Measure the Evacuees' Preference on Architectural Cues by CAVE

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Abstract: An evacuees' preference prediction function on architectural cues are described here as a crucial part of the evacuation model to simulate how the evacuees search the route to exit according to the architectural information in the public underground space. The model is developed to evaluate the egress design in the initial space design stage and to provide the existing compositive evacuation models a support on the usage of architectural information. First the over simplification on the architectural information in the existing evacuation models is discussed. Then a list of so-called architectural cues and the related evacuation model are introduced, in which the evacuees always egress to the seen or remembered architectural cue with the highest preference in every step. The emphasis of the paper is put on the analysis of the preference function including the CAVE-based conjoint analysis research method, the experiment design and implementation of the virtual drill, and the estimation of the parameters from the collected choices. The preference function for five architectural cue pairs, Doorway-Doorway, Stair-Stair, Exit-Exit, Doorway-Stair, Exit-Stair is built from the choice data of nearly one hundred Chinese subjects.

1. INTRODUCTION

The underground development in the mega cities is an inevitable solution for the endless land demand. With more and more multi-functional public spaces built in the underground and woven into each other, the underground space network has become very complex. To evaluate its security, performance-based evaluation methods depend heavily on evacuation models, which predicts the ASET (available safe egress time) and RSET (the required safe egress time) to be sure the former is longer than the latter (Tubbs, 2007). ASET is predicted by a set of models on fire and smoke dynamics. RSET is predicted by a set of models on human egress behaviour. As the starting point of RSET calculation, the predicted evacuees' routes to exit are the most basic and crucial part.

Arthur and Passini both argued that the evacuation is a kind of wayfinding, in which evacuees use the so-called cues that are all the information available in the environment to find the route to exit. The cues include the verbal (from information desk, staffs, etc.), the graphic (signage, map, etc.), the architectural (entrance, corridor, stair, etc.), and the spatial (how things relates to each other) (Arthur and Passini, 1990, Passini, 1984). Additionally, the information derived from the other evacuees' movement is also regarded as a useful cue to find the way out (Helbing, 2000, Murakami, 2002, Schadschneider, 2001, Was, 2006).

In contrast with the other well investigated information sources, the architectural information is over simplified, or just used as a movement constraint. In general, according to the methods to compute the route to exit, these evacuation models can be classified into the global information based and the local information based (Hostikka, 2007, Kuligowski, 2005, Pan, 2006). Obviously the visitors are mostly unfamiliar with the environment in the public underground space and have no exterior building form to understand the circulation system, which make it impossible for them to have the global information. In the local information based category, there are three branches: none architectural (signage based, e.g. PEDroute), subjective architectural (operator designating the importance for every part of the space, e.g. BGRAF), and hypothesized architectural (using random constrain searching or shortest route to visible exit, e.g. MASSegress). None of these branches use the architectural information properly. Because no architectural information is used; or the operator's comprehension on the space is not always the same as the evacuee's; or the evacuees will not always take the shortest visible exit. Several evidences are also available in the validations of the models: FDS+Evac, MASSegress, CRISP3, EGRESS, EVACNET4, EXIT89, WAYOUT, which indicates that there are obvious differences between the simulated route to exit and the evacuees' routes (Hostikka, 2007, Kuligowski, 2005). The former lacks an architectural information support.

In this research an agent-based evacuation simulation model is developed to predict how the evacuees will use the architectural cues to find their route to exit, which can be used to evaluate the space design independently in the initial stage and be integrated into the existing compositive evacuation models to provide supports on architectural information. Other information sources such as the signage, cognitive map, crowd and threatening situation are not considered in this model. The core of the model is a preference function to predict the evacuees' choice among the architectural cues to be the goal of the next step. With the assumption "If a setting works well under normal conditions, it will have a better chance of working well in emergency conditions." (Arthur and Passini 1992) a set of CAVE-based experiments are implemented to collect about one hundred subjects' choices on difference architectural cue pairs. Then the preference function is built from these data by conjoint analysis method.

