent-based approach.

One of the main problem of evacuation models developing is making the simulation more realistic. The most realistic modelling requires detailed 3D models with a rich set of simulated parameter. In developing such models, special attention should be paid to modelling character's behaviour. Existing 2D and 3D models have a large number of simplifications, especially in terms of the psycho-physical state of characters [1-12].

In this regard, the purpose of this study is to develop graphs describing the physical and psychological states of people in emergency situations, in particular, in case of fire. This task requires taking into account various physical parameters of the characters, as well as detailed modeling of their psychological state and behavior. In our work, the description of states and transitions between them is performed in the form of an extended finite state machine. Automatic description will further simplify the process of analysis, testing and verification of the model through the use of tools of the automata theory [13-14].

The development of such graphs (extended finite state machines) will allow to obtain algorithms for transitions between states on the basis of which their software implementation will be performed. The results of the development of state graphs and software implementations of the transition algorithms will form the basis of the 3D modeling system of evacuation processes with an increased degree of realism of the model characters behavior. The implementation of these algorithms and the 3D modelling system based on them is carried out in the

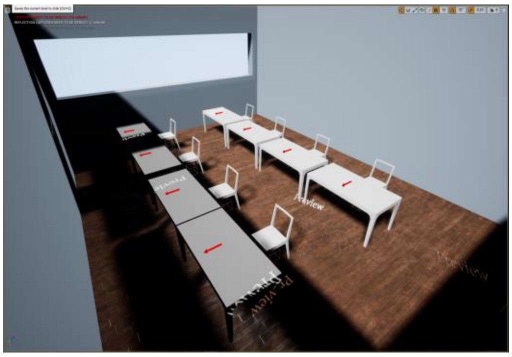
Unreal Engine environment. This environment has great functionality and in the future will allow the addition of VR technology into the model.

2 MODEL DESCRIPTION

As noted above, the development of a detailed 3D model is carried out in the *Unreal Engine* environment. The programming of the characters behavior was made using the *Blueprint* visual programming tool. In this tool all processes are represented as blocks that contain a specific code that performs the required action. There are many types of such blocks: event blocks, action blocks and auxiliary blocks. The *Blueprint* visual programming tool allows to implement all possible actions of the character during evacuation.

To conduct simulation experiments in the *Unreal Engine* examples of test environments (buildings, rooms) were designed and algorithms for the fire and smoke propagation were implemented [12]. Examples of the test environments are shown in Figure 1.

a)



b)

Figure 1: Examples of test environments: a) building; b) room.

During the simulation each character has a set of parameters. Some of parameters are constant and do not change during the simulation. These parameters are: *weight, age, readiness for emergencies, temperament, leader* (the ability to lead people). The parameters to change are: *health, speed* and *stress*. In the simulation these parameters and processes of interaction with the environment will determine the physical state of each character and his behavior during the evacuation. The model considers four possible *Temperaments: Melancholic, Choleric, Sanguine and Phlegmatic*. This parameter determines the psychological state of the characters and their actions.

3 PHYSICAL AND PSYCHOLOGICAL STATES GRAPHS

To increase the realism of the simulation of the evacuation process we have developed extended finite state machines describing the physical and psychological states of the characters. These states of the character will determine its behavior during the simulation. The development of the extended final state machines was carried out in conjunction with a psychologist from Tomsk State Pedagogical University. The involvement of specialists in the field of psychology will significantly increase the realism of behavioral modeling.

3.1 The Physical States Graph

The physical states extended finite state machine is described as

$$M_{Physical\ state} = \{S, X, Y, V, T\},$$

where S is a finite set of states; X is a set of input symbols; Y is a set of output symbols; V is a set of context variables; T is a set of transitions between states [13-14].

The set of states S provides five physical states for each character is

$$S = \{S_1, S_2, S_3, S_4, S_5\},$$

where S_1 – *Initial state;* S_2 – *Intoxication;* S_3 – *Injury;* S_4 – *Intoxication/Injury;* S_5 – *Death*.

