A VISION-BASED SIMULATION SYSTEM OF NAVIGATION THROUGH VIRTUAL ENVIRONMENT

Qunli Chen
Department of Architecture, Building and Planning
Eindhoven University of Technology
P.O. Box 513, 5600 MB, Eindhoven, the Netherlands
Email: Q.Chen@tue.nl

Bauke de Vries
Department of Architecture, Building and Planning
Eindhoven University of Technology
P.O. Box 513, 5600 MB, Eindhoven, the Netherlands
Email: B.d.Vries@tue.nl

Chengyu Sun
College of Architecture and Urban Planning
Tongji University
200092 Shanghai, P.R. China
Email: ibund@126.com

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ABSTRACT

Current wayfinding simulation systems take little account of the architectural information in the built environment, which indicates that, there is an underestimation of the influence of architectural information on individual's wayfinding behaviour. In presented studies, a vision-based simulation system is introduced. In this simulation system, an agent is designed to navigate through virtual built environments with only architectural information provided. The decisions made by this agent on the egress in each room are determined by agent's familiarity of current environment. Familiarity of the environment will increase as the agent's exploring of the virtual environment.

INTRODUCTION

Finding a way to certain destination is one of the most inevitable behaviours in our daily life, and it has been extensively studied in the last 50 years. In wayfinding tasks, several kinds of cues can be used, namely the verbal (information obtained from the reception, staff members, etc.), the graphic (map of the environment, signage showing the location or pointing to certain location, etc.), the architectural (entrances, stairs, corridors, etc.), and the spatial (spatial relationship of objects in the environment) (Arthur and Passini 1992; Passini 1984). Early analyses of indoor wayfinding suggested that signage and colour codes could provide landmarks, but the addition of these cues after construction can be futile (Passini and Shiels 1987). This suggests that, architectural information has a significant influence on human's decision making during their wayfinding. However, in most researches, the function of the architectural information was underestimated -- it was often treated as the constraint of the architectural spaces.

Recently, Sun (2009; 2006) developed a model for underground space evacuation simulation. In this model, based on the architectural information perceived, the agent makes choices on the egresses such that it could escape from the underground space in a short time. Sun's research provides a good start on how the architectural information will affect human's decision making, however, his work suffers from a number of limitations. Firstly, room illumination in the built environment is not considered. Secondly, in his model, egresses of the same type are painted with the same colour, as a consequence, agent's choices on the egresses are influenced by the specific colour assigned to certain egress types. Last but not least, in his simulation system, the agent cannot turn back to visited rooms, which is implausible in reality.

In this paper, we will present a vision-based system which simulates human wayfinding behaviour in virtual office environment with only architectural information provided. Following an introduction on the architectural information in the built environment, we will present the modules composed the simulation system in detail, especially the Information Perception module and the Egress Choosing module. In the end of this paper, we will conclude the current status of this simulation system and provide an outlook of further work.

ARCHITECTURAL INFORMATION IN WAYFINDING

As people interact with the environment, they perceive information and acquire knowledge from surrounding spaces. Many researches investigate various visual cues that would be acquired from surrounding spaces in the context wayfinding (Cutting and Vishton 1995; de Kort, Ijsselsteijn et al. 2003; Ijsselsteijn, de Ridder et al. 2000; Janzen, Schade et al. 2001; Nash, Edwards et al. 2000; Riecke, Veen et al. 2002). Rapoport (Rapoport 1982) summaries these visual cues into three categories with clearer framework, namely Non-fixed cues, Semi-fixed cues, and Fixed-cues. Non-fixed cues are defined as pieces of information that can be perceived from dynamic objects (e.g. interaction between humans). Located in the built environment, Semi-fixed cues are some special objects that can be reconstructed with ease. Objects like maps, signs, and different decorations are semi-fixed cues. These cues will provide information on egress direction in the built

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environment. The last cue category, the Fixed-cues, also offer information on egress direction in the built environment, however these cues are part of the built environment and thus they are difficult to be reconstructed. Fixed cue is also called architectural cue, and according to Passini's argument on wayfinding strategies (Passini 1984), it can be divided into categories, namely global architectural cue and local architectural cue.

Global architectural cues can be perceived from building forms, and these cues provide information on the spatial relationships between different parts of the built environment. Four types of sources in the built environment can provide global architectural information：the circulation system, the exterior form of the building, the visible structural frameworks, and the atrium. An individual will have certain familiarity of the built environment when he perceives the global architectural cues. Based on his familiarity of the entire environment, he could split the wayfinding task into sequential parts. In other words, the individual could plan his wayfinding when he perceived global architectural cue of the built environment.

