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Energy Procedia 134 (2017) 131–140

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Conference on Sustainability in Energy and Buildings, SEB-17, 5-7 July 2017, Chania, Crete, Greece

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.

Peer-review under responsibility of KES International.

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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1876-6102
Peer-review under responsibility of KES International.
10.1016/j.egypro.2017.09.549

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 or macroscopic rules (i.e.: density-speeds diagrams) to determine evacuation speeds [24–26]. Agent-Based Models (ABM) [26] take advantage of behaviours definition for each simulated evacuee, by adopting a microscopic method [1]. As for simulation models of other evacuation kinds [27–29], this approach allows enriching the interaction representation with psychological rules and individual's features, and it could be easily combined to other microscopic ones, such as the Social Force Model (SFM) [30]. SFM assigns experimental-based individual's motion behaviours, by representing them in terms of attractive and repulsive forces (due to interactions with other evacuees and environmental elements). SFM has been combined to ABM techniques for evacuation simulation [1,27,30], but it has never applied to flood-induced evacuation, mainly because of its limits in initial behavioural investigations.

According to BD methods, this paper provides the first part of a work involving the development of a simulation tool for flood risk assessment in existing urban areas. To this end, experimental investigations on human behaviours in flood-induced evacuation are here presented. Real World events analyses (i.e.: videotapes) are used for defining qualitative and quantitative evacuees' motion aspects [30,31]. Then, behavioural patterns are organized in a theoretical model, which combines ABM and SFM techniques. SFM modifications are drafted to consider peculiar noticed behaviours. The microscopic-Lagrangian approach could be able to consider variances in individuals' and environment characterization, as well as in their relations [1,27,30]. Future activities will implement the model in simulators to obtain tools for BD-based analysis of architectural space safety performances and risk-reduction solution evaluations.

Nomenclature

CUR	curiosity effect [-]; variation range: [0,1]
$C_w, p_{Cw}(t)$	barycentre of an obstacle, and its position at instant t
D, V	floodwaters depth [m] and speed [m/s]
D_w	man-unmovable obstacles distance [m]
F_{attr}, F_{rep}	modulus of attractive and repulsive forces between the evacuee, other pedestrians and the environment [N]
g	gravity acceleration (9.81m/s^2)
i, $p_i(t)$	evacuee (pedestrian), position of the pedestrian at instant t
$i_{channel}$	open channel slope [%]
M	specific force for width unit [m^3/m]
m_e	memory effect [-]; variation range: from 0 (unfamiliar path) to 1 (familiar path)
n	Manning coefficient for an open channel
N, N_e	max number of visible persons; number of persons along a certain path
O_e	rescuers'/evacuation plan effect [-]; variation range: from 0 (not present) to 1 (present)
O_g	modulus of drive-to-target (attraction towards safe areas) force [N]
$P_{s,e}$	probability to reach a certain safe area s by using a certain evacuation path e [-]
t	instant of evaluation [s]
$v_i(t)$	modulus of the individual's velocity [m/s]
V_e	preferred individual's speed in floodwaters, depending on M [m/s]
w, $p_w(t)$	obstacle, position of the obstacle at instant t in reference to the individual position
$\varepsilon(t)$	modulus of random variation of forces due to particular evacuee's behaviours [N]

3. Methodologies

3.1. Phases

From a general point of view, the definition of a flood-induced evacuation simulator can be organized according to points 1 to 4 in BD-methodology, as described at Section 1. This work involves points 1 and 2 by providing: 1) the definition of evacuation behaviours (organized in a chronological order) according to quantitative and qualitative analysis of real World videotapes; 2) the ABM-based model organization for experimental flood-induced evacuation interactions representation, from a microscopic point of view, by proposing SFM-based motion criteria.