The input and output symbol sets are described as

$$X = \{smoke, fire, hit, health\},$$

$$Y = \{health, stress\}.$$

Input symbols are *smoke, fire, hit*: *smoke* is an impact of smoke on the character; *fire* is an impact of fire; *hit* is an external hit (construction or other character); *health* is a character's health parameter. The set of context variables is the same as the set of output symbols.

The set of state transitions is defined as

$$T_{n\to m} = \{S_n, x, P, up, S_m\},$$

where S_n – initial state; x – input parameters; P – predicate (transition condition); up – update function; S_m – final state.

Figure 2 shows an extended finite state machine of transitions from one physical state to another.

In the *Initial state* (S_1) the character has the maximum values of the *Health* and *Speed* parameters and minimum value of the *Stress* parameter. The transition to the state of *Intoxication* (S_2) occurs when the conditions for finding the character in the smoke at least some minimum time (Figure 3).

The transition to the state of *Injury* (S_3) occurs under two conditions: external impact (hit) and direct contact with fire for a minimum time of fire interaction (Figure 4).

If the character was in the *Intoxication* state and is exposed to fire or impact, then he goes into the *Intoxication/Injury* state. Similarly, the transition from the state of *Injury* is carried out when exposed to smoke (Figure 5).

$$T_{1\to 2} = \{\langle S_1, smoke, t > t_{\min}, (health--,\ stress++), S_2\rangle\}.$$

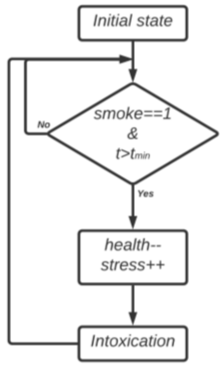


Figure 3: The $T_{1\to 2}$ transition algorithm to the state of *Intoxication*.

$$T_{1\to 3} = \{\langle S_1, fire, t > t_{min}, (health--,\ stress++), S_3\rangle,$$
$$\langle S_1, hit, ,(health--,\ stress++), S_3\rangle\}.$$

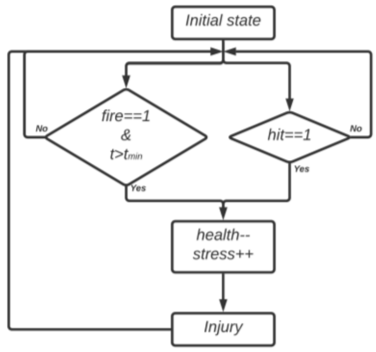


Figure 4: The transition algorithm to the *Injury state* (S_3).

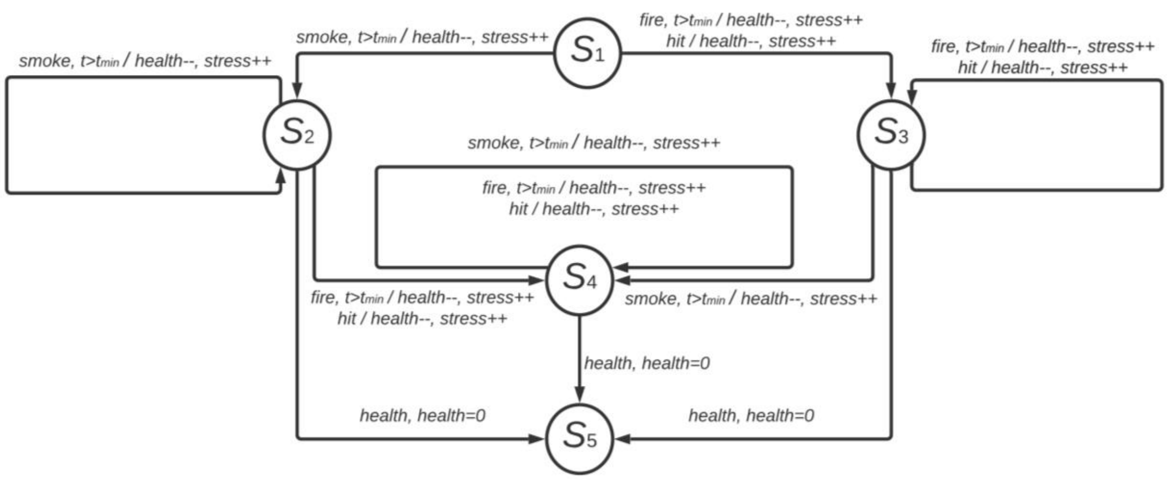


Figure 2: Physical states extended finite state machine.

