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# Flooding risk in existing urban environment: from human behavioral patterns to a microscopic simulation model

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**Abstract**

Climate changes-related floods will seriously strike population in existing urban environment. Despite Current assessment methods seem to underestimate the human behaviors influence on individuals' safety, especially during outdoor evacuation. Representing pedestrians' evacuation would allow considering the "human" factor in risk analysis. This work proposes a flood-induced pedestrians' evacuation simulation model, based on a combined microscopic approach. Behavioral rules, obtained by real events videotapes analyses, are organized in an agent-based model. Motion criteria proposals are based on the Social Force Model. Experimental motion quantities values are offered. The model will be implemented in a risk assessment simulation tool.


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*Keywords:* urban flood; human behaviours; evacuation; existing urban scenario; behavioural model; architetctural spaces performance assessment

## 1. Introduction

Understanding and representing how people behave in emergency conditions are key factors in the analysis of architectural spaces performances in relation to the safety levels for exposed population, and in the definition of risk-reduction strategies [1,2]. During a disaster, individuals have to solve critical interactions between them and surrounding environmental conditions (i.e.: other neighbouring people; built scenario, including possible disaster-induced modifications) in order to restore safe conditions. From this point of view, the evacuation process [1–3] is one of the most significant emergency phases: the interactions between man-surrounding scenario can lead people to

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additional hazardous conditions (e.g.: toxic smokes in fire; debris in earthquakes; floodwaters level in floods), and even impede them to reach safe areas and rescuers' aid. Thus, tools and methods for analysing the "human" factor in the first emergency phases should adopt a joint man–environment investigation approach [1,2]. Such behavioural analyses results could be combined to traditional risk assessment evaluations for providing [1,3,4]: comprehensive "risk maps" for safety performance of built environment; defining community resistance (and resilience); proposing risk-reduction solutions (i.e.: based on a direct help to damaged individuals) in terms of emergency management actions, interventions on built environment and evacuation support systems (e.g.: building components). This work tries to provide the bases for developing such tools and methods for the flooding risk assessment.

## 2. Flooding risks and the "human" factor

The "Behavioural Design" – BD (or rather psychonomics [2]) approach for safety in (and of) built environment [1,5] could supply effective strategies to include the "human" factor in risk assessment analysis, and they could be applied to the flood-induced emergencies. According to this approach, main stages to reach a similar goal are: 1) *understanding human behaviours in emergencies*, thanking to experimental activities; 2) *defining models for representing human emergency behaviours* and related interactions with the architectural space (modified by the event); 3) *developing simulation software* for safety planners (e.g.: architects, engineers) and validating them through real-World data comparisons); 4) *evaluating built environment safety performances and critical issues for individuals* in emergency by means of simulation, in case of different risk-reduction solutions presence, according to Key Performance Indicators [2,4]. This approach for built environment performance assessment is really significant in case of [1,2]: "dynamic" development of disaster and environmental conditions; complex and large spaces (e.g.: urban centres because of high population density, individuals' features, familiarity with space layout, possible low preparedness level in relation to safety procedures and evacuation plan). Fire safety engineering successfully applies these criteria for both evaluation activities [2] and proposals of assistance tools for evacuees [5]. Related rules have been also codified by national regulations (e.g.: NFPA 101) and international guidelines (e.g.: PD 7974-6:2004). Recent attempts in extending the BD approach to earthquake safety issues included urban scenarios applications [1].

Flood-induced emergencies in urban scenarios represent a major situation [6]: they include "dynamic" event characterization (i.e.: floodwater spreading during the time, with possible related influence on human safety and built elements damages) and complex spaces problems. Besides, climate changes [7] will be able to increase hazardous conditions (e.g.: occurrence probabilities; event kind and effects) for exposed population in existing urban environment, especially for wide conurbations, compact urban fabrics, mixed pedestrians'-vehicles evacuation flows [8,9]. Inefficient early warning systems and evacuation procedures [3,10] can also lead people to directly face with significant floodwaters propagation and related environmental modifications during the time. Current risk assessment methods are mainly based on hazard and vulnerability analyses, such as occurrence probability for different flooding types and territorial vulnerability [6]. Models for simulating flood-inundation development [11,12] and estimating economic and life losses are offered [13,14]. However, the "human" factor seems to be generally restricted to exposure-influencing factors, such as demographic data, risk perception and communications to exposed population [15]. Thus, this study would like to focus on critical behavioural issues during the evacuation phase, by proposing a BD-based model for representing man-environment interactions.

Previous studies on flood evacuation behaviours underline how man-environment (and man-floodwaters) interferences can affect the individuals' abandon hazardous areas, conservation of safe conditions while evacuating and reaching a refuge point [16–19]. They generally involve precise case studies analysis by using questionnaires to damaged or exposed population [10,16,20,21], while real World events analyses (by means of real world videotapes) are very limited [8,18]. In particular, researches on floodwaters effect on individual's stability and motion speed, by describing the floodwater flows in terms of stream depth and speed [22], have been provided. These works generally adopt laboratory experiments and scale representation of human body [23]. Additional main behaviours engage: evacuation delays for risk underestimation and attachment to belongings [20]; social attachment and solidarity phenomena between damaged individuals [16]; a sort of "fear of floating elements" (e.g.: vehicles) dragged by floodwaters [17]. Emergency timelines tried to merge evacuation and disaster management aspects [3].

Simulation models have been developed for different flood emergency. Many models based the simulated evacuees' behaviours on questionnaires results [10,21], and principally adopt floodwaters-evacuees speed relations