On the contrary, local architectural cues can be perceived from three-dimensional geometric features of the local architectural elements (e.g. stairs, entrances, corridors). Perceiving local architectural cues will not increase the individual's familiarity of the entire built environment. In fact, an individual can only gain more familiarity by exploring more of the built environment. Furthermore, this individual cannot make any plan on wayfinding. Sun summaries four types of sources where we can obtain local architectural cues in a built environment (Sun 2009): the types of the architectural element in the circulation system, distance from the architectural elements to the individual, the scale of the architectural element, and the angular position of the architectural elements in the individual's view.

FRAMEWORK OF THE MODEL

Several modules are embedded in our simulation system, namely Information Perception module, Egress Choosing module and Move module. In the Information Perception module, the rendered image of captured scene will be converted to a depth estimation image and a grey-scaled image, with which the architectural information in current scene can be directly obtained, or calculated based on obtained information. A certain search strategy will be chosen in the Egress Choosing module, given the architectural information in current scene and agent's familiarity in the current room. Finally, the agent will execute the decision made in the Egress Choosing module, and then steps into a new room. Figure 1 shows how these modules compose the simulation system.

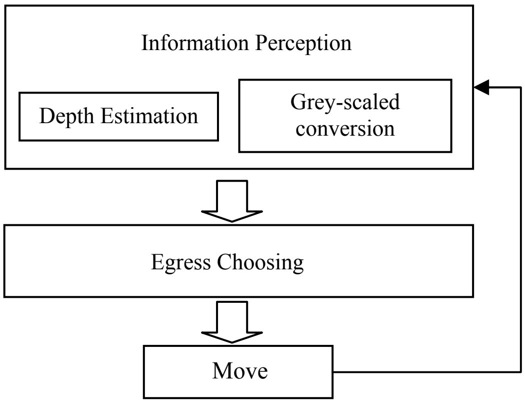

Figure 1: Framework of the simulation model

INFORMATION PERCEPTION MODULE

In this section, we will present how the rendered image of current scene will be converted into a depth estimation image and a grey-scaled image, and what kind of architectural information will be obtained from these images.

Image Conversion

Synthetic vision is implemented in our simulation system for perceiving visual objects in the build environment. The rendering technique of the computer graphics enables our agent to perceive architectural information within its viewing field in the current room.

Before the image of current scene is rendered, a measurement of the room illumination in the current room will be conducted. According to our findings in previous experiments, human will well perceive the visual objects in virtual environment as they do in reality only when the room illumination in the virtual environment is higher than 35 lux. In the virtual environment, room illuminations lower than 35 lux will lead misrecognition of the perceived object even when the geometry of this object is relatively simple.

Once the agent finds the room illumination in the current room is higher than 35 lux, an image of current view will be rendered. Next, a grey-scaled image and a depth estimation image will be generated, as shown in Figure 2.

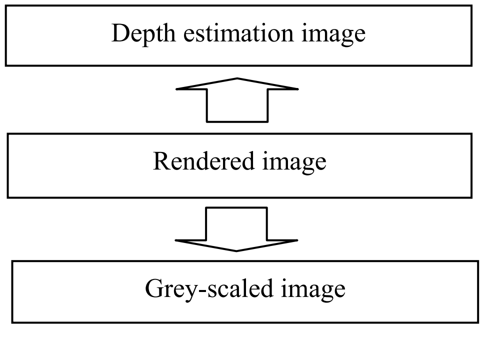

Figure 2: Conversion of the rendered image

Depth Estimation
A Z-buffering filter is employed in the conversion process from the rendered image to the depth estimation image. As a result, given a rendered image of current scene, our agent knows the distance from its observation point to any of the object pixels within its viewing field in the image.

Grey-scaled Conversion
A grey-scaled filter is applied to convert the rendered RGB image into a grey-scale image (grey level ranging between 0 and 100). After the conversion, grey levels of the architectural cues will be normalised into three levels, namely dark (grey level = 25), medium (grey level = 50), and bright (grey level = 75).

In the simulation system, we assume that the ceilings and the floors in the same built environment are designed of the same colour respectively, which indicates that, they cannot provide any useful information during agent's wayfinding. As a result, the grey level normalization of the ceiling and the floor are ignored.