3.2. Real World events database characterization

Previous researches [31] on human behaviours definition are used for database creation. A database of real event footages (70 videotapes) from all over the World is chosen (available at goo.gl/We58jB). All selected footages have confirmed geographical localization and date (from mass-media channel, civil defense or government agencies, performed by fixed cameras (i.e.: CCTV), or present in more than one different videos); they involve outdoor public and private spaces (i.e.: streets, squares, courtyards, private gardens), but some indoor scenes could be included. Videotapes are numerated: in the following, videotapes number is offered in curly brackets. World-wide scale observation allows tracking "representative" (average and general, related to different geographical areas, cultural, and social background) behaviours [31]. Fig. 1 resumes the videotapes database. As reported by previous works [19], the pedestrians' risk level (Fig. 1-c) are calculated by multiplying floodwaters depth *D* [m] and speed *V* [m/s]. Related Fig. 1 values are categorized by: "low", if lower than 0.6m^2/s; "medium", for 0.6 to 0.8 m^2/s; "high", for 0.8 to 1.2 m^2/s; "extreme", if higher than 1.2m^2/s. Methods for *D* and *V* estimation are offered at Section 2.3.

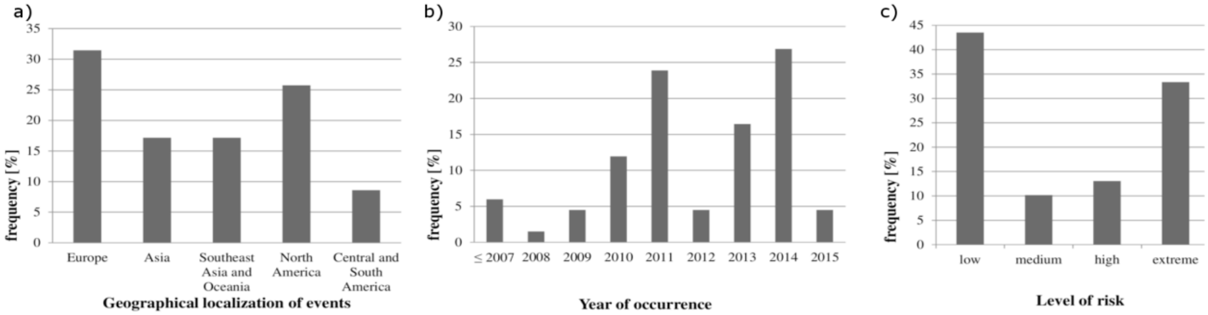

Fig. 1. Videotapes database characterization per: (a) geographical localization; (b) year; (c) risk level.

3.3. Methods for behavioural and motion quantities analysis

Behaviours and motion quantities are retrieved thanking to database footages analysis [31]. Qualitative analyses concern behavioural patterns definition. Noticed behaviours must be present at least in the 30% of the whole analysed sample. "Common" (noticed in other kinds of evacuation) and "peculiar" (typically connected with flood evacuation) evacuation behaviours are distinguished [31]. Then, they are organized according to the different evacuation phases, as proposed by previous works on emergency process [1–3].

Quantitative analyses are performed by using the freeware image analysis software Tracker [32]. Perspective filters are applied and flood-affected environment dimensions calibration procedure uses reference elements (or rather, visible and clearly measurable elements with known dimension, such as cars; approximation of 10cm) [31]. Floodwaters depth *D* [m/s] is directly measured in the videotape. A water flow uniform motion in wide rectangular-shaped open channels can be adopted when dealing with urban scenarios, where buildings and fences define the banks for the water flows [11]. Equation 1 evaluates floodwaters *V* [m/s].

$$V = \frac{1}{n} \cdot \sqrt{i_{channel}} \cdot D^{2/3} \tag{1}$$

Considered *n* is equal to 0.016 (outdoor conditions, asphalt paved surfaces [33]). $i_{channel}$ can be estimated through Tracker procedures or geo-localized data[1]. Evacuee's motion speed and distance from obstacles are calculated by

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[1] e.g., in this study we used the following tool: https://www.daftlogic.com/sandbox-google-maps-find-altitude.htm (last access: 10/02/2017)

means of Tracker and current pedestrians' tracking techniques: the manual tracking method because of videotapes features (e.g.: not uniform backgrounds to human motion; images resolution). Data from this study are added to previous results, so as to check literature correlations [22]. M is calculated according to Equation 2.

$$M = \frac{V^2 \cdot D}{g} + \frac{D^2}{2} \tag{2}$$

Finally, previous works generally suggest that people moving along (or near) obstacles are principally influenced by elements which distance is ≤3m [31]. Hence, man-obstacles distances D_w are evaluated by distinguishing three main classes for data (0÷1m; 1÷2 m; 2÷3m); these analyses refer to 62 individuals in 10 different videotapes scenes, when the individual is walking along an unmovable obstacle. Obstacles that can be dragged by the floodwaters (e.g.: vehicles) are not considered because of their instability problems [17]. Individuals' speeds in upstream motion are related to floodwaters flow specific force for width unit M [m^3/m] [22].