$$T_{3\to 4}=\{\langle S_3, smoke, t>t_{\min}, (health--, stress++), S_4\rangle\},$$

$$T_{2\to 4}=\{\langle S_2, fire, t>t_{min}, (health--, stress++), S_2\rangle,$$

$$\langle S_2, hit, , (health--, stress++), S_4\rangle\}.$$

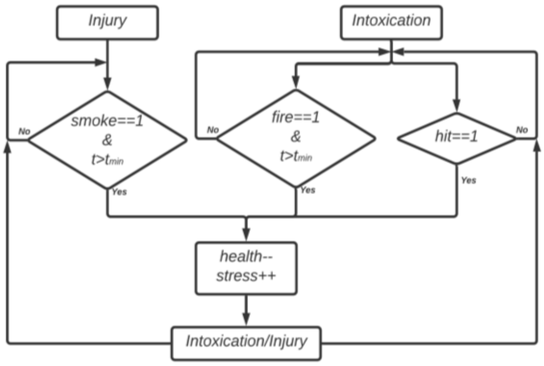


Figure 5: The transition algorithm to the state of *Intoxication/Injury* (S_4).

During the transition to *Injury*, *Intoxication* or *Intoxication/Injury* states there is a decrease in the *Health/Speed* and an increase in the *Stress* parameters of the character (Figure 2).

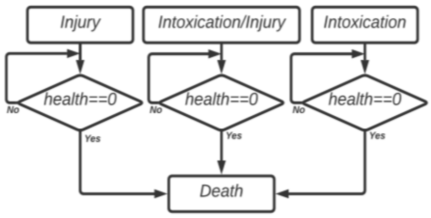


Figure 6: The transition algorithm to the state of *Death* (S_5) from S_2, S_3, S_4 states.

The transition to the *Death* state is possible from all states (except the *Initial state*) if *Health* parameter is equal to zero (Figure 6):

$$T_{2\to 5}=\{\langle S_2, health, health=0, \ , S_5\rangle\};$$

$$T_{3\to 5}=\{\langle S_3, health, health=0, \ , S_5\rangle\};$$

$$T_{4\to 5}=\{\langle S_4, health, health=0, \ , S_5\rangle\}.$$

3.2 The Psychological State Graph

The psychological state graph is described similarly to the physical extended finite state machine:

$$M_{Psychological\ state}=\{S, X, Y, V, T\}.$$

The set of states S also provides five states for each character:

$$S=\{S_1, S_2, S_3, S_4, S_5\},$$

where S_1 – *Calm;* S_2 – *Panic;* S_3 – *Psychology;* S_4 – *Sympathy;* S_5 – *Group*.

The input and output symbol sets are described as

$$X=\{stress, leader, EmPr\},$$

$$Y=\{action\}.$$

Input symbols are *stress, leader, emergency preparedness (EmPr).* The set of output symbols contains an *action* symbol which is defined in each specific state according to separate rules.

The set of transitions state is defined as in the previous case

$$T_{n\to m}=\{S_n, x, P, up, S_m\}.$$

The extended finite state machine of the psychological states of the characters is shown in Figure 7.

