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Agent-based model for earthquake pedestrians' evacuation in urban outdoor scenarios: Behavioural patterns definition and evacuation paths choice

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ABSTRACT

The assessment of seismic risk at urban scale does not actually consider aspects related to human behaviours, unlike other kind of events; moreover, the simulation of phases of pedestrian evacuation and motion in earthquake evacuation is a rarely inquired issue. From this point of view, this work proposes an innovative approach to earthquake evacuation, presenting an agent based model to describe phases and rules of motion for pedestrians. The model is based on the analysis of videotapes concerning real events. Results firstly show a scheme of chronological organisation of experimentally noticed behaviours activated during an earthquake evacuation. Secondly, the related behavioural agent-based model is presented by using the i^* language and posing attention to relationships between pedestrians and environment. A particular attention is given to the relationships in evacuation paths choice depending on configuration of environment and damage distribution after earthquake. Additionally, experimental values of distance between people and evacuation average speed in the first phases of outdoor motion are provided. The mathematical definitions for the model and the software implementation of the model will be implemented.

1. Introduction

The evaluation of seismic risk R at building or urban scale can be defined using three pillars: hazard H, vulnerability V and exposed elements E (Ambraseys, 1983), as showed in the following equation:

$$R = R(H, V, E) \quad (1)$$

Notations are reported in Appendix A. A large number of studies approach the definition and evaluation of H parameter (Klügel, 2008; Panza et al., 2012); some of them also refer to researches about soil nature (Meletti et al., 2008; Orozova and Suhadolc, 1999; Semih Yücemen, 1993), while others propose applications to specific areas (Jiménez and Posadas, 2006; Panza and Romanelli, 2001). Other studies analyse V parameter (Calvi et al., 2006; Palacios Molina, 2004), with structural analysis for different buildings (Barbat et al., 1996; Giovinazzi and Lagomarsino, 2001; Grimaz et al., 1997), and definition of methodologies for loss estimation including various aspects (Federal Emergency Management Agency, 2009; Mouroux and Brun, 2006a, 2006b). The exposure parameter E (Chen et al., 1997; Mouroux and Brun, 2006a) concerns human presence in a scenario, or the historical and artistic value of buildings.

Several studies deal with human behaviour analysis in evacuation cases, but only few of them concern post-earthquake evacuation, and none of them define a link with the evaluation of E. In order to provide a more accurate evaluation of E, it should be also taken account of human behaviour during the earthquake and the first evacuation phase.

The majority of aforementioned studies are about fire evacuation or big structure evacuation (Averill et al., 2005; Chu et al., 2006; Dederichs and Larusdottir, 2010; Fahy and Proulx, 2001; Helbing et al., 2002; Johnson et al., 1994; Mawson, 2007; Muir et al., 1996; Nilsson and Johansson, 2009; Nilsson et al., 2010; Pietrantoni and Prati, 2003; Riad et al., 1999; Shen, 2006; Shields and Boyce, 2000; Zheng et al., 2009). They investigate "pre-movement" phase (Chu et al., 2006; Johnson et al., 1994; Nilsson and Johansson, 2009; Nilsson et al., 2010; Shen, 2006; Shields and Boyce, 2000; Zheng et al., 2009), phenomena of social attachment[1]

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[1] This phenomenon could be summarized as pedestrians' waiting for other known people both during the evacuation starting and the effective motion, in order to be reunited with family or clan members and friends.

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(Mawson, 2007) and attachment to objects[2] (Riad et al., 1999), "memory effects"[3] (Helbing et al., 2002; Lakoba and Finkelstein, 2005), "Herd Behaviour"[4] (Helbing et al., 2002). They pointed out that panic situations are usually due to the presence of particular conditions especially in psychological perception of environment and dangers (Auf Der Heide, 2004; Averill et al., 2005; Pietrantoni and Prati, 2003). They also notice a maximum of distance that provokes activation of interaction mechanisms between people and between people and obstacles[5] (Lakoba and Finkelstein, 2005).

Only few works deal with earthquake evacuations (Alexander, 1990; Arnold et al., 1982; Boileau et al., 1978; Grünthal, 1998; Hori, 2011; James, 1968; Osaragi, 2012; Prati et al., 2012; Takuma, 1972; Turner et al., 1986). Regarding behaviours in case of earthquake, inferior limit in perception of seism and limit for panic conditions are defined using EMS-98 intensity scale (Grünthal, 1998). These studies evidence the presence of "pre-movement" phase, cohesion bonds (Alexander, 1990; Prati et al., 2012), the influence of geographical background in behaviours (Alexander, 1990; Boileau et al., 1978), and the so called "fear of buildings" (Alexander, 1990; Arnold et al., 1982; Takuma, 1972), with frightened people that prefer to run out of buildings during the earthquake (Alexander, 1990). The decision-making and behaviour of individuals attempting to reach home on foot in the wake of a devastating earthquake is also inquired (Osaragi, 2012). Average speeds in first evacuation phases in real events are investigated (Hori, 2011).