3.4. Model development and representation according to ABM and SFM approaches

Results from experimental analysis on evacuation behaviours are combined to previous literature research results, by adopting an ABM approach [28], with the aim to develop the bases for an emergency simulation model. According to the aforementioned microscopic point of view, this approach models each "particle" evidenced by the behavioural real world analysis (including both people and environmental elements), one by one. The particles are the so called agents, and each one owns rules for interacting with the surrounding ones. The result of this work activity is the definition of the *intentional model*, which is graphically represented by using the *i** language [34]. The intentional model discussion is combined to motion rules on a modified SFM [30], for including noticed flood behaviours.

4. Results

Results of the videotapes database analysis verify the presence of evacuation behaviours that are "common" to other kind of evacuations [2,30,31], and also confirm the outcomes of previous studies on man-floodwaters interactions [8,17,18,22]. Firstly, the main reference elements for each evacuee involved in the flood-induced evacuation behaviors can be represented by: floodwaters; environment (including both obstacles and guidance elements, such as well-known evacuation procedures and rescuers' presence; other surrounding evacuees; personal belongings. Table 1 summarizes the list of noticed evacuation behaviours for each evacuation stage.

The *attachment to belongings* [20] can provoke delay in evacuation starting, as shown for the two videotape frames in Fig. 2-a in indoor conditions {10} (time interval between them of about 10s): the individual is trying to salvage things (by putting them on the top of a shelf), while waters levels are growing. This behaviour also recurs in outdoor conditions (i.e.: because of interactions with vehicles and contained objects) (e.g.: {17, 28, 47, 58}). Some aspects in *"curiosity" effect and evacuation decision* (e.g.: {1, 11, 37}) are common with other evacuation kinds, because of risk level estimation and information exchange tasks [2,20,31]. Many retrieved videotapes (e.g.: {1, 57, 61}) involve smartphone video recording of people placed along streets and near floodwaters. In these cases, people seem to spend time in similar activities because of a sort of risk underestimation and surrounding low damage level (as for other emergencies [1]). This behaviour can recur during the whole evacuation. Group behaviours [30] and other pro-social evacuees' attitudes [16] could amplify related effects. Fig. 2-b shows a significant example: individuals (in the white circle) avoid to distance themselves from unsafe areas because of social attachment and "curiosity" purposes. These "pre-movement behaviours" could provoke significant delays and slowing down in evacuation and could also expose people to life-loss conditions [14], especially in places where early warning systems are not effective [10]. Hence, simulation models became essential so as to assess inhabitants' safety levels.

While moving in floodwaters, evacuees allow being attracted by unmovable obstacles because these elements can supply them possible help in case of stability problems [17,18,22] (*Attraction to unmovable obstacles* behaviour) {1, 11, 33}. Fig. 2-c shows evacuees who hold on to fixed obstacles (some high fence poles, evidenced by dark rectangles) and other ones who prefer to move towards (see black arrows) them so as to gain a support against hazardous floodwaters conditions {33}. As shown in Fig. 2-d {1}, evacuees moving in urban streets prefer to walk near buildings walls or fences (at the streets sides), mainly because of general raised sidewalks presence and of floodwaters lower speeds related the open channel configuration [11,33]. Spontaneous feelings of safety given by particular objects in the urban fabric are also retrieved in other emergencies: in earthquake evacuation, people allow to move towards (or near) "low obstacles" (e.g.: trees, shelters, street furniture) in order to find temporary "safe" positions [1]. Fig. 3-a summarizes the percentage distribution of D_w (organized into classes) for the whole sample and for each risk level. Although this sample should be enriched by further real-World data, some interesting results could be stressed. The most frequent class seems to involve D_w=1m to 2m. In case of low risk level, people seem to reach unmovable objects in an easier way because of more favourable floodwaters flow characteristics (D, V) in respect to higher risk levels: related distances become lower. Motion rules should consider a sort of attractive force towards these environmental elements, and these could be set according to experimental distances.