In most of the built environment, global illumination is applied. Therefore, after conversion and normalisation in the rendered image, each architectural cue in the scene will only hold one grey value. Figure 3 is a sample of the converted grey-scaled image.

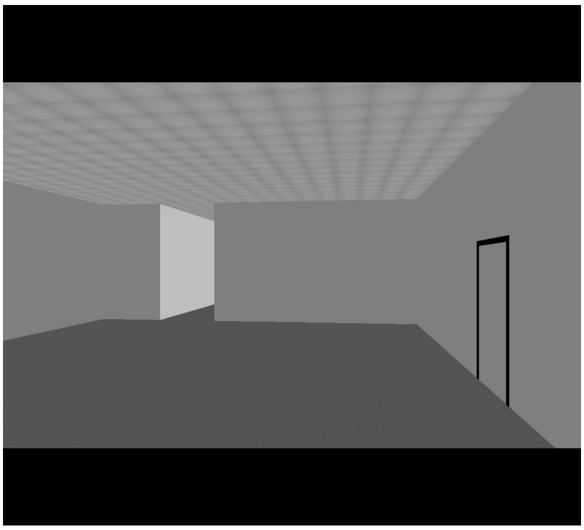

Figure 3: A transformed grey-scale image sample

Architectural Information Acquisition

The rendered image itself is in fact a pixel array, where architectural cues of the built environment in view are patterns in this pixel array. By accessing the information stored in each pixel in this pixel array, the agent will obtain information of the room and egresses in current environment. Room information includes room ID, the size of the current room, the grey level of the room (the room is composed of a number of walls, thus the grey level of these walls is the grey level of the room), and whether or not there is a landmark in the current room; egress information includes egress ID, egress grey level, and egress width (see Figure 4). Special isolated objects, which are semi-fixed cues according to Rapoport's definition (Rapoport 1982), are treated as landmarks in the built environment.

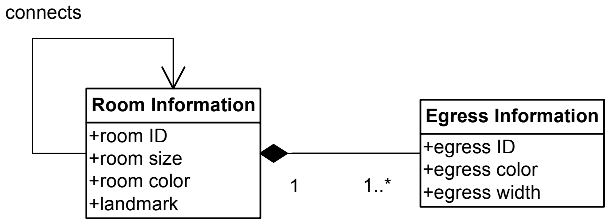

Figure 4: Simplified class diagram of the information perceived in the build environment

In our simulation system, doors and corridors are all recognised as egresses. When the perceived egress is a door, egress ID and door width can be obtained from the pixel information in the rendered images directly. When the perceived egress is a corridor, the width of this corridor can be calculated from the distance (D_1, D_2) and the angle (A_1) (see Figure 5).

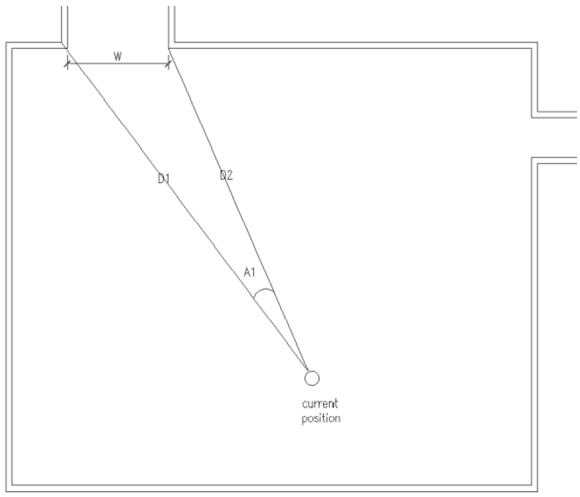

Figure 5: Width of the corridor can be calculated

EGRESS CHOOSING MODULE

Based on the information obtained in the Information Perception module, our agent needs to select a search strategy as to choose an egress in the current room. According to agent's familiarity of current environment, all searching strategies are categorized into two groups: search in a new room, and search in a visited room. Details of these search strategies will be presented in the following.

Search In A New Room

When the agent steps into a room for the first time, it has no knowledge of this room. As a result, it will select one of the following searching strategies to approach the destination: random walk, follow the boundary, and perceive egresses features.

Random Walk
Random walk is one extreme case of search strategies. With this search strategy, the agent will make a random choice on the egresses in the current room, regardless of the information perceived in this room. In other words, each egress within the agent's viewing field has equal probability to be chosen.

