AN ARCHITECTURE-BASED MODEL FOR UNDERGROUND SPACE EVACUATION SIMULATION

Chengyu Sun
College of Architecture and Urban Planning
Tongji University
200092 Shanghai, P. R. China

apolloc@online.sh.cn

Bauke de Vries
Faculty of Architecture, Building and Planning
Technische Universiteit Eindhoven
P.O Box 513, 00 MB Eindhoven, the Netherlands
B.d.Vries@tue.nl

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Evacuation, Agent-based simulation, Architectural clue

ABSTRACT

There is no simulation model on evacuation nowadays taking the architectural inducement into account, which means that most of the architectural environment which influences the evacuation behavior, is ignored. In this paper a concept model named AMUSE is presented based on an agent framework, with an agent that is designed to perceive the architectural environment as various clues, choose the right one and follow the related actions to evacuate in an underground space like real human beings would do. To investigate how the architectural clues take effect during the agent's decision making process in evacuation, the authors classified 10 types of the architectural foreground clues constituting a complete architectural vocabulary. In the future work, statistic data from a series of tests in virtual environments are planned to calibrate the model, which will finally result in a performance-based evaluation tool for the architect on the evacuation efficiency of the underground space design.

RESEARCH AIM

As argued by Rapoport and later on by Lawson, the architectural environment is composed of an architectural vocabulary transmitting a variety of meanings which is perceived by its users and influences their behavior (Rapoport 1982) (Lawson 2001). Erica Kuligowski performed a broad study on the 30 existing simulation models for evacuation simulation (Kuligowski and Peacock 2005), which indicated all the models use 2D plans, exits and stairs to define the architectural environment and don't use an architectural vocabulary. Thus they are very weak in the simulation on the architectural inducement upon the human trying to escape. A simulation model with the ability to describe the architectural environment by a complete architectural vocabulary that drives the human evacuation needs to be developed. Such a model would be complementary to the existing sub models in the evacuation simulation, such as individual character model, group behavior model, fire & smoke spreading model, etc. With this architecture-based model, a practical performance-based evaluation tool on the evacuation efficiency of the underground space design is being developed. The evacuation simulation tool will contribute to the emerging public security problem of the booming underground space development in China's metropolis in the coming 10 years.

AN ARCHITECTURE-BASED EVACUATION MODEL

The Assumptions

First, since testing an evacuation model under real circumstances is not possible, the assumption is made that 'normal' behavior is also a good estimate in an emergent situation. It was argued by Arthur and Passini that "If a setting works well under normal conditions, it will have a better chance of working well in emergency conditions." (Arthur and Passini 1992).
Second, the architectural vocabulary of an environment can be investigated purely by masking the other sub environments such as the sign environment, the interior decoration environment, the light environment, etc.
Third, without the interferences from the other sub models, the architectural vocabulary will not change from a normal situation to an emergent situation.
Fourth, the human beings perceive the architectural vocabulary mostly by their vision. The status of an architectural clue in the vision can be "Visible" or "Invisible", which is determined by the architectural environment, the human's position, orientation, view field angle and maximum visible distance.
Fifth, without the possibility of representing the pure architectural vocabulary as it exists in the real world, in this research it is represented and investigated in virtual environments.

The Architectural Clues In The Underground Spaces

In the Exosomatic Visual Architecture (Turner and Penn 2002), the researchers did a successful simulation of the human's natural movement (Gibson 1979), in which the agent's step was driven by the distance from the agent to the surrounding boundaries of the walkable surface. Driving the agent merely according to the walkable surface might mislead the agent in some cases, when the visible region is different from the walkable region such as a crossing bridge with two atriums on the both sides.