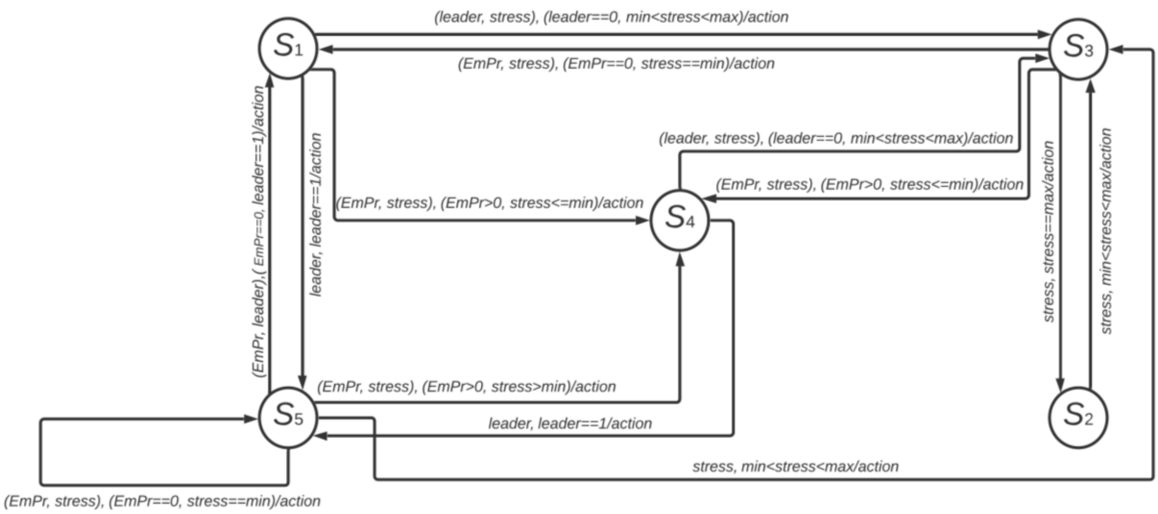


Figure 7: Psychological states extended finite state machine.

The *Psychology state* (S_3) have three sub-states: *Stupor, Aggression* and *Selfishness*.

The state of *Calm* corresponds to the appropriate behavior of the character. In this state the *stress* parameter has a minimum value. The transition to the *Psychology* state is performed if the value of the *stress* parameter becomes higher than the minimum. The transition to the state of *Sympathy* is performed if the *EmPr* parameter has a non-zero value and a character with a *health* parameter below the threshold value will fall into the field of view of this character. The transition to the *Group* state is performed if the group led by the *leader* falls into the field of view of the character.

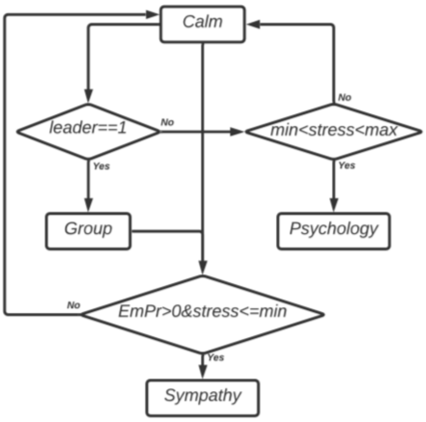


Figure 8: The algorithm of transitions from *Calm* state.

The transitions from *Calm* state can be described as (Figure 8):

$$T_{1\to 3} = \{\langle S_1, leader, stress, leader = 0 \,\&\, \max > stress > \min, \ , S_3\rangle\};$$

$$T_{1\to 5} = \{\langle S_1, leader, leader = 1, \ , S_5\rangle\};$$

$$T_{1\to 4} = \{\langle S_1, stress, EmPr, Em.Pr. > 0 \,\&\, stress <= min, \ , S_4\rangle\}.$$

The transition to the *Panic* state (S_2) occurs only from the *Psychology* state at the maximum value of the *stress* parameter of the character. In the *Panic* state, the character behaves inappropriately and makes chaotic movements. Each character in this state forms a "panic radius" around him. Some characters in this radius may increase the *stress* parameter. The transition back to the *Psychology* state is performed if the value of the *stress* parameter drops below the threshold value.

The transitions from *Panic* state can be described as (Figure 9).

As noted above the *Psychology* state (S_3) has three sub-states. In the *Stupor* substate the character is completely immobilized. Depending on the values of the *stress* parameter characters of all *Temperaments* can fall into this substate. In the *Aggression* substate the character can cause both physical and moral damage to others charactersы. Only characters with a *Choleric* temperament can fall into this substate. In the *Selfishness* substate the character performs actions to rob the property of a certain territory and other characters. Only characters with a *Sanguine* temperament can fall into this substate. The transition to the state of *Sympathy* from the state of *Psychology* is carried out if the *stress* parameter drops to a value below the average, the *EmPr* parameter is not equal to 0 and a other character with the *health* parameter below the threshold value will come into view. And the transition to the *Calm* state is performed if the value of the *stress* parameter drops to a value below the average. The transitions from *Psychology* state can be described as (Figure 10).