Follow The Boundary
If the agent finds that the current room is one of the boundary rooms in the entire environment, it may simply follow the boundary on the left or right hand to see whether or not the destination is along the boundary.

Perceive Egress Features
With this search strategy the agent will choose an egress based on the preference function deduced from our earlier experiments. In our earlier experiments, we find that among several attributes that influence individual's decision on the egress in the built environment with only architectural information provided, the width of the egress (W), the grey level contrast of the egress and the room (G), and the gender of the individual are of great significance according to the analysis based on data collected from real human navigation in a virtual environment. According to our analysis, the predicted probability that an egress will be chosen in a cue pair is determined by:

$$p_i = \frac{e^{Z_{picked}}}{e^{Z_{picked}} + e^{Z_{unpicked}}} \qquad (1)$$

Where:
p_i is predicted probability of an egress being chosen in a cue pair
$Z_{\text{picked}} = \beta_0 + \beta_1 \text{W} + \beta_2 \text{G} + \beta_3 Gender$

$Z_{\text{unpicked}} = 0$ (the alternative in the choice set)

β_0 is the B value of the intercept

β_i is the B value of a specific variable level

Search In A Visited Room

If the agent has visited the current room, it will hold certain familiarity of this room. Accordingly, it will apply some different searching strategies, namely random walk, follow boundary, follow a known route, and follow orientation.

Random Walk
It is possible that the agent will apply the random walk search strategy, despite the fact that it has visited the current room before: the agent will treat the visited room as a new room, and makes random choice on the egresses in this room.

Follow Boundary
Even though the agent has visited the current room, it may still follow the boundary to see whether or not the destination is along the boundary.

Follow A Known Route
If the agent finds the current room is a visited room, it might follow a known route. In other words, the agent will retrieve the decision made on the egresses last time and choose the same egress again.

Follow Orientation
In this search strategy, we assume that the agent will make use of its build-in "compass": as long as the agent knows the orientation of the destination, it will simply choose an egress which will lead a closer direction orientating to the destination, regardless of the architectural information in the environment.

We apply the following algorithm to calculate which egress has a higher probability to lead to the destination orientation. In our algorithm, we define S(x, y) as the middle point of the start, D(x, y) as the middle point of the destination room, C(x, y) as our agent's current position, and P_i(x, y) as egresses positions (middle point of the egresses) in the current room. Figure 6 shows the relationships between DS, SC and θ. In this figure, SD is the distance between the start and the destination, SC is the distance between the start and agent's current position, and θ is the angle between line SC and line SD. Smaller angle θ indicates closer of point C against line SD. When point C is close enough to line SD, the direction of line SD will have little difference with the direction of line CD.

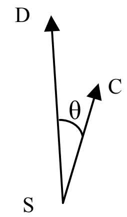

Figure 6：Relations of the start room, destination room, and agent's current position

In each room, except for the entrance, there will be a number of egresses that can be chosen, and each of them holds a fixed θ against the line SD, we name them as θ_i. Given the value of $\cos\theta_i$ (the value can be calculated following the law of cosine), the probability each egress being chosen with the follow orientation search strategy will be:

$$p_i = \frac{\cos\theta_i}{\sum \cos\theta_i}.$$

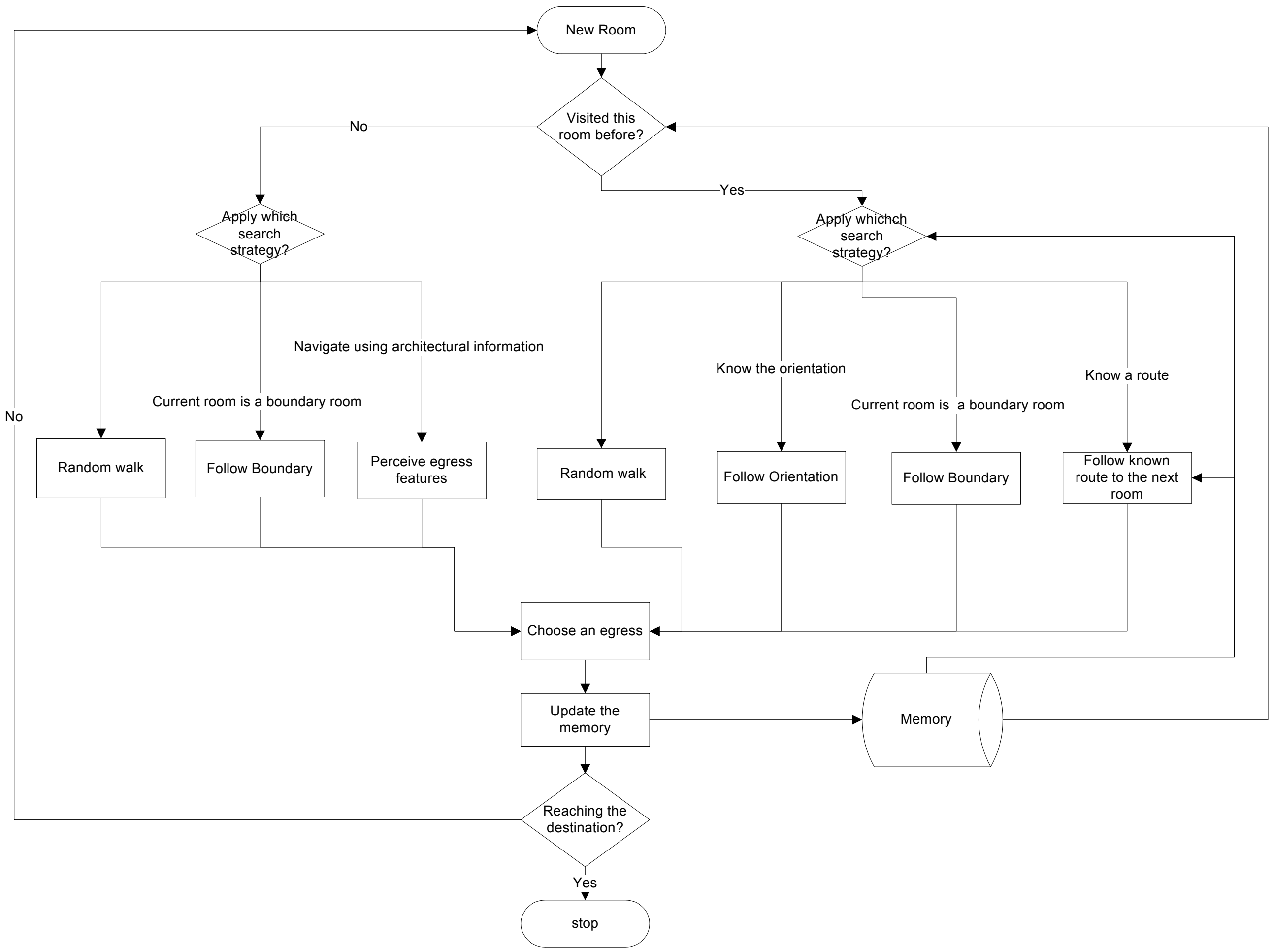

Figure 7: Flowchart of egress choosing module

Probability Of Choosing Search Strategies

Given distinct familiarity of the current room, the agent will apply different search strategies to make decision upon the egresses in this room. This indicates that, during the wayfinding process, the agent could only apply one search strategy during the whole searching process, or change the search strategy every a few rooms, or follow one search strategy in each room.

In the current room, each available search strategy has a certain probability to be chosen by the agent. These probabilities will be deduced through experiments with real human navigation in a VR environment. Figure 7 shows how a search strategy will be chosen in the current room.

AGENT

Several types of information are stored by our agent, namely status information, task information, search strategy information, and agent's memory, as shown in Figure 8.

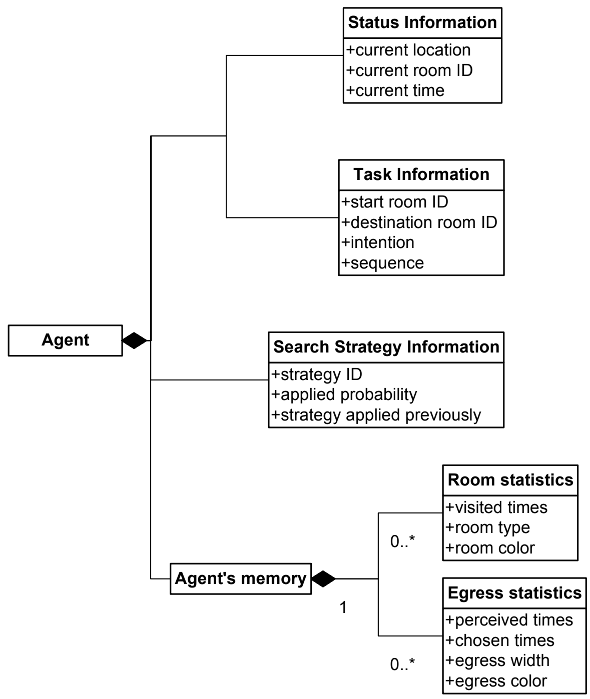

Figure 8: Simplified class diagram of the information stored by the agent

Status Information
Status information involves information about agent's current location in the built environment, the room ID if the agent is within a room, and current time. Current time gives information on how long the agent has spent in the wayfinding process.