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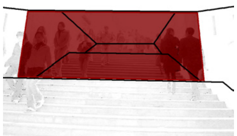
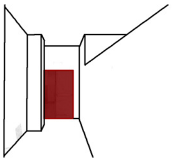
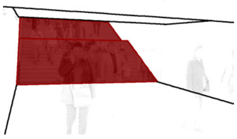
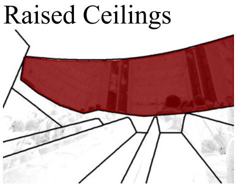
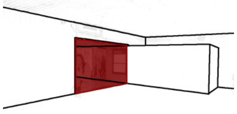
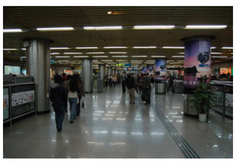
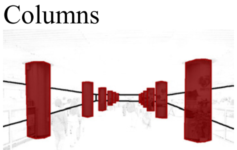
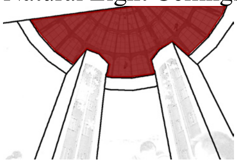
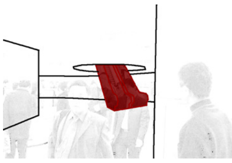
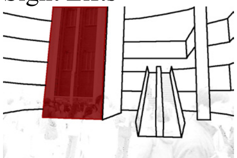
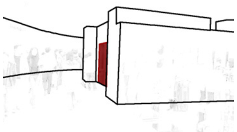
Therefore an additional method called "Sign Posting" is introduced by them, where a perceived spot in the environment can tell the further moving opportunity to the agent. The walkable surface detection plus the semiotic clue model is the basis of our simulation model. In our model, the Sign Posting spots are developed into a serial of architectural clue types, which tell the agent the information on evacuating direction rather than the natural movement. The authors called them Foreground Clues. Enclosing walls and handrails are considered Background Clues and will only have an effect on the agent's movement if no Foreground Clues are perceived. In total 10 types of Foreground Clues were identified after studying architectural environments. In Table 1 the Foreground Clues are listed by order of priority during the evacuation according to a questionnaire of 102 subjects in Shanghai. Other observations that were made through the questionnaire:

- In underground stations, exits are not always perceived as a safe direction, because they sometimes lead to other underground spaces and not to the outside space.
- Stopped escalators are used as normal stairs.
- In contrast with the fire escape regulations, some subjects choose lifts to evacuate.

Table 1: The Foreground Clues.

Real Scene	Foreground Clue	Related Actions
	Outdoors 	Approach it. Egress simulation terminates on arrival.
	Exits 	Approach it. Go out on the nearest level to the ground, and look ahead on arrival. Forbid the exit in the future decision making process.
	Stairs/Slopes 	Approach it. Go out on the nearest level to the ground, and look around on arrival.
	Raised Ceilings 	Approach the cg of the planar projection. Look around on arrival.
	Doorways 	Approach it. Go out along the normal line direction on arrival.
	Columns 	Observe the ends of the columns' axis. If there is no other Foreground Clue, move naturally without the detection on these columns.

	Natural Light Ceilings 	Approach the cg of the planar projection, look around on arrival.
	Escalators 	Approach it. Go out on the nearest level to the ground. Look around on arrival.
	Sight Lifts 	Approach it, look around on arrival. If without Foreground Clues, move naturally.
	Lifts 	Approach it, look around on arrival. If without Foreground Clues, move naturally.

AMUSE

The process of the evacuation in an architectural environment can be explained as the following sequence: (i) perceive architectural clues, (ii) interpret their meaning and (iii) take actions. Based on such a concept, the authors built the agent-based model AMUSE, using a "seeing, choosing and following clues" mechanism. All these architectural clues compose an architectural vocabulary, which supports the four evacuation strategies of Ozel (1987):

A. Going to the visible security targets, such as exits, fire stairs.

B. Following blindly, such as following the corridors or other persons.

C. Going along a serial decision points.

D. Going along a remembered path.

The architectural environment is modeled as a Remembered Environment and a Visible Environment (See Figure 1). The Visible Environment consists of Foreground Clues and Background Clues. The former are the architectural entities such as exits, stairs, which support the strategy A & C. The latter are the walkable surface defined by walls and handrails, which support strategy B. In the Remembered Environment all the Foreground Clues seen by the agent before the evacuation are transformed into remembered Foreground Clues, such as remembered exits and stairs along the entering path, which support the strategy D.