$$T_{2\to 3} = \{\langle S_2, stress, \max > stress > \min, \ , S_3\rangle\}.$$

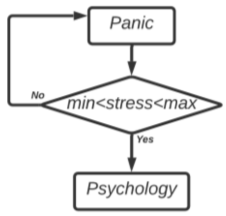


Figure 9: The algorithm of transitions from *Panic* state (S_2).

$$T_{3\to 2} = \{\langle S_3, stress, stress = \max, \ , S_2\rangle\};$$

$$T_{3\to 1} = \{\langle S_3, (EmPr, stress), Em.Pr. = 0 \,\&\, stress = min, \ , S_1\rangle\};$$

$$T_{3\to 4} = \{\langle S_3, EmPr, Em.Pr. > 0, \ , S_4\rangle\}.$$

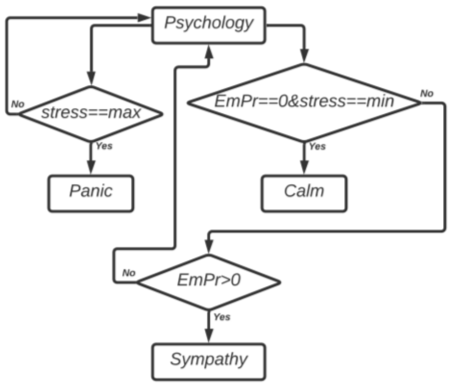


Figure 10: The algorithm of transitions from *Psychology* state (S_3).

The *Sympathy* (state S_4) is a state that represents a character prepared for emergencies. This character has the skills to help other characters with a decreased *health* parameter and an increased *stress* parameter. The transition to the *Psychology* state is carried out if the value of the *stress* parameter becomes higher than the minimum. And the transition to the *Group* state is carried out when the organized group will fall into the field of view of this character. In this case the character joins the group. The transitions from *Sympathy* state can be described as (Figure 11):

$$T_{4\to 5} = \{\langle S_4, Leader = 1, S_5 \rangle\};$$
$$T_{4\to 3} = \{\langle S_4, Leader = 0 \,\&\, \max > Stress > \min, S_3 \rangle\}.$$

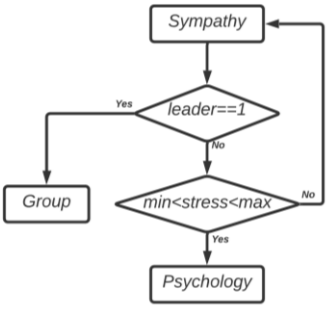


Figure 11: The algorithm of transitions from *Sympathy* state (S_4).

A *Group* (state S_5) is a state in which there is one character who is the *Leader*. The leader is the character with the maximum value of the *EmPr* parameter. The leader does not help the victims if they fall into his field of vision. If the *stress* parameter of the *Leader* increases to the average value or his *health* parameter decreases to the minimum, then he stops leading the group and the group breaks up. The speed of the group depends on the speed of the *Leader* (Figure 12).

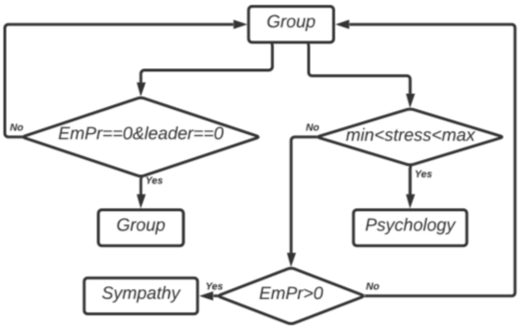


Figure 12: The algorithm of transitions from *Group* state (S_5).

