Abstract
This research focuses on back-homing instinct, visible escape direction choices and tracking among escape direction choices in case of emergency, and to show the environment where such behavioral characteristics appear in a quantitative manner. An evacuation simulator using a walkthrough system was conducted. The results showed that 50% of evacuees who were not familiar with an architectural structure chose back-homing and the others searched for a new evacuation direction when they noticed a fire. For subjects who chose back-homing, 46.6% of evacuees still chose back-homing after observing the surrounding area and obtaining environmental information on both signs and other evacuees, while 53.4% chose to search for a new escape direction by following signs or other evacuees. It was found that the level concerning memory of a route to an evacuation point and the distance to an evacuation point also affects an escape choice. Also, the ratio of choice of visible escape routes differs according to the case. As a result of the research, it is possible to use this information to design an architectural structure and equipment in a building to minimize fire damage, by establishing evacuation simulation software.

Keywords: evacuation simulator; evacuation behavior; escape direction choices; evacuation behavior choices

1. Introduction
1.1 The background
In conducting research on evacuation behavior in the case of a fire, it can be difficult to carry out a test by creating a real-life fire situation, physically, economically and in terms of avoidance of risk. However, a computer simulation can recreate the affects of various environments and estimate a result in such an environment. Previously, similar simulation research was done with a computer. Through such previous research, the evacuation behavior of an evacuee was predicted.

Now, there are 7 points which are known to affect evacuation behavior in a fire:
1. Back homing
2. Daily circulation tendency
3. Tracking
4. Visible escape route choice
5. Instinctive risk avoidance
6. Behavior based on image
7. Straightness

The above research is important in terms of evacuation behavior. Many tests for understanding evacuation behavior have been conducted. Previous research has found the visible distance of an evacuation light and effective width of stairs in a quantitative manner. However, evacuation direction choice was only understood as a qualitative tendency.

Although research focusing on evacuation direction choice in a normal, non-emergency situation has been carried out, no quantitative conclusion has been drawn concerning evacuation direction choices.

In order to develop better real-life simulation software, it is necessary to understand evacuation direction choices quantitatively and the relationship between the special characteristics of the room or building and the evacuation behavior and relationship between evacuation behavior and factors which affect evacuation and escape behavior in a quantitative manner.

To collect data on the quantitative relationship, evacuation simulation is carried out using a walkthrough system which can conduct various tests by inputting different variables based on the conditions of a structure and equipment such as the size of space, shape of a building, etc. Evacuation simulation has
been proven by many researchers to be an effective tool for obtaining quantitative results.

1.2 Objectives of research

In this research, with consideration of the above matters, the authors focused on the back-homing instinct, visible direction choice and tracking from among the behavioral characteristics of evacuation direction and indexed these properties in a quantitative manner. Specifically, the purpose of this research is to ascertain how an evacuee chooses from the following 4 and obtain data concerning the ratios between such choices.

1. Check whether evacuees select the back-homing instinct or search for a new escape direction. Note whether evacuees are familiar or not with the structure of a building or have some memory of route or routes to the present position.
2. Check, in the case of seeing emergency escape signs or other evacuees, whether evacuees who chose the back-homing instinct now choose to follow the signs or other evacuees or still adhere to the back-homing instinct.
3. Check, in the case of seeing emergency escape signs or other evacuees, whether evacuees who chose to search for a new escape direction followed the signs or the other evacuees, and check which criteria an evacuee chose if both cases are found.
4. Check the visible direction choice based on a broad definition as to whether evacuees checked other directions before they found signs or other evacuees, or tracked them without previously checking other directions.

In order to ascertain the above 4 matters, the authors developed an evacuation simulator operated by the walkthrough system and evaluated the evacuation behavioral characteristics of evacuees with regard to direction choices in a quantitative manner, and collected data which can be used for simulation software which attempts to achieve a better real-life evacuation simulation.

2. Evacuation Behavior of an Evacuee in the Case of Fire

In this research, the authors focused on the back-homing instinct, visible direction choice and tracking among the behavioral characteristics of evacuation direction choice, based on consideration of the evacuees’ thinking.

2.1 Back-homing instinct

In this research, back-homing instinct means the behavior in which an evacuee who is not familiar with a building structure or has entered it for the first time tracks the route by which he/she entered. If an evacuee does not track the route by which he/she entered, such behavior is called search for a new escape direction.