The outline of the paper is as follows: First we will describe the list of architectural cues and the framework of the whole model. Next the focus is put on the research how to measure the evacuees' preference including the method, the experiment design and the data analysis. We will finish with conclusions and outlooks.

2. ARCHITECTURAL CUE MODEL FOR UNDERGROUND SPACE EVACUATION

From previous research (Sun and Vries 2006) a list of recognizable architectural cues was deduced from questionnaires, namely Outdoors, Exits, Stairs, Slopes, Escalator, Raised Ceilings, Columns and Doorways. Three main cues: Doorway, Stair / Slope / Escalator, and Exit are selected from the list to be the elementary architectural cues of the model in this stage according to Tubbs' Egress Design Checklist (Tubbs, 2007).

The model assumes that from the architectural cues in sight and memory, the evacuee selects the architectural cue with the highest preference and approach to it. If he passed an Exit cue or a Stair cue to the ground level, the evacuation terminates. Otherwise, he will see, choose and move again and again. After a stair is used, all the remembered stairs and doorways are forgotten. After a doorway is passed, all the remembered doorways are forgotten. When there is no cue available, the evacuee turns back (Fig. 1).

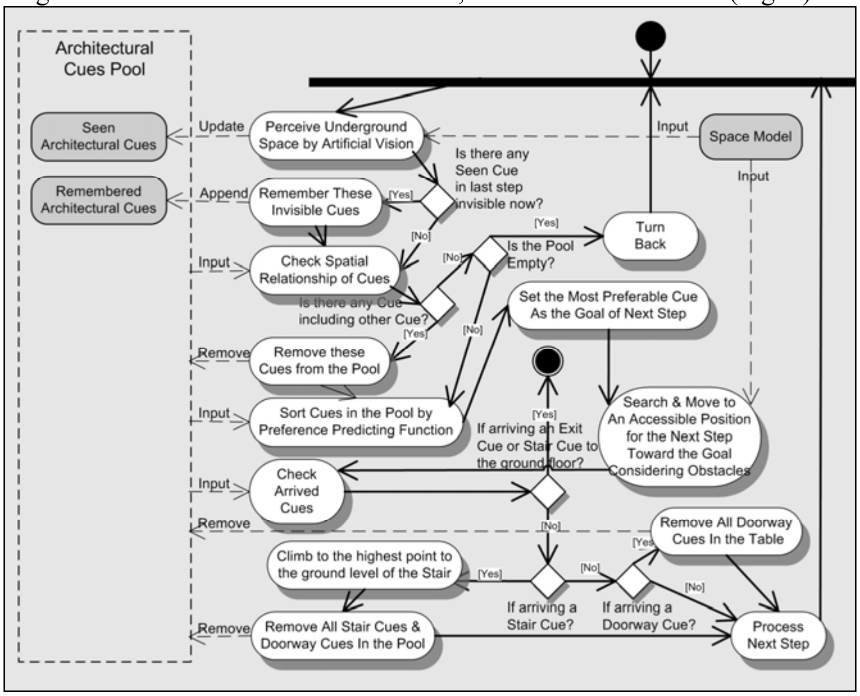

Figure 1. The framework of Architectural Cue Model

To simulate this process, the agent uses its artificial vision to perceive the environment and recognize the three kinds of elementary cues in the 3-dimensional space to support the decision making during the evacuation simulation. The pixel-based recognition algorithm of the cues in the agent's vision will be presented in another publication. In the following section the research is described to measure the evacuees' preference on the architectural cues to build the crucial preference function in this model.

3. RESEARCH METHOD

To observe the evacuees' preference only on the architectural cue, the authors used the experimental psychology research method with controlled stimulant to the subjects in a CAVE-based virtual drill. The subjects' choices between the cue pairs as the responses to the stimulants are regressed into evacuees' preference by the Conjoint Analysis approach.