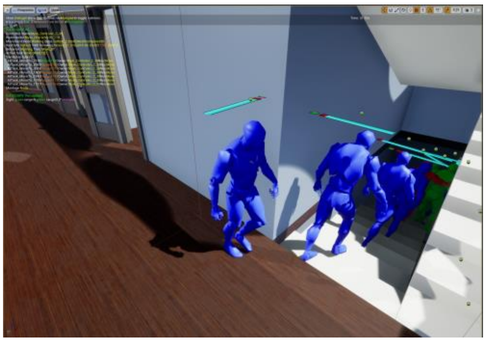
The transitions from *Group* state can be described as

$$T_{4\to 5} = \{\langle S_4, leader, leader = 1, \ , S_5 \rangle\};$$
$$T_{4\to 3} = \{\langle S_4, (leader, stress), leader = 0 \,\&\, \max > Stress > \min, \ , S_3 \rangle\}.$$

4 AN EXAMPL OF GRAPHS IMPLEMENTATION

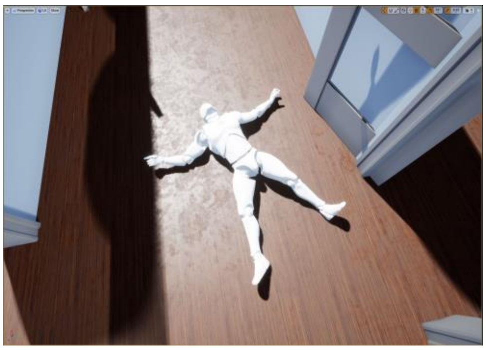
This section provides examples of graphs implementation for changing the physical and psychological states of characters in our model. The practical implementation was carried out in the *Unreal Engine* program.

As noted above when receiving various injuries characters can change their physical state. For example, fall to the *Injury*, *Intoxication* or *Death* states. Figure 13 shows model examples of characters actions in these states.



a)

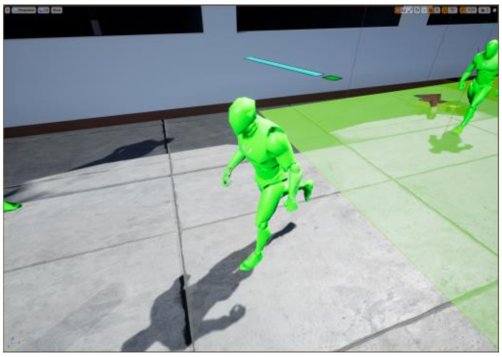
b)



c)

Figure 13: Examples of characters actions in different physical states: a) *Intoxication*; b) *Injury*; c) *Death*.

In model the characters color changes depending on their state. According to the graph shown in Figure 7 the characters can be in various psychological states. These states will determine the actions that the character performs during the evacuation. Figure 14 shows examples of *Calm* and *Sympathy* states.



a)

b)

Figure 14: Examples of characters actions in different psychological states: a) *Calm*; b) *Sympathy*.

In Figure 14a the character is in a *Calm* state and performs the run action at maximum speed. At the same time his speed is determined by the level of *health* and the absence of obstacles. Figure 14b shows the process of providing assistance. In this case another character with a low level of *health* falls into the field of view of the character who is in the *Sympathy* state (red color). Providing assistance leads to their joint evacuation, thereby increasing the speed of the character.

5 CONCLUSIONS

This paper presents the results of the development of graphs (extended finite state machines) describing the physical and psychological states of people in the evacuation process. When developing graphs five states of the characters in the evacuation process were identified. Based on these graphs algorithms for transitions between states were developed and software in the *Unreal Engine* system was implemented. The results of the development formed the basis of a comprehensive 3D modeling system for the people evacuation in emergency situations. In this case we considered a fire in the building as a possible emergency situation. The conducted test experiments on modeling show the adequacy of the choice of states and the set of the characters actions.

In our opinion, the developed graphs and software will increase the realism of modeling processes. Taking into account a large number of states and actions of characters in the model will expand its possible use by specialized organizations. However, it should be noted that the issues of the psychological state of people (characters in the 3D modeling system) and their behavior are quite complex and ambiguous. In this regard, it is planned to conduct additional studies of the adequacy of the simulation results including the expert assessments of psychologists and rescuers.

The development of a detailed 3D model with increased realism of the characters' behavior will open up new areas of such models application. In particular, a detailed accounting of the characters behavior depending on their psycho-physical states will allow to use this model in the field of life safety and obtaining at a new level of detailing statistical data on evacuation processes.

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