Task Information
Wayfinding tasks may differ in the start, destination, the intention, and the sequence. For each wayfinding task, the start room ID, destination room ID, the intention of this way dinging task, and the sequence of this wayfinding task are recorded here. The intention of the wayfinding task determines the start room ID and the destination room ID, more importantly, it has significant influence on the search strategy the agent may apply. The sequence shows how many times the agent has repeated a wayfinding task.

Search Strategy Information
As mentioned in the egress choosing module, our agent might follow a search strategy for the whole wayfinding task, or for several rooms, or just for one room. The search strategy ID and the probability of this search strategy when it was chosen, along with the search strategy the agent applied in previous room will be recorded by the agent.

Agent's Memory
In the simulation system, agent's familiarity of the current room is determined by the statistics the agent collected of the room itself and the egresses involved in this room. Room statistics contains data on the size of the room, the grey level of the room, and how many times the current room has been visited, while egress statistics includes data on egress width, egress grey level, how many times the current egress has been perceived, and how many times the current egress has been chosen according to certain search strategy. It is possible that the agent would miss a certain egress in a room if this egress is not within the agent's viewing field and the agent does not look around. For example, given a room being visited for five times, the perceived times of certain egress in this room might be less than five, and the chosen times of this egress might be zero.

Furthermore, the decay of agent's familiarity of the environment is also considered in the simulation system. We assume that the agent can only remember the information of a fixed number of rooms (N). If the number of visited rooms exceeds N, the agent will conduct a scan of the visited rooms according to their visited sequence: from the first visited room to latest visited room in the queue, the room with least visited times will be removed from the queue. Next time when this removed room is visited, it will be treated as a new room. In other words, the agent will only remember recently visited rooms and the more frequently visited rooms.

MOVE MODULE

Once an egress is selected in the current room, the agent will execute the decision by walking towards the egress and then stepping into the next room.

CONCLUSIONS AND FURTHER RESEARCH

In this paper, we raised a vision-based system which simulates human wayfinding behaviour in virtual office environment. Unlike other wayfinding simulation systems, the agent designed in our system collects architectural information of current environment and then makes choice on the egresses employing certain search strategy based on its familiarity of current environment.

This proposed simulation system can be used for testing and evaluation purposes in architectural design problems. After a series of transformation, a CAD model of an office environment can be given to our simulation system as input. By setting the wayfinding task, we can employ the designed agent to predict how human may behave in this office environment in reality. This helps the architects, from the aspect of wayfinding efficiency and space utility, to improve their design.

Currently we are working on obtaining the probability that a search strategy might be employed as to select an egress in a given environment. These probabilities will be deduced from the analysis based on data collected from one of our earlier experiments. Next, we will concentrate on embedding all modules in the agent. It should be noted that, the agent in our simulation system cannot look around or wander around, thus the agent's wayfinding behaviour is limited.

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AUTHOR BIOGRAPHIES

QUNLI CHEN was born in Xining, China. He finished his master study in the University of Bristol in UK. Currently he is working as a PhD candidate under the supervision of Prof.dr.ir. Bauke de Vries from the Eindhoven University of Technology in the Netherlands. His research interests are mainly focus on human behaviour in the built environment, especially way finding in the virtual environment using architectural cues. His email: Q.Chen@tue.nl

BAUKE DE VRIES has a Doctors (1996) degree from the Eindhoven University of Technology. The subject of his PhD thesis was “Communication in the Building Industry: A strategy for implementing electronic information exchange”. From 2001 to present he is Professor and the chair of the Design Systems group at the Eindhoven University of Technology. His main research topics are: Computer Aided Architectural Design (CAAD), Product and Process Modelling, Human Behaviour in the Built Environment, VR technology and Interfaces and Knowledge Based Systems. His email is: B.d.Vries@tue.nl

CHENGYU SUN was born in Shanghai, China. He studied architecture and obtained his doctor degree in TU/e, The Netherlands. Now he is working at Tongji University, P. R. China. His email: ibund@126.com