3.1 CAVE-based Conjoint Analysis

Concerning the risk of the real environment evacuation based observation (Arthur and Passini, 1992) and the interferences from the other non-architectural information, the authors regarded the laboratory experiment based observation as the suitable solution for the research.

The experimental psychology develops its research methods from paper-and-pencil technique to visual aided techniques and simulations (Bovy and Stern, 1990). Recently, the virtual reality technology was argued as a better solution for the space related research. It features (Tan, 2003):

The avoidance from the risks in real environment;

The sense of time and space;

The interaction between the subject and the environment;

The complete control of stimulants;

The built-in technique to record the subjects' response.

Among the virtual reality techniques, CAVE system is the only one that is capable to provide the similar view field as human beings and the sense of scale and distance (Friedman, 2005), which is necessary for the virtual drill. Consequently, a CAVE system was built for the research. Similar to the other CAVE-based preference researches e.g. ICARUS (Dijkstra, 1999), the preference function is surveyed according to the Conjoint Analysis approach, in which the architectural cues are presented as paired evacuation directions to the subjects in a set of scenes designed carefully. The subjects are asked to evacuate in this virtual scene by choosing one of the two cues as the egress direction. The recorded choices are collected and used to estimate the parameters of the evacuees' preference function (Eq.1).

$$p(c_i) = \frac{e^{z_i}}{e^{z_i} + e^0} \qquad (1)$$

Where:

$p(c_i)$ is the probability of cue *i* being chosen in the cue pair;

$Z_i = \beta_{type} + \beta_{side} + \beta_{A1} + \beta_{A2} + \beta_d + \beta_w + \beta_h + \beta_0$

β_0 is the intercept. β_i is the B value related to the variable level.

3.2 Attributes of the Architectural Cues

The variables of the above function map to the attributes of the architectural cues, which are defined as the following (Fig. 2, 3, 4):

The cue type is defined as TYPE.

The side of the cue in a cue pair is defined as LR.

The distance from the cue to observation point, defined as D.

The width of the cue is defined as W.

The height of the cue is defined as H.

The angle between the direction of the view direction and the cue is defined as A1.

The angle between the direction of the view direction and the cue direction is defined as A2.

