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A comprehensive method for environmentally sensitive and behavioral microscopic egress analysis in case of fire in buildings

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ABSTRACT

This paper presents a new comprehensive method for microscopic building egress analysis, which considers the behavioral response of occupants to the various environmental conditions in case of fire in a building. This method distinguishes between different types of building users in order to calculate the appropriate egress route for each of them. The egress analysis described in this paper is integrated in the Building Information Modeling (BIM) environment and includes a special wayfinding algorithm. This algorithm has direct access to the digital building model and uses the results of appropriate model-based numerical fire simulations for each egress scenario. With this method, the algorithm behind the egress analysis can access the building properties as well as the environmental parameters in order to realize a reliable egress analysis.

1. Introduction

The safety of people is the central concern of every fire protection concept for buildings. In this connection, it is necessary to ensure that the endangered people have a safe and rapid evacuation in emergency situations like fire incidents through egress analyses. Although, the egress analysis is an essential part of the development of safety concepts, the deployment of computer-aided egress simulations is unusual and it is rather a paper-based process. This is particularly due to the shortcomings of the existing computer models for egress analysis described in Section 5.

There are different laws, policies, and regulations that deal with the egress and evacuation of people from buildings in the case of fire. In developing egress and evacuation concepts, human beings with their characteristics play a significant role. However, because of the difficulties in modeling of human behavior in dangerous situations, most of the regulations are based on very simplified application rules. In addition to the characteristics of the endangered people, the building properties and the environmental conditions are the other important parameters in the development of safety concepts (Schneider and Kirchberger, 2006). These aspects depend strongly on each other and have mutual influences. In dangerous situations, people make decisions based on their experiences with similar cases and they behave based on their psychological state and physiological abilities. Proulx introduces in Proulx (1993) a stress model for people facing a fire and emphasizes how essentially the behavior of human beings can be affected during an extreme situation. Moreover, there are research works like (Horiuchi et al., 1986; Kimura and Sime, 1988) that show that the wayfinding process of people is very different depending on their familiarity with the ways inside the building. In addition to this, people always respond to their immediately changing environmental conditions. In case of fire in buildings, the spread of fire and smoke directly affects the decision of occupants for a certain escape way. Hence, it is necessary that an egress analysis considers three essential aspects: the behavioral characteristics, building properties, and the variable environmental conditions. This paper presents a new comprehensive method for microscopic building egress analysis considering the mentioned significant parameters.

2. Egress and evacuation

There is often no clear difference between the terms "egress" and "evacuation" in technical literature. However, they explain two different facts with varied characteristics. Egress explains the self-rescue process of the endangered people without having any support of the rescue staff or other endangered people (Abolghasemzadeh, 2012). During the egress process, people in general behave instinctively based on their individual characteristics and experiences. The egress process usually occurs before the rescue teams have started their operations. Evacuation, in contrast to egress, is a planned and controlled process during which qualified and trained specialists rescue people from extreme situations, like

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fire incidents in buildings (Abolghasemzadeh, 2012). The rescue and evacuation are usually task of the fire brigade, the police, or emergency medical organizations, like the Red Cross.

Thus, the fire safety concepts have to ensure both a secure egress and a secure evacuation in case of fire incidents in buildings. Consequently, the fire safety concept should ensure on one hand that the building occupants will be able to leave the hazard area without running into danger and getting into panic, and on the other hand, if there are still people inside the building after the rescue crews arrive, that a safe evacuation operation is possible. Hence, an egress analysis is necessary in any fire safety concept.

It should also be noted that the behavior of individuals in panic situations is very unpredictable and a deterministic analysis would not be suitable for analysis of such situations. The scope of the presented work is on the early phase of the egress where the safety concept has still not failed and people's response is rational, not random or unpredictable. This is because the objective in this work is to provide a new method to reinforce the development of safety concepts and mind a panic situation.