2.2 Tracking

In this research, tracking means tracking of emergency escape signs and tracking of other evacuees.

2.2.1 Tracking of emergency escape signs

In this research, tracking of signs means behavior in which an evacuee tracks an emergency sign when he/she finds it.

2.2.2 Tracking of other evacuees

In this research, tracking of other evacuees means the behavior in which an evacuee follows other evacuees when he/she encounters them.

2.3 Visible direction choice

In this research, visible direction choice means the behavior in which an evacuee follows signs and other evacuees which he/she encounters, without checking other directions. Tracking described in 2.2 is a behavior in which an evacuee follows signs or other evacuees which he/she considers safer, in comparison with other environments.

3. Evacuation Simulation Operated by the Walkthrough System

Today, 3-dimensional computer graphics (hereinafter referred to as CG) technology has drastically improved. Therefore, it is possible to immediately reflect what is operated on a PC to CG in real time (hereinafter referred to as real time CG). A simulator which enables various experiences in virtual space using real-time CG (hereinafter referred to as experience-type simulator) are used for education and training.

In relation to building fire prevention, such an experience-type simulation has been developed. Also, previous research indicates that a walkthrough system can be used for behavior regarding a route search for evacuation guidance and the experience gained by running a walkthrough system is also effective for use in evacuation planning. The purpose of this research is to learn the evacuation behavior of an evacuee through the use of an evacuation simulation.

3.1 Walkthrough system

Walkthrough system is a system by which a subject can control virtual walking in a virtual building on a PC. A system developed in previous research is called VAWS (Virtual Architecture Walkthrough System). In this research, the authors further developed VAWS. Fig. 1. shows the structure of the VAWS used in this research.

At first, the authors made a 3-dimensional CG model with commercial CG software (AutoCAD and 3dsMax) and changed it to data for a walkthrough program with the 3-dimensional model CG data change program. (Deep Exploration CAD Edition)

A walkthrough program enables a one-person view of CG data of a building and flexible walking in the building by control of the keyboard arrow keys in the directions of front, rear, left and right.
3.2 Development of evacuation simulators

An evacuation simulator allows a subject to experience evacuation from a fire based on his/her own control, in a fire setting and evacuation made by the walkthrough program where a subject can walk through a virtual building on a PC. In developing an evacuation simulator, the authors used C++ language as a programming language (Microsoft Visual C++ 13) and Microsoft DirectX 14 for processing of 3-dimensional CG data.

3.2.1 Evacuee model

In an evacuee model, except for a test subject the evacuation simulator acts in accordance with the behavioral algorithms of an evacuee (See 3.2.2.). This simulation can reproduce a real situation by making evacuee models on the evacuation simulator display, with control by a test subject. In this case, an evacuee model can move along an evacuation route according to timed steps and a CG model with animated walk steps in the coordinate can be shown.

The number of evacuee models in the evacuation simulator is 100 persons in total. Seventy of them are in the room, while 30 are in the corridor. A room of evacuee models and the position of evacuee models are automatically selected by the computer. The walking speed of evacuee models is 1.27m per second. The walking speed is set at the same speed, regardless of the presence of smoke. The sight of evacuee models is set at 60°.

3.2.2 Behavioral algorithm of evacuee models

Evacuee models in an evacuation simulator act in accordance with the algorithm shown in Fig.2., once the simulation starts.

First, it is necessary to make one of the evacuee models search for a goal. The goal includes a sign and evacuation route. Other evacuees should not be a goal. This means that evacuee models on an evacuation simulator display should regard only the sign and evacuation way as a goal. After finding a goal visually, such a goal is set as a destination. If an evacuee model heads for the goal and reaches the destination which is an evacuation route, it is deemed that the evacuation model ended evacuation. If the destination which the evacuation model reached is not an evacuation route, the evacuation model should search for a goal again. If the evacuee model finds both the emergency exit sign and evacuation route, the evacuation route should be set as a destination.

If a destination is not found, it is necessary to search to the left and right in the range of 180°. This means that an evacuee model should find a goal in the range of 360°.

3.2.3 Visible range in smoke

An evacuee model in the evacuation simulator test can see all views without the influence of smoke. However, a subject in the test can see only 4-6m if there is smoke.

3.2.4 Space model

The building in the evacuation simulator is Engineering Bldg. 1 of The University of Tokyo. In this test, only the first floor was used and the building structure was slightly changed as shown in Fig.3.

In the evacuation simulator, a fire occurs when the subject is in Room No. 15, 114 or 120. The subjects
start evacuation from either of these rooms and the routes to reach the three points are as follows:

### 3.2.5 Evacuation guidance signs

Evacuation guidance signs are necessary in order to find the direction of an evacuation route. If there is an evacuation guidance sign within the sight of an evacuee model, such a sign is set as the destination. (Fig.4.)

### 3.2.6 Evacuation route

An evacuation route was made so simple that the simulator can recognize a particular object as an evacuation route if the simulator finds it, though an actual human may presume the evacuation route based on consideration of various kinds of information. It is deemed that such a place is the final destination of an evacuee and that evacuation ends when he/she passes it. (Fig.4.)

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**Fig.3.** First Floor, Faculty of Engineering Bldg.1, The University of Tokyo

**Fig.4.** The Position of Evacuation Guidance Signs and Evacuation Routes on the First Floor of the Faculty of Engineering Bldg. 1 of The University of Tokyo

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### 4. Test of Behavioral Characteristics Concerning Evacuation Direction Choices

The test of behavioral characteristics concerning evacuation direction choices is a test in which a subject can select an evacuation route in the case of a fire in the evacuation simulator.

#### 4.1 Overview of the test

Fig.5. shows the flowchart of the test. The procedures will be discussed in detail later.

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**Fig.5.** The Flowchart of the Test of Behavioral Characteristics Concerning Evacuation Direction Choices

Instructions should be given for the subject to head for the specified destination of 1 of 3 points after entering the building from the starting point (in front of the building entrance) (more information in section 3.2.4). After the subject has reached a specified location, it is noticed by the subject that a fire has occurred. The subject starts evacuation and then can select the evacuation route of his/her own choosing. The researcher records the behavioral characteristics of evacuation direction choices and conducts an interview with the subject after the evacuation has ended concerning the reasons for making the evacuation direction choices.

The tests were conducted with and without smoke in 2 situations at 3 points; 6 times in total.

#### 4.2 Subject

A total of 20 persons took part in this test, 12 of who were aged between 21 and 36. The general walking speed in the evacuation simulator was measured as 1.27m/second in case of free walking. Therefore, the walking speed of the subjects in the evacuation simulator display is set as 1.27m per second.
5. Finding and Consideration

5.1 Back-homing instinct and search for a new escape direction

As a result of interviews, 50% of the subjects who found the fire before starting evacuation chose the back-homing instinct, while 50% chose to search for a new escape direction. At the time when the subjects obtained environmental information from an emergency escape sign, other evacuees or both concerning taking an action, 46.6% of those who chose the back-homing instinct continued with that choice, while 53.4% chose to search for a new escape direction.

The ratio of choosing back-homing instinct and search for a new escape direction resulting from the difference of the level of memory of routes to reach a destination is shown in Fig.6. As a result, it is found that there is a proportional relationship between the level of memory of routes to reach a destination and back-homing instinct, while there is an inversely proportional relationship between the level of memory of routes to reach a destination and the search for a new escape direction. This relationship can be expressed by the following formulas.

\[
\text{The level of memory of routes to reach a destination} \propto \text{Back-homing instinct}
\]

\[
\text{The level of memory of routes to reach a destination} \propto \frac{1}{\text{search for a new escape direction}}
\]

The subjects who have a clear memory of routes to reach a destination chose the back-homing instinct. However, there is a different tendency in those subjects who have what is termed a perfect memory of routes to reach a destination to those who chose the back-homing instinct.

The reason why subjects chose to search for a new escape direction without choosing back-homing instinct is shown in Fig.7. As a result of inquiring about the reason, 55% of them chose the reason as "long distance". This means that the distance to the destination greatly affects the subject's choice. Also, it was found that, if an entrance is located in a distant place, there is higher possibility that a search for a new escape direction will be chosen than the back-homing instinct.

![Fig.7. Reason for Choices Concerning Search for a New Escape Direction by a Person who has Perfect Memory](image)

Also, it was found that the existence of smoke affects the subject's ratio of choices. This means that 4 out of 20 persons chose back-homing instinct as a result of consideration that it would be difficult to find other evacuation methods if there is smoke. In addition, 4 out of 20 persons immediately chose to search for a new escape direction, based on the consideration that it would take time even if they track the route from their current position.