A large number of models simulating human behaviour and motion both in normal and evacuation conditions is present (Helbing and Johansson, 2010; Helbing et al., 2002; Heliövaara et al., 2012; Hori, 2011; Hughes, 2002; Lakoba and Finkelstein, 2005; Langston et al., 2006; Osaragi, 2004; Pelechano and Malkawi, 2008; Schadschneider, 2001; Smith et al., 2009; Zanlungo et al., 2012), such as the Social Force model (Helbing and Johansson, 2010; Helbing et al., 2002; Lakoba and Finkelstein, 2005; Zanlungo et al., 2011). The Social Force model approaches analysis of real cases (normal and evacuation condition) to define a motion law for pedestrians. However that model has never been applied to post-earthquake evacuation for its limitation essentially due to initial inquires of authors (Helbing et al., 2002), which did not investigate this event and related human behaviours.

The aim of our work is to provide and implement a model that take advantages of the Social Force model and makes it capable to describe pedestrians' motion in post-earthquake evacuation. This can be accomplished in two steps: the definition of the behavioural theoretical model and the operative integration on the Social Force model.

This paper offers a first step for our work. The behavioural theoretical model is based on an experimental inquiry about human behaviour in post-earthquake evacuations using videotape analysis related to real events. This approach was adopted also to previous studies (Helbing et al., 2002; Hori, 2011). Qualitative and quantitative aspects of pedestrian motion are investigated. Behaviours are organised in order to have a scheme of the relationships that are activated during the evacuation procedure. These data are utilised to define a behavioural flowchart capable to describe the evacuation process, and to introduce corrections and integrations to Social Force model. In the following part of our work, the mathematical definition of motion law and the simulation software implementation will be provided.

The adoption of an agent-based approach (Manenti and Manzoni, 2011) is strictly connect to the possibility, on one side, to define interaction between various agents present in the scenario (the same interaction between pedestrians and between pedestrians and environment suggested by the Social Force model (Helbing and Johansson, 2010; Helbing et al., 2002)), and, on the other hand, to independently modelling each agent, and in particular the one describing a general pedestrian.

2. Phases, database definition, and methods for database analysis

2.1. Phases

From a general point of view, our definition of an agent-Based model for Post-Earthquake pedestrians' evacuation in urban outdoor scenarios concerns the following steps:

- Videotape analysis to define behaviours activated in post-earthquake evacuation and organisation of them in order of activation.
- Definition of the behavioural model including intentional model, behavioural flowchart and criteria of motion and of path choice.
- Operative definition of quantities concerning criteria of motion and of path choice, including motion law.
- Implementation of the model in a simulation software in order to validate the proposed model.
- Validation of the model through the related software, comparing average speed values, path choice, and distance between people during evacuation.

This paper regards the first steps of our work, and it is divided in the following phases (the corresponding paragraph, in which relative results are explained, is indicated in brackets, in italics):

- Quantitative and qualitative analysis of a selected videotapes database, about both pre-movement time and motion; definition of a list of noticed behaviours and their organisation in a chronological order of activation (*Noticed behaviours*).
- Definition of actors involved in evacuation, of interaction among pedestrians and between pedestrians and environment (obstacles, buildings, ...), with related organisation of noticed behaviours into a intentional model, using i^* as modelling language (*Intentional model*).
- Description of the series of actions, behaviours and choices acted by a single pedestrian during the evacuation (*Behavioural flowchart*).
- Characterisation in physical terms of criteria used by a pedestrian for his choices and his motion (*Criteria of motion*).

These steps are developed in order to correct and integrate to the Social Force model. A solving equation for pedestrian motion will be obtained on these bases.

2.2. Database definition

Fig. 1 proposes a general overview of the analysed videotape database, distinguishing different essential statistical information: magnitude of the earthquake (Fig. 1A), percentage of events per year (Fig. 1B), geographical distribution (Fig. 1C), number of visible people in the scene (Fig. 1D) and particular condition in evacuation (Fig. 1E).

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[2] That is pedestrians' collecting belongings and other things they care for.

[3] This could be summarized as people in evacuation conditions that choose well-known paths.

[4] That is, a convergence of pedestrians' behaviors and choices when they are in group conditions.

[5] Elements (both people and obstacles) are taken into account for pedestrian's evaluations only if they are placed closer than the activation distance from the pedestrian.