Table 1. Evacuation behaviours summary: behaviours marked by * are common to other evacuation kinds.

Evacuation stage	Evacuation behaviours (and main reference)	Scenario condition	Total number of video	Statistical frequency [%]	Reference elements
Pre-movement	*Attachment to belongings**: people prefer to spend time in collecting personal belongings before evacuation [20]	Indoor + outdoor	16	88	Belongings
	"Curiosity" effect and evacuation decision: individuals' delays in evacuation starting are due to floodwaters observations event and recording with smartphones or cameras. This task could involve visible risk evaluation and information exchange with neighbouring people.	Outdoor	66	41	Environment Floodwaters
Motion towards evacuation areas	*Attraction towards safe areas**: people would like to exit/move far from hazardous floodwaters, and reaching "safer conditions" in the "safe" areas [30]	Indoor + outdoor	40	60	Environment Floodwaters
	Attraction toward unmovable obstacles: people prefer to move towards (and along) environmental elements (e.g.: walls, street lights, trees, railings, fences) in order to reach possible supports during the motion in floodwaters; physical contact is allowed	Outdoor with unmovable environmental objects	10	90	Environment
	Fear of moving elements: people prefer to move far from floating objects (e.g. vehicles), that lost their stability and are dragged by floodwaters [17]	Outdoor with obstacles dragged by the floodwaters	4	75	Environment
	*Group phenomena**: pedestrians interacts for creating groups, avoiding motion overlapping, maintaining group cohesion for social attachment; herding behaviours in choices can be noticed [30,31]; pro-social behaviours can be activated [16]	Outdoor	66	32	Pedestrians
	*Increased guide effect for the presence of rescuers or evacuation leader**: an improvement of emergency phases (i.e.: appropriate behaviours, motion speeds) is noticed when at least one of these factors occurs [31]	Outdoor with presence of rescuers or evacuation leader	9	78	Environment Pedestrians
	Floodwaters interactions: speeds of people moving towards floodwaters are slowed down [19,22]; in case of medium or high pedestrians' risk level, floodwaters can impede evacuees' motion because of stability problems [18] (and lead them to further life risks [14])	Outdoor with medium or higher level of risk	39	31	Floodwaters
Safe area reaching	*Safe area definition*: evacuation targets are areas with lower level of visible damage, in terms of floodwaters depth and flows (e.g.: ground elevations); evacuation timing and social attachment criteria could be used by people during the target choice [10,16,25,26]	Outdoor	14	31	Environment Floodwaters Pedestrians

Finally, *floodwaters interactions* are codified in a quantitative way, by combining experimental values with previous results on individuals' speed V_e [m/s] against the specific force per width unit M [m^3/m] of the floodwaters flow [22]. Figure 3-b shows previous works values (by evidencing the minimum values for each *M*), this study real world data and the proposed M-V_e equation (based on a power function). The M-V_e equation is obtaining by interpolating minimum values for corridor (horizontal motion, comparable to videotapes analysis conditions) [22].

Fig. 2. Significant evacuation behaviours: (a) indoor "attachment to belongings" in two frames (time step of about 10s); (b) "curiosity" effect and social attachment of people in "safer areas" (in the white circle) in relation to surrounding scenario and incoming evacuees (black circle; direction given by black arrow); (c) and (d) attraction towards unmovable obstacles.

