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Agent-based simulation of building evacuation: Combining human behavior with predictable spatial accessibility in a fire emergency

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ABSTRACT

The building environment and evacuation behavior are decisive factors for building evacuation performance. Shifting toward the use of agent-based models, many current studies have considered the heterogeneous evacuation behavior resulting from an individualized perception of the building environment, but few studies have incorporated the evacuees' awareness of the predictable change in the spatial accessibility by activated fire safety facilities during emergency scenarios. To investigate the specific influence of such spatial change on the evacuation performance, this study presents an agent-based building evacuation model in which the evacuee's knowledge, including both the spatial knowledge of the stationary environment during a normal situation and the event knowledge of the predictable spatial change for fire-fighting purposes, is considered. In addition, a semantic representation of building environment is developed to represent the alterable connectivity structure when considering the fire safety facilities. Using the proposed model, a series of evacuation simulations have been conducted for groups of evacuees with different knowledge levels during three specific fire scenarios. The simulation results suggest that the proposed model can evaluate the potential influence of the spatial change on the evacuation efficiency, which is dependent on the evacuees' knowledge level and the location of the fire safety facilities. The model, although a prototype at this stage, will facilitate more realistic evacuation simulation in fire emergency scenarios and will support building evacuation management.

1. Introduction

Efficient emergency evacuation is important for building fire safety. The inner space of a building is divided by physical barriers into enclosures such as rooms and corridors that are connected to each other through openings such as doors and windows. The connectivity structure of these enclosures determines the spatial accessibility throughout the building and is a crucial factor for building emergency evacuation [25]. When a fire emergency occurs in the building, the connectivity structure might be changed for fire-fighting purposes. According to the Hong Kong building fire safety code [4], a large building should be divided into fire compartments. Separated parts, such as fire rolling shutters, will be activated according to the

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location of the burning point to resist the passage of fire and toxic gasses to or from another part of the building. However, the activated separated parts also break the spatial connectivity between the adjacent spaces and, consequently, some escape routes are blocked. Therefore, it is necessary to consider the change in the connectivity structure by activated fire safety facilities during emergency situations, which usually leads to different but predictable spatial accessibility.

The evacuees' knowledge of spatial accessibility may greatly influence the evacuation efficiency [21]. Taking an office building for instance, the staff could be familiar with every place and the connectivity structure inside the building, while the public may only know the main entrance and the particular route through which they came in. As people tend to attach to familiar places during the evacuation [44], the staff and the public may follow different escape routes which are not necessarily the shortest route. Moreover, the staff who have attended fire drills could be aware of the potentially changed spatial accessibility due to activated separated parts and avoid the blocked routes in advance. In contrast, the public who lack awareness of the activated separated parts may walk into a blocked route causing U-turns and 'turbulence'. Therefore, in order to assess the evacuees' capability of escape and provide critical evacuation assistance, it is important to consider not only the evacuees' knowledge of the spatial accessibility during normal situation but also their awareness of the predictable spatial change regarding the fire safety facilities.

Given the above mentioned facts, the purpose of this study was to simulate building evacuation with a focus on the potentially changed spatial accessibility by fire safety facilities. To reach this goal, we developed a semantic model to represent the alterable connectivity structure within a building regarding the fire safety facilities. The evacuee's knowledge, including not only the spatial accessibility during a normal situation but also the predictable change by the activated fire safety facilities during an emergency situation, is considered in the evacuation model. This approach is expected to predict a more reliable building evacuation performance and thus provide a more rational basis for evacuation management. The paper is organized as follows: In the next section, we briefly review the related work in the field of building evacuation simulation. In Section 3, a framework of the proposed evacuation model is presented considering the predictable change in the connectivity structure and the evacuees' knowledge of the predictable spatial accessibility. The detailed implementation method is described in Section 4, and in Section 5, the evacuation simulation of a campus building is performed with a discussion of the simulation results. The conclusions are given in the final section.

2. Related work

The building environment and human behavior are the two critical scenario variables in real-world building evacuation [21]. Focusing on these two variables, the essential task of evacuation simulation is to represent the evacuee's interaction with the building environment [11].

Pioneering work in building evacuation simulation mainly focused on the fixed spatial constraints of the building environment with the purpose of optimizing the evacuees' movement and minimizing the evacuation time. This focus is particularly true for models such as EVACNET4 [8,20], EESCAPE [19] and Exit89 [5], where the connectivity structure of the building is modeled as a fixed network. However, the assumption that the spatial accessibility within the building remains the same could be easily violated in a fire emergency situation as exits or routes might be blocked due to certain conditions (e.g., smoke or flames). Models such as FDS + Evac [23] and STEPS [27] have considered the dynamic availability of exits or routes during emergency situations. Furthermore, in order to depict reliable environmental conditions, fire simulators have been coupled with evacuation models [10,12,46]. However, the approaches adopted to represent the building environment, including the coarse network, the fine network and the continuous space [24] are mainly concerned with the dynamic spatial accessibility, if any, in terms of environmental conditions or manual control by the user. Functional feature of the building, such as the fire safety facilities, and its influence on spatial accessibility has not been fully considered.

The evacuee's behavior can be represented in many different ways. Earlier models simulate the evacuees as a continuous homogeneous mass that behaves as a fluid flowing along the corridors. The speed of the fluid flow is calculated as a function of the density subject to the geometric features of the environment [9,33,36]. In fact, the evacuee's movement could be significantly influenced by interactions with obstacles such as walls and other evacuees. In view of this, models such as the magnetic model [31], social force model [15], floor fluid model [2] and multi-grid model [45] simulate the evacuees as homogeneous particles moving around as an emergent function of attractive force, repulsion force and friction force regarding the interaction with the surrounding environment. In order to reproduce heterogeneous evacuation behaviors, agent-based simulation has been widely used [42,50]. The agents may have different familiarities with the building and choose their own escape route which is not necessarily the shortest path [32,34,48]. The impact of exit's visibility on route selection has been highlighted [7,22], especially in smoke-filled environment [30,41]. Moreover, individual differences in route selection regarding the dynamic spatial accessibility due to congestion, smoke or flames have been considered. Agents may follow a self-estimated quickest route [18] and decide whether to redirect away from the danger [12] depending on their physical and psychological characteristics. However, these studies do not fully describe individualized route choices in relation to the evacuees' awareness of the predictable change of spatial accessibility when certain fire safety facilities are activated.

From a review of previous work, we noticed that there is growing concern for the dynamic spatial accessibility during emergency situations and heterogeneous evacuation behavior resulting from the individualized perception of the building environment [11,24,35,50]. However, the existing models are primarily concerned with the evacuees' knowledge of fixed