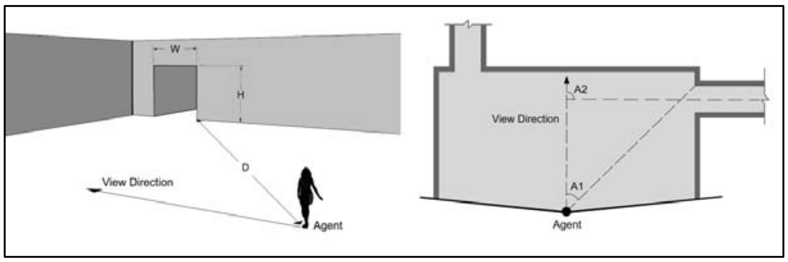

Figure 2. Variables of Doorway

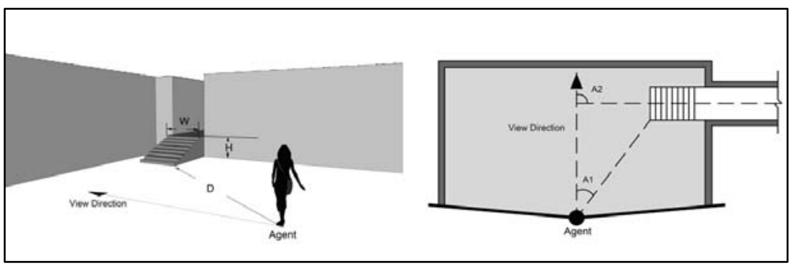

Figure 3. Variables of Stair / Slope / Escalator

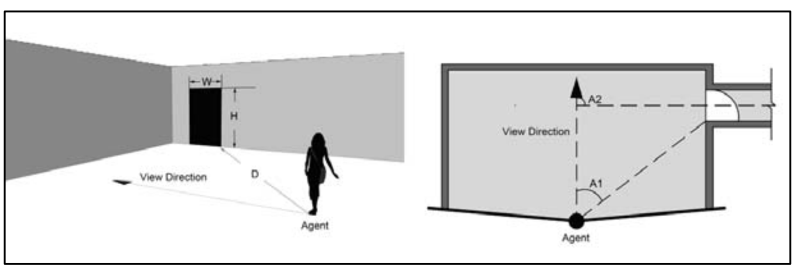

Figure 4. Variables of Exit

3.3 The Design of Scenes with Paired Cues

The three elementary cues are combined into five kinds of cue pairs each related with a set of scenes with the attributes at different levels. The Doorway-Exit pair is not included in the experiment because of the obvious evacuation preference on them. According to the practical values used in the underground design and the size of the subjects, the levels and the corresponding profiles of the five scene sets are designed as in Table 1.

Table 1. Design of the variable level and scene profile

Scene Type	Levels of the Variables							Number of Scenes By Fractional Factorial Design
	Type	LR	A1	A2	D	H	W	
Doorway Doorway	n/a	2	7	7	7	5	7	49
Stair Stair	n/a	2	7	7	7	5	7	49
Exit Exit	n/a	2	7	7	7	5	7	49
Doorway Stair	2	2	7	9	7	5	7	81
Exit Stair	2	2	7	9	7	5	7	81

3.4 Encoding & Decoding

Every scene is generated into a set of variable levels by factional factorial design. For an example, the generated scene No.39 in Stair-Exit set is indicated in Table 2.

Next, the levels are decoded into attribute values of the two cues in one scene. The level of variable "Type" maps to Doorway, Stair, or Exit. The level of variable "LR" maps to the Left or Right side the cue is on to the other. The level of the variable "A1" maps to the ratio between the two A1 attribute values of the both sides. The level mapping of the other variables "A2", "D", "H", "W" is the same as A1. When the pair contains only one kind of cue, the ratio is the value of the left cue to the value of the right. When the pair contains two different kinds of cues, the ratio is the value of the stair to the value of the other cue. The exact values of the both sides of a pair are assigned by the ratio and the underground design practise. Scene No.39 is decoded in Table 3.

When the subject makes a choice between the two cues, the choice will be recorded into two rows of variables with the levels encoded again. In the cue pair with the same cue type, the first row is encoded from the left cue. The second is for the right. In the cue pair with the different cue types, the first row is encoded from the cue of Stair. The second is for the other cue. If the cue is picked, the variable “Chosen” is set to 1, otherwise 0. If the cue is a Stair, variable “Cue Type” is set to 1, otherwise 0. If the cue is on the right side to the other, the variable “Side” is set to 1, otherwise 0. To achieve a high resolution capable to distinguish the ratio of the left to the right from the ratio of the right to the left, or the ratio of the stair to the other from the ratio of the other to the stair, the number of levels in the scene generation (Table 1.) is doubled. Scene No.39 is taken as an example in Table 4.

With these rows, the parameters of the evacuees’ preference function can be estimated by the Multi-nomial Logistic Regression module in SPSS.

Table 2. Designed Levels of Scene No.39 in Stair-Exit set

ID	**Left Cue Type Level**	**Ratio Level**				
		A1	**A2**	**D**	**W**	**H**
39	2	1	7	5	7	4

Table 3. Practical Dimensions of Scene No.39 in Stair-Exit set

ID	**Left Type**	**Right Type**	**lA1-rA1 (degree)**	**lA2-rA2 (degree)**	**lD-rD (meter)**	**lW-rW (meter)**	**lH-rH (meter)**
39	Exit	Stair	60 : 7.5	5 : 40	10 : 20	1 : 7.2	2.5 : 5.0

Table 4. Recorded Data of Scene No.39 in Stair-Exit set

Chosen	**Cue Type**	**Side**	**A1**	**A2**	**D**	**W**	**H**
1	1	1	1	7	5	7	4
0	0	0	14	12	10	8	7

4. EXPERIMENT

The CAVE-based virtual drill was executed in Oct 1st-7th, 2007 at College of Architecture and Urban Planning, Tongji University. The first group of subjects are 96 undergraduate students from grade 1 to 4. They did the drill for scene sets of Doorway-Doorway, Stair-Stair and Stair-Doorway. The second group of subjects are 91 undergraduate students from grade 1 to 4. They did the drill for scene sets of Exit-Exit, Stair-Exit and one extra scene of Doorway-Doorway. One subject’s record of a Stair-Exit scene missed.

4.1 The Experiment Facilities

A special CAVE system is designed and built for this experiment, which provides all the observers a same observing height by the "height adjuster" and a wide view field (180 degree in horizontal and 70 degree in vertical). Such a special design moves the eyes of the observer to 1.75m above the ground and enables them to see an object 7.5m above the ground at a distance of 5m. (Fig. 5).

To impose some stress on the subjects, they are asked to complete the evacuation choices as soon as possible for a higher score. Moreover they hear a noisy alarming sound during the experiment. And they can notice a counting down timer in the view. All these strategies make the subjects strained through the experiment.

To avoid the operational preferences of the mouse or the arrow keys by one hand, the subjects are asked to use the both hands, the left one on key Z to run toward the left side and the right hand on key M to run toward the right side.

The evacuating choices of all the subjects are composed of the side of choice, the cue type and the geometric features at every key stroke, which is recorded by a Visual Basic program.

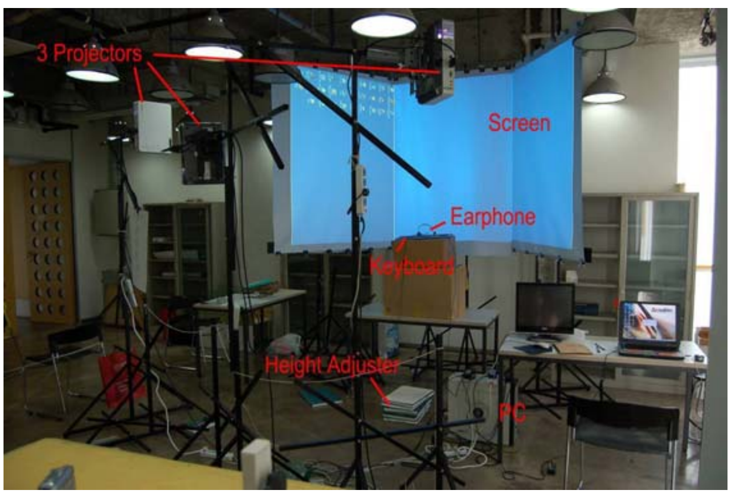

Figure 5. The CAVE for the experiment

4.2 The Experiment Procedure

Every subject is asked to hear a recorded direction first, in which they are told that they are staying in a set of underground spaces. There is an alarming sound urging all the persons to evacuate as soon as possible for some emergent situation. Most persons have evacuated successfully. He is the only person in this space. He or she can press Key Z to run toward the left architectural cue in the scene or Key M toward the right to evacuate to the most likely safe direction by their instinct. All the scenes that they explore are separated and not related to each other in space.

Then the experiment assistant tunes up the height adjustor to set the observer's eyes on a proper height. After he practices choosing between the left and right cues in the virtual environment, the virtual evacuation choice sampling starts. The subjects can notice a counting down timer on the screen during their decision making. And they are told that the time of the choices is used for scoring. With such a kind of pressure all the choices of the scenes are recorded for further estimation (Fig. 6).

To keep the subjects fresh in mind, the time period of the experiment for one subject is designed within 10 minutes. The average time of the first group on the 49 scenes of Doorway-Doorway, the 49 scenes of Stair-Stair and the 81 scenes of Stair-Doorway is about 6 minutes. The average time of the second group on the 49 scenes of Exit-Exit and the 81 scenes of Stair-Exit is about half and 4 minutes.