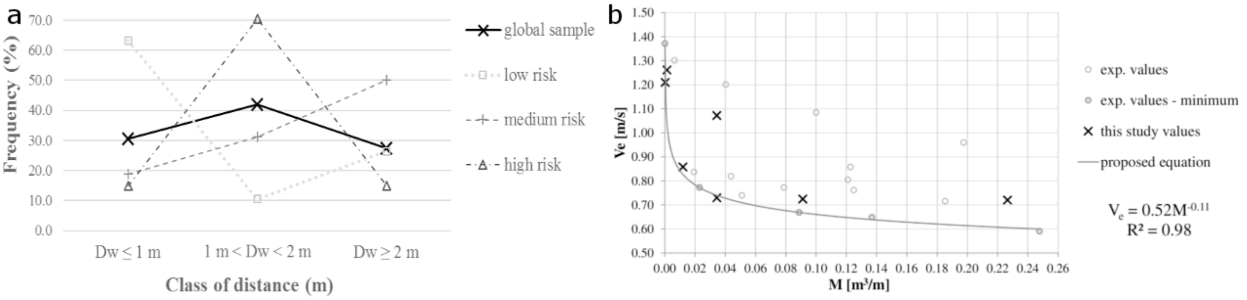

Fig. 3. Motion quantities: (a) D_w distribution by considering the whole sample and the level of risk for pedestrians; (b) M-V_e relationship (power function) by merging previous works ("exp. values") and this study values.

5. Discussion

Behaviours analyses results can be combined to literature researches on emergency evacuation simulation: they allow tracing the three main agents involved in flood-induced evacuation according to a ABM-SFM approach. The *agent "i"* plays the *Pedestrian* rule, and performs his/her actions in reference to *floodwaters* and *environment*, as shown by the intentional model at Fig. 4. The i* diagram includes Table 1 behaviours in (dependency) and offers a chronological evacuation process scheme (event). In the following, intentional model blocks in are offered in italics.

Floodwaters can be characterized by *D, V, M* during the time, thanking to a *hydrodynamic simulation* model [11]. Similar values influence the evacuation starting, especially in case of absence of early warning systems: the individual's estimation of flood severity is used to evaluate the necessity to evacuate [3,10]. *i*'s effective motion activities (including outdoor ones) can start after pre-movement behaviours (*evacuation started*).

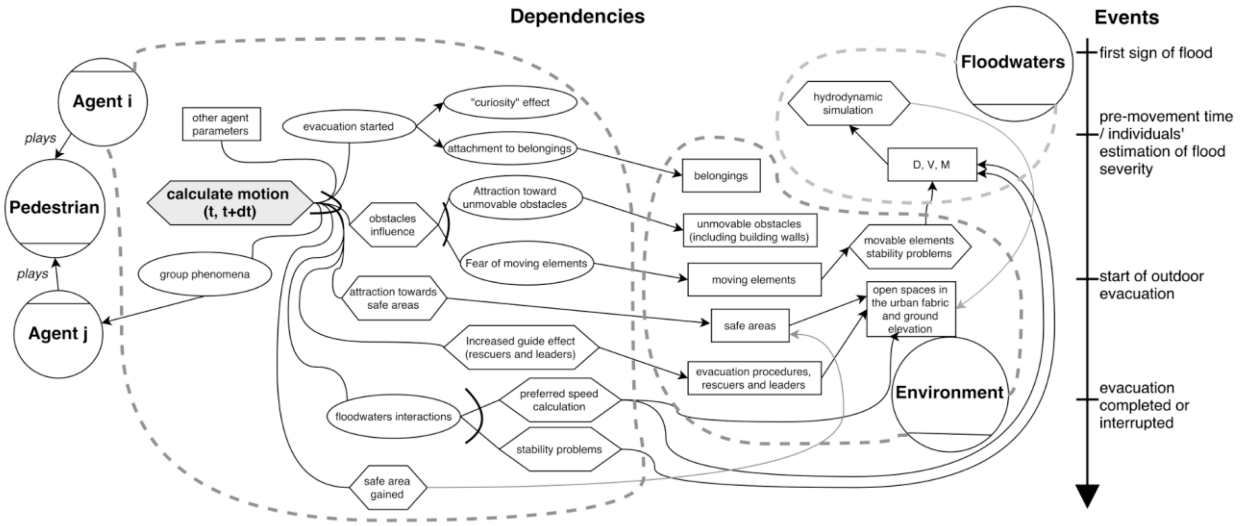

Fig. 1. Evacuation dependencies based on the behavioural investