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Planning labor evacuation for construction sites using BIM and agent-based simulation

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ABSTRACT

This paper presents a framework that aids contractors and safety managers in planning labor evacuation for construction sites using Building Information Modelling (BIM) and computer simulation by modeling the appropriate construction method alternatives. The proposed framework estimates the execution time, total cost, and evacuation time for construction projects, taking safety into consideration. Agent-based simulation is utilized to model the behavior of laborers in evacuation situations. A MassMotion simulation platform is utilized to implement agent-based simulation and to imitate labor behavior during emergency evacuation under various conditions. Ranking and Selection (R&S) statistical procedures are used to determine the best simulated model configuration among the considered four alternatives. Multi Criteria Decision Making (MCDM) is applied to help in selecting the suitable construction method alternative. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is used to identify the best construction method alternative taking into consideration three main criteria which are: construction total cost, execution time, and evacuation time of the labor. The proposed framework is examined within the context of a case study that considers evacuation of labor during the construction of a building in an Egyptian social housing national project.

1. Introduction

Construction sites are considered very risky environments that contains a large number of construction labor performing various activities. There are many different circumstances of natural disasters or anthropogenic (human-made) hazards that would cause the evacuation of construction sites, such as fire, structural collapse, gas leaks, earthquakes, explosions, and civil disorders. To reduce potential hazards when emergencies happen in construction sites, it is essential to prepare safety evacuation plans to direct labor to retreat from the hazard location in a rapid and safe manner. According to Occupational Safety and Health Administration (OSHA, 2015) and other agencies, predicting evacuation time required for the labor to vacate is the major objective when preparing the evacuation plan for construction sites. Construction site environment changes continuously which means the number of occupants, spaces and evacuation routes changes from one day to another. Evacuation conditions for occupants that work in construction sites could be very different from the conditions that can be expected in public buildings. Although many evacuation models have been used in studying emergency evacuation for decades, little research has been done for construction sites.

Generally, a number of previous studies were focused on the evacuation issues of the large population in public environment, such as malls, stadiums, airports and multistory buildings. These environments that have fixed spatial and occupants. Besides, the evacuation process was conducted on operation stage of these environments. In addition, while most existing studies aim at an indoor system, emergency evacuation system for outdoor and construction sites environments are also needed. Construction site environment contain many temporary works, its changes continuously that which means the number of occupants, spaces and evacuation routes changes from one day to another. Common problem when established evacuation route in construction site may include obstructed hallways from materials and equipment that can impact the ability to quickly evacuate a construction site. This research proposes a framework that is capable to estimate the evacuation time of labor over the different points of time before project execution. Thus, the proposed model helps the contractors to develop effective evacuation plan when an emergency or disaster happens and using this model can test emergency evacuation plans prior to construction to identify whether the planned construction method is appropriate to be adopted. The proposed framework that integrates Building Information Modeling (BIM) with computer simulation to

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planning emergency labor evacuation on a construction site. Based on agent-based model technology, MassMotion software simulates the labor behavior and movements. The proposed framework estimates the total evacuation time, time of execution, and total cost for a given construction setting.

2. Literature review

Nowadays, new technologies and tools are available to manage and plan the emergency evacuation of labor in construction sites. Building Information Modelling (BIM) technology has been introduced to provide comprehensive building information for three-dimension (3D) visualizations of the interior design of the building under study. BIM model produces the 4D model by linking the model elements and time schedules (Eastman et al., 2011). Modeling and Simulation tools are used to gain increased understanding of labor behavior during the emergency. Agent-based modelling tools are used to model the behavior of labor in evacuation situations. It provides a natural description of labor movements and produces realistic simulation. These new technologies increase the accuracy and improve planning of the evacuation processes for construction sites as described in the below subsections.

2.1. Building Information Modelling (BIM)

Building Information Modeling (BIM) technology provides a digital representation of the actual physical characteristics of a building.BIM provides a perfect platform for sharing the information among designer, managers, contractors, engineers, and more importantly, the construction industry. BIM can provide information and documents that are related to emergency evacuation and calculate the safety performance and evacuation routes before the project begins. BIM provides accurate building information and exceptional details of the facility. For the last few years, there has been an increasing emphasis within BIM research and evacuation simulation systems. Ruppel et al. (2009) developed a BIM-ISEE (Immersive Safety Engineering Environment) to model emergency situations in buildings and applied the situations to a group of individuals fearing danger. The model integrated fire and evacuation simulation with BIM tools. Wang et al. (2012) developed a model to simulate emergency evacuation based on BIM and Discrete Event Systems Specification (DEVS). The model can be used to analyze bottlenecks and the maximum occupation for determining an optical evacuation plan. Wang et al. (2014) integrated BIM and a serious game engine to provide real-time fire evacuation guidance. The study introduced a BIM based virtual environment (BIM-VE) to improving building emergency management. Mayer et al. (2014) developed a pedestrian simulation model based on BIM data to identify potential threats in the design phase of a building and evaluate protective measures. This model can utilize information of the BIM model during the operation phase of a building.