5.2 Back-homing instinct and Tracking

Tracking includes tracking of posted emergency signs and tracking of other evacuees. The cases of evacuation behaviors for the subjects who chose back-homing instinct are divided into 3 categories.

1. Tracking of other evacuees
2. Tracking of signs
3. Both tracking of other evacuees and tracking of signs

The ratio of choices is shown in Fig.8. If an emergency evacuation sign was seen, 60% of the subjects followed it, while 40% ignored it. If other evacuees were seen, 40% of the subjects followed them, while 60% ignored them.

If the emergency sign was seen by other evacuees who moved in the direction indicated by it, 72% of the subjects followed that direction, while 28% ignored it.

This means that more subjects are likely to follow signs and evacuees moving in the same direction indicated by the signs than those who choose the back-homing instinct or are likely to follow the sign rather than following other evacuees. The stated reason why subjects ignored the sign and other evacuees related to the level regarding memory of routes to reach a
destination as shown in Fig.9.
There is a tendency that more subjects who have a good memory of routes to reach a destination ignore the sign and other evacuees. It is found that there is a proportional relation between the level of memory of routes to reach a destination and ignoring the sign and ignoring other evacuees. This relationship is expressed by the following formulas:

Ignoring the sign $\propto \text{level of memory of routes to reach a destination}^n$

Ignoring other evacuees $\propto \text{level of memory of routes to reach a destination}^m$

$n$ and $m$ are constant and positive numbers and $n > m$.

5.3 Search for a new escape direction and Tracking

The evacuation behaviors of persons who chose to search for a new escape direction are divided into 3 cases:
1. Tracking of other evacuees
2. Tracking of the signs
3. Tracking of other evacuees and the signs

It was found that the ratio of choices of the subjects who chose to search for a new escape direction are different from the ratio of choices of subjects who chose back-homing instinct in 3 cases. It is likely that the subjects who chose back-homing instinct ignored the sign and other evacuees. Meanwhile, the subjects who chose search for a new escape direction do not ignore anything. One hundred percent of them followed the sign or other evacuees.

If the direction of the signs and other evacuees are the same in the case of finding both of them, 71% of the subjects chose the direction of the signs, while 29% chose the direction of other evacuees. This means that they trusted the signs more than other evacuees.

5.4 Visible direction choice and other directions

There is a difference in the level of visible direction choices, in terms of whether evacuees check other directions if they find other evacuees or follow other evacuees without checking other directions. The ratio of choices of visible direction in the 3 cases is shown in Table 1.

| Visible direction choice | Other evacuees | Signs | Other evacuees and signs |
|--------------------------|---------------|------|--------------------------|
| Checking other direction | 55%           | 17%  | 6%                       |

The ratio of choices concerning visible direction depends on the case. If other evacuees are found, the ratio of choice of visible direction is 45%. It is lower than cases where the exit sign is found and those in which both the exit sign and other evacuees are found. If the sign is found, the ratio of choice of visible direction is 83%. The highest ratio of choices is 94%, which is the case of finding signs and other evacuees.

5.5 Evacuation completion time

The average evacuation completion time with and without smoke, which is found as a result of the test of behavioral characteristics of evacuation direction choices, is shown in Table 2.

| Without smoke | Room 15 | Room 114 | Room 120 |
|---------------|---------|----------|----------|
| With smoke    | 65.55   | 62.7     | 76.6     |

Generally, it is considered that evacuation completion time with smoke is longer than evacuation completion time without smoke. There is previous research concerning decrease of walking speed in an environment with smoke\(^6\).

The authors found no difference between the environment with smoke and the environment without smoke in this test. Subjects in Room No. 15 could evacuate more quickly in the environment with smoke. This was because the speed of walking was set at the same speed, regardless of the existence of smoke.
5.6 Other findings

It was found from this test that there are many kinds of human behavior.

1. If the evacuation direction of other evacuees is not one way only, there is a tendency that subjects do not trust other evacuees.
2. If the direction of evacuation of other evacuees is not one way only, subjects choose the direction of the majority if they choose to follow them.
3. If other evacuees are hesitant about the evacuation direction, the subject does not trust other evacuees.
4. If there is a sign with unclear evacuation directions, the subjects ignore it and follow other evacuees.
5. A right-handed person is likely to be more conscious of the right direction in evacuation.
6. If visibility is poor due to smoke, the subject is likely to rely on an object which comes into view first during evacuation.