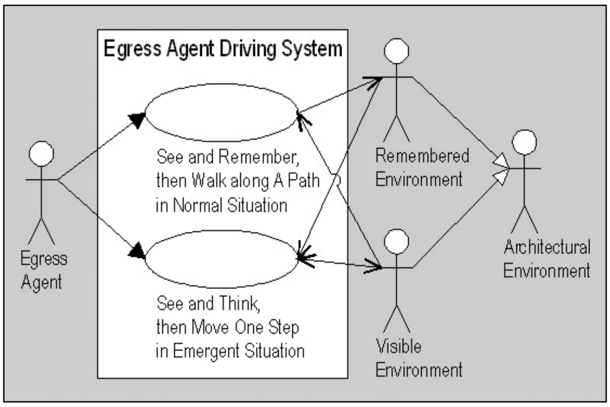


Figure 1: The Use Case Diagram of AMUSE

The agent perceives the architectural environment through its vision (See Figure 2). The Background Clue is only used for natural movement in the agent's decision making process, when there is no available Foreground Clue seen or remembered. The Foreground Clues' perception is based on the agent's view rendering ability, which enables the agent to see the architectural clue as a human does.

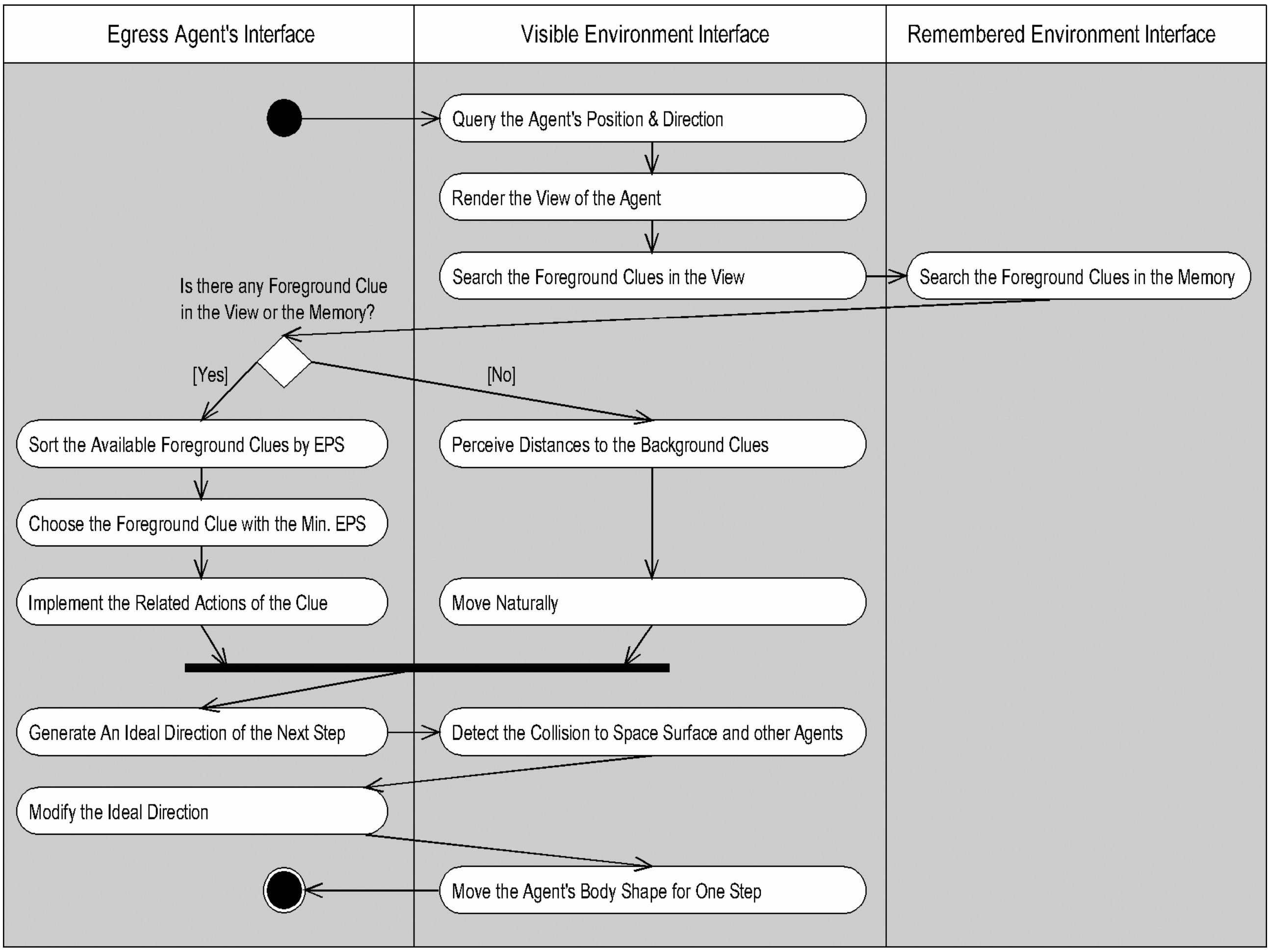


Figure 2: The Activity Diagram of the Egress Use Case in AMUSE

The communication between the agents is also based on the vision. The agents in the environment will be interpreted as Moving Obstacles and Moving Clues. The former means some Foreground Clues in the view field will be hidden by the other agent's body shape. The latter means the agent will regard the other agent's moving direction as stimuli, which will influence its following behavior. In our first prototype the agent will move at the speed of $1.5ms^{-1}$ with every step of 0.75m (Turner and Penn 2002).