Figure 6. A subject is making choice between two stairs

5. ANALYSES

After the experiment, the subjects' choices on the five kinds of cue pairs were collected. They are 4795 choices on Doorway-Doorway, 4704 choices on Stair-Stair, 4459 choices on Exit-Exit, 7776 choices on Stair-Doorway, and 7370 choices on Stair-Exit.

5.1 The Model Performance

The five sets of parameters of Eq. 1 were estimated from the corresponding choices by Multi-nomial Logistic Regression module in SPSS. The five sets of parameters are ranked from low to high by the McFadden R square and the Overall Predicted Correction Percentage, which indicates the good-of-fitness and the prediction performance of the model (Table 5.).

It is obvious that to make choice between Stair and Doorway is much easier and with more confidence than to make choice between two Doorways for an evacuee in the underground. Thus, the performance disparity between the five kinds of cue pairs corresponds to the uncertainty of the choice itself naturally.

Table 5. The performance of the model

Cue Pair Type	**McFadden R square**	**Overall Predicted Correction Percentage**
Doorway Doorway	0.105	65.1%
Stair Exit	0.149	69.2%
Stair Stair	0.209	71.8%
Exit Exit	0.220	73.5%
Stair Doorway	0.314	79.7%

5.2 The Attributes of Architectural Cues

In Fig. 7-11 the estimated parameters also indicate the relationship between the weight and the ratio. To illustrate the symmetry of the ratio, it is pre-processed by a logarithm function. The trend of these curves indicates that reducing Distance, or increasing Width, or increasing Height can all raise the preference of a cue being chosen. In contrast, increasing Distance, or reducing Width, or reducing Height can make the preference to decline.

From these curves it is also clear that the variable Distance usually has a larger weight value range than the other variables, except for the variable Width in Doorway-Doorway pair. Such an observation may be an ostensible evidence to support the assumption used by some evacuation models that the evacuees always run to the closest exit or staircase. However, it is indeed all the variables that influence the preference of the cue being chosen in concert.

The variable utility on the preference is different for sure according to the weight value range of each variable. From the view of an architect, some variables can be configured in the design process such as the variable Cue Type, D, W and H. The others are varying dynamically according to the evacuee's orientation such as the variable A1, A2 and LR, which are out of their control. Then the variable Cue Type, D, W and H are observed for their utilities on the preference. The abilities of the variable to influence the cue choice are indicated in the following Table 6, which is related to the weight value ranges.