6. Conclusion

In this research, the testing of evacuation behavior was carried out based on the evacuation simulator operated by the walkthrough program which was developed,

1. As a result of interviews, 50% of the subjects who were not familiar with the structure of the building or came to it for the first time and found the fire before starting evacuation chose the back-homing instinct, while 50% of them chose to search for a new escape direction. At the time when the subjects obtained environmental information from the emergency exit sign, other evacuees or both in choosing an action, 46.6% of the subjects who chose the back-homing instinct continuously chose it, while 53.4% chose to search for a new escape direction.
2. It was found that there is a proportional relationship between the level of memory of routes to reach a destination and the back-homing instinct, while there is an inversely proportional relationship between the level of memory of routes to reach a destination and search for a new escape direction. Furthermore, the distance to the destination greatly affects the subject’s choice. Also, it was found that, if an entrance is located in a distant place, there is a higher possibility that a search for a new escape direction will be chosen more than the back-homing instinct.
3. More subjects than those who chose the back-homing instinct are likely to follow the sign rather than following other evacuees. Also, the reason why subjects ignored both the sign and other evacuees was related to the level of memory of the route to reach a destination.
4. It is likely that the subjects who choose the back-homing instinct will ignore the sign and other evacuees. Meanwhile, the subjects who choose to search for a new escape direction do not ignore anything. One hundred percent of them followed the sign or other evacuees.
5. The ratio of visible direction choices depends on the case. If other evacuees are found, the ratio of choice of visible direction is lower than cases in which the sign is found and cases in which both the sign and other evacuees are found. The highest ratio of choices is in the case of finding signs and other evacuees moving in the same direction.

As shown in the above research, the authors concluded that they could prove the relationship between the space properties of the building and evacuation behavioral characteristic, the relationship between evacuation behavioral characteristics, and the relationship between the factors which affect behavior based on the properties and evacuation behavioral characteristics, in a quantitative manner. In the future, the authors wish to establish a real evacuation behavior simulation which is representative of an actual fire as much as possible, and incorporate the building structure and firefighting equipment in the building to minimize the damage from fire.

Notes

1 Ref.1-4.
2 The original title, [Kisousei] 帰巣性 was translated as "Back homing", [Nichijoudoushikou] 日常 機動性 was translated as "Daily circulation tendency", [Tsuishusei] 退行性 was translated as "Receding", [Ishikiroseikutousei] 易視経路選択性 was translated as "Visible escape route choice", [Honnottekikenkaihisei] 本能的危険回避性 was translated as "Instinctive risk avoidance", [Imeiginimototsukukoudou] イメー ジに基づく行動 was translated as "Behavior based on image", [chokushinsei] 直進性 was translated as "Straightness".
3 Ref.5-9.
4 Ref.10-13.
5 Ref.14-15.
6 Search for a new escape direction is a word made to use in this research which means searching for a new evacuation route in such a manner as described herein or finding for a new evacuation route without following evacuation signs or other evacuees.
7 Ref.16.
8 Ref.17-19.
9 Ref.19.
10 AutoCAD is a CAD (Computer Aided Design or Computer Aided Drafting) software application for 2D and 3D design and drafting, developed and sold by Autodesk, Inc.
11 Autodesk 3ds Max, formerly 3D Studio MAX, is a modeling, animation and rendering package developed by Autodesk Media and Entertainment. It has modeling capabilities, a flexible plug-in architecture and is able to be used on the Microsoft Windows platform.
12 Deep Exploration CAD Edition enables your extended teams to easily create and deliver visual product communications and collaborate more effectively. Rapidly and easily transform, author, and publish 2D and 3D product graphics and documents on your desktop using existing engineering CAD design data and other digital content.
Microsoft Visual C++ (often abbreviated as MSVC) is a commercial integrated development environment (IDE) product engineered by Microsoft for the C, C++, and C++/CLI programming languages. It has tools for developing and debugging C++ code, especially code written for the Microsoft Windows API, the DirectX API, and the Microsoft .NET Framework.

Microsoft DirectX is a collection of application programming interfaces (APIs) for handling tasks related to multimedia, especially game programming and video, on Microsoft platforms.

The level of memory of routes to reach a destination is the memory of the route taken from the entrance to the starting point.

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