The agent's decision-making process with regard to the evaluation of the perceived architectural clues is determined by the Evacuation Priority Score (Eq. 1). For All the Foreground Clues seen or remembered the agent will synthesize the relative weight, the distance from the clue and the direction angle with the clue, to calculate the EPS. The agent will sort the Foreground Clues and finally the Foreground Clue with the min. EPS will be chosen, and the related actions (see Table 1) will be implemented. The agent's evacuation simulation will run until all agents arrive at a Foreground Clue type of Outdoor.

$$EPS = W_i \times D \times A \tag{1}$$

Where:

W_i = the relative weight for every Foreground Clue type.

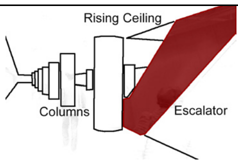
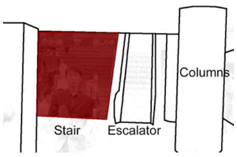
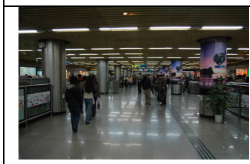
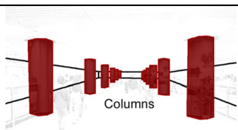
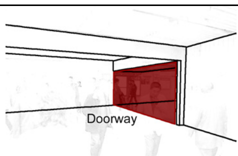
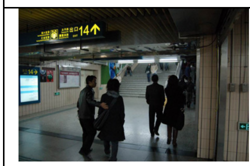
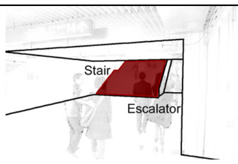
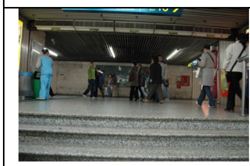
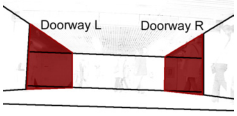
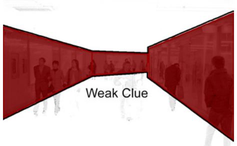
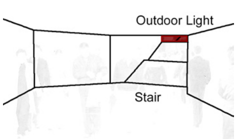
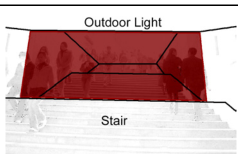
D = the distance from the agent to the clue. When D=0, use a very small value to replace it.

A = the direction angle from the agent moving direction to the clue.