The egress analysis can be carried out based on two different types of considerations: "macroscopic" and "microscopic." Whereas the macroscopic egress analysis deals with groups of people and their collective response to the dangerous situation, the microscopic egress analysis focuses on the individual behavior of the endangered people. Depending on the building usability, an appropriate egress analysis has to be chosen. For instance, the macroscopic approach could be suitable for stadiums or cinema halls, and the microscopic approach, for office or residential buildings. In this research work, the focus will be on the microscopic egress analysis and on the individual's wayfinding performance.

3. Egress timing

According to Proulx (2008) and Gwynne and Rosenbaum (2008), the egress times can be divided into several time sections, which are defined as follows (Fig. 1):

- "Detection time" (dt_{Det})
  The interval between fire ignition and its detection.
- "Alarm time" (dt_{Alarm})
  The time from fire detection to alarm activation.
- "Recognition time" (dt_{Reco})
  A large amount of alarm signals are either false or unintended alarms (Hess, 1998). Due to this fact, people typically do not react to the alarm signals immediately. The time that an occupant needs to interpret the signal as a serious warning after activation of the alarm signal is the recognition time and is a part of the premovement time. In other words, this is the time in which the occupants consider the fire as an obvious dangerous incident.
- "Response time" (dt_{Resp})
  This is the time between the recognition time and the first move of the occupant to evacuate the building. Response time is also a part of the premovement time.
- "Premovement time" (dt_{Pre})
  This time includes all the time intervals that a person needs to decide to move after being alarmed, that is, the time for recognition and response. It is also called "delay time to start."
- "Movement time" (dt_{Move})
  It begins after the decision to move until an area of safety is reached.
- "Egress time" (dt_{Egress}) This is the time that a person after an alarm signal needs to leave the hazard zone and to reach a safe area (inside or outside the building). Thus, egress time includes both premovement and movement time.

The "Available Safe Egress Time" (ASET) is the time between fire ignition and the time at which the acceptance criteria are met. The required time from fire ignition to the time at which all occupants – without any injuries and without having any support of the rescue staff or other endangered people – reach a safe area is the "Required Safe Escape Time" (RSET). As a rule, the fire safety concept has to ensure that RSET in each critical scenario is shorter than ASET. Whereas the values for ASET are given by the official institutions, the value for RSET has to be determined through suitable simulations by the safety engineer. The difference between ASET and RSET is called "margin of safety" (dt_{Margin}). If the value calculated for RSET does not meet the ASET, then there is no escape way available for a safe egress and as a result a panic situation is expected. In such case, the reaction of endangered people will be unpredictable which is out of the scope of this paper.

The egress timing emphasizes that the occupant's characteristics, building properties, and environmental conditions play a significant role in the recognition and response time. Consequently, these aspects can influence the wayfinding process and the movement time. Thus, these aspects must be considered essential criteria for calculation of RSET in egress analysis.

4. Influencing criteria for egress timing in case of fire

4.1. Occupant's characteristics

As mentioned before, the characteristics of building occupants have a crucial role in the egress process and they consequently affect the egress timing. The following occupant's characteristics are relevant in this connection and have to be considered in microscopic egress analyses (Schneider and Kirchberger, 2006; Proulx, 2008):

1. Required premovement time (including the recognition and response time).

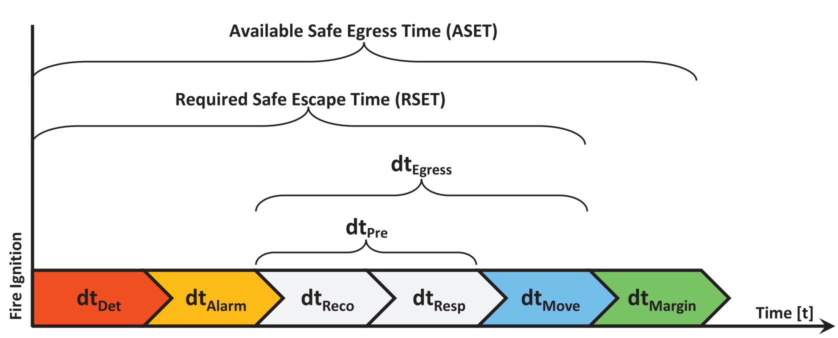

Fig. 1. Egress timing in accordance with Proulx (2008) and Gwynne and Rosenbaum (2008).