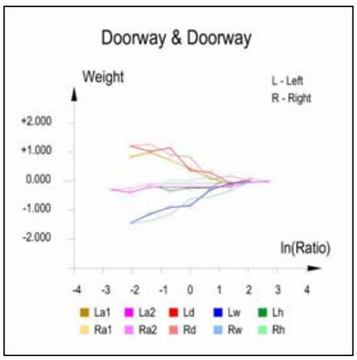

Figure 7. Curves of Doorway-Doorway

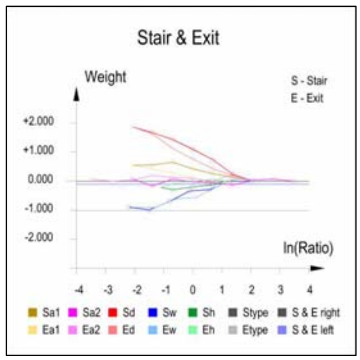

Figure 8. Curves of Stair-Exit

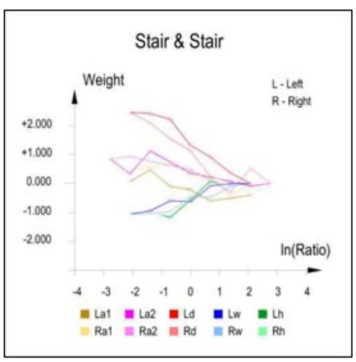

Figure 9. Curves of Stair-Stair

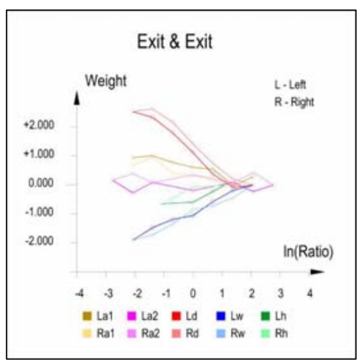

Figure 10. Curves of Exit-Exit

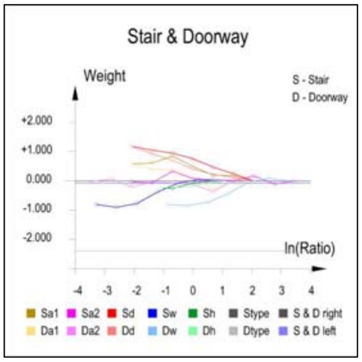

Figure 11. Curves of Stair-Doorway

Table 6. The variable utility on the preference

Cue Pair Type	**Ability to influence the preference (range of B value from Eq.1)**
Doorway Doorway	Width > Distance > Height 1.449 > 1.352 > 0.474
Stair Exit	Distance > Width ≈ Cue Type > Height 1.875 > 1.08 ≈ 1.009 > 0.373
Stair Stair	Distance > Height > Width 2.473 > 1.267 > 1.043
Exit Exit	Distance > Width > Height 2.713 > 1.909 > 0.663
Stair Doorway	Cue Type > Distance > Width > Height 2.392 > 1.184 > 0.997 > 0.271

5.3 Preference between Stair and Exit

There is an obvious and interesting evidence indicating subjects have a propensity to choose a stair rather than an exit sometimes. The weight value range of Variable Type is 1.009, which can have a great impact on the over all preference function comparing to the weight value ranges of the other variables (D: 1.875, W: 1.08, H: 0.373). With several interviews after the experiment, the authors realized that the preference between Stair and Exit is greatly affects by the tons of reports about the death caused by the blocked exits on TV and Radio in Shanghai. So the local social background does have an impact on the evacuees' preference.

6. CONCLUSIONS

The measured evacuees' preference function on architectural cues can predict their choices at different levels of correction according to the ease or difficulty of the choice itself. Ranked from the highest correction choice pair to the lowest they are: Stair-Doorway, Exit-Exit, Stair-Exit, Stair-Stair, Doorway-Doorway. This result is very natural when we recall how easy we making choice between Stair and Doorway, and how difficult we searching a way out in a labyrinth only with doorways.

The preference function indicates that all the attributes effect the choice on the architectural cues, not only distance but also width, height and the directions. Consequently the assumption that evacuees always go to the exit with shortest distance is incorrect. The other variables should be also considered simultaneously. For example, it might be possible that a further doorway but much wider is more attractive than a closer one but much narrower, which was also observed in a previous experiment (Sun and de Vries, 2007). However, the impact of the variable on the preference is different indicated by its weight value range. The Distance is the most powerful attribute in the four kinds of cue pairs, except for Doorway-Doorway pair, in which the Width is the most powerful one and it is always a competitor to Distance in the other cue pairs. Moreover, Height becomes the second powerful attribute in Stair-Stair pair naturally.

The preference to Stair rather than Exit indicates the local social effect on searching the route to exit. This observation is an evidence for the argument of social effect on human behaviour in built environment (Hall, 1966).

7. SUMMARY & OUTLOOK

In this paper, a CAVE-based experiment measuring the evacuees' preference on architectural cues is introduced. The research method has proven that a paired cue evacuation decision model can be constructed through the Conjoint Analysis method. According to the preference function the nearest exit assumption in other evacuation models is questionable in some circumstances. Moreover, a set of architectural cue attributes and their quantitive utilities on the preference are discovered.

The next step in this research project is to validate the architectural cue model supported by this preference function. Finally the model will be integrated into a CAD system to support architects in evaluating their underground designs and enhance the other compositive evacuation models.

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