AN ILLUSTRATION

To illustrate the model AMUSE clearly, the authors used the Xujiahui Subway Station as an example to demonstrate how the model works (Table 2). When the agent is supposed getting off a train and starting to evacuate, it uses the architectural clues in its vision to evacuate until it arrives at the architectural clue type Outdoor which is the termination of the evacuation.

Table 2: A Demonstrated Evacuation Route

<table>
<tr><th>Real Scene</th><th>Architectural Space</th><th>Agent's Behavior</th></tr>
<tr><td></td><td></td><td>After getting off the train, the agent arrives at the platform. There are 3 Foreground Clues: the columns, the raised ceiling and the escalator in the view. Through calculations on EPS it picks the escalator for the next step. Then it implements the related actions to move to it.</td></tr>
<tr><td></td><td></td><td>Arriving at the escalator, the agent "sees" the stair. Through calculations on EPS it picks the stairs instead of the escalator, and moves to it.</td></tr>
<tr><td></td><td></td><td>Arriving at the stair, the agent comes out at the upper level. In the view there is the Foreground Clue "columns". Then it moves along the columns.</td></tr>
<tr><td></td><td></td><td>At the end of the columns, the agent "sees" the Foreground Clue "doorway". Then the agent moving to the doorway.</td></tr>
<tr><td></td><td></td><td>During moving, the agent "sees" another Foreground Clue "stair" in the front. Through calculations on EPS it moves to it.</td></tr>
<tr><td></td><td></td><td>Arriving at the stair, the agent comes out at the upper level. Then the agent sees two doorways. It moves to the center of the two doorways.</td></tr>
<tr><td></td><td></td><td>Looking to the right, the agent doesn't see any Foreground Clue but Background Clue.</td></tr>
<tr><td></td><td></td><td>Looking to the left, the agent sees two Foreground Clues: stair and outdoor light. Through calculations on EPS the agent turns to left, and moves to the outdoor light.</td></tr>
<tr><td></td><td></td><td>Arriving at the outdoor light, the agent terminates the evacuation.</td></tr>
</table>

VIRTUAL TESTING IN THE FUTURE

To implement the model in a computer program the authors still have some parameters to determine through tests, such as the related actions of the 10 Foreground Clue types and the relative weights W1…W10 (Table 1). In a virtual testing environment the following series of tests are planned:

The first set of tests: 10 spaces, each containing one type of Foreground Clue, and subjects under evacuation. The program records the behavior patterns of the subjects during the evacuation, which can be used to adjust the related actions in Table 1.

The second set of tests: at most 10 virtual scenarios. In each there are two types of Foreground Clues at different distances. By changing one's distance dynamically and asking the subject to choose a clue to evacuate, we find a relative weight between all pairs of Foreground Clues. Finally, W1....W10 can be found. The same process will be repeated but for different angles.

The third set of tests: several virtual environments according to the underground space in real world. The subjects enter from one entrance and move to a certain position through the shortest path. Then they are requested to egress. The program can record the egress path, which can be compared with the simulated path. From this comparison conclusions can be drawn about the accuracy and about the reliability of the model.

Finally, the authors will develop a tool for the architectural design practices, based on the model AMUSE.

CONCLUSION

An architecture-based model AMUSE is proposed and presented in this paper. Ten types of architectural foreground clues that constitute a vocabulary abstracted from the architectural environment are concluded. These architectural foreground clues are a necessary part of any evacuation simulation method.

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AUTHOR BIOGRAPHIES

CHENGYU SUN was born in Shanghai, China. He studied architecture and obtained his degree in Tongji University. Now he leads a sub-project called "Evaluation System of the Evacuation Efficiency for the Underground Space Designs in Shanghai", which is a PhD project supervised by Bauke de Vries and also funded by National Natural Science Foundation of China (50408038). His email is: ibund@126.com.

BAUKE DE VRIES was born in The Netherlands. He is Professor at the Eindhoven University of Technology and chair of the Design Systems group. His e-mail is: B.d.Vries@tue.nl and his Web-page can be found at http://www.ds.arch.tue.nl/bauke.