2.2. Computer simulation

Evacuation simulation is an important tool for analyzing and assessing the safety of labor on a construction site. It can be used for modelling the emergency evacuation to predict and understand the performance of the evacuation process in a specific building (Zheng et al., 2009). The contractors and safety managers can use simulation to estimate evacuation time and find the potential bottleneck a reason the building construction site before the construction has begun. Many researchers have adopted agent-based modelling techniques to use in evacuation simulation. It provides a natural description of labor movement during the emergency evacuation simulation. In addition, agent-based modelling techniques are capable to produce realistic and detailed simulation. Bonabeau (2002) introduced the basic principles and possibilities of agent based simulation and application methods in evacuation, flow management and diffusion. Klugl and Rindsfuser (2007) studied the crowd movement centered on an agent-based modelling and simulation in the traffic and transportation domain. Pan et al. (2007) studied the human and social behavior during emergency evacuations in buildings through developing a multi-agent simulation framework able to demonstrate different emergent behaviors. Lin et al. (2010) developed an agent-based simulation model for a 2-story office building. The model uses the evacuation data that was collected by video cameras during fire drills in the building. Zaharia et al. (2011) proposed an agent-based model for the simulation of an emergency route by taking into account the problem of uncharacteristic actions of people under distress conditions caused by a disaster. Bernardini et al. (2014) proposed an evacuation simulation model using agent-based modelling techniques and through analysis of videotapes recording real events. His study included modifying the social force model in order to describe typical behaviors. Tan et al. (2015) presented an agent-based evacuation model in which the evacuee's knowledge is considered to evaluate the potential influence of the spatial change on the evacuation efficiency.

In General, other related work in emergency evacuation includes work by Filippoupolitis et al. (2008) presented emergency simulation system using wireless sensor networks to monitor the spread of the hazards while an external event generator provides input to the sensors, while Filippoupolitis and Gelenbe (2009) suggested a distributed decision support system designed for providing directions to evacuees during the evacuation of a building in the presence of a spreading hazard. In other work, Filippoupolitis et al. (2009) evaluated network of decision nodes and sensor nodes on the one hand9 and a wireless network for two-way communication between trapped civilians and an operation centre on the other hand. Research efforts have been put to compute the motion of an individual agent (Gelenbe and Cao, 1998) and to survey autonomous motion (Gelenbe et al., 1997).

Dimakis et al. (2010) who propose a distributed building evacuation simulator tool to support the evaluation of alternative emergency courses of action in confined environments such as buildings or ships. Gorbil and Gelenbe (2012) proposed the use of opportunistic communications to provide emergency evacuation support in built areas when other means of communication have broken down, and also investigates the resilience and performance for this communications. Moreover, Gelenbe and Wu (2013) discussed future research on emergency management systems that rely on sensor networks to locate hazards and people, both evacuees and emergency personnel, and communications between evacuees and emergency personnel. Other work Akinwande et al. (2015) investigated the use of dynamic grouping of evacuees based on their characteristics through using the concepts of the Cognitive Packet Networks (CPN) which uses a neural algorithm based technique for finding paths.

2.3. Ranking and Selection procedures

Ranking and Selection (R&S) procedures are developed to choose the best population or a subset that contains the best from competing alternatives (Goldsman et al., 1991). These statistical procedures are classified into two general approaches: indifference-zone selection procedures (IZP) and subset selection procedures (SSP). The formal procedure (IZP) provides a guarantee of selecting the single best system, where an indifference-zone parameter δ represents the range and the experimenter is "indifferent" to alternatives within δ of the best system. Whereas, later procedure (SSP) chooses a subset of the available alternatives so that there is a defined probability guaranteeing that the subset includes the best system (Wang et al., 2011). Several studies on R &S procedures have been reported in the simulation field. Kelton and Law (2000) introduced R&S with references to more advanced concepts. Nelson et al. (2001) provided new perspectives that included a comprehensive state of the art review of R&S in simulation. The study represented a compromise between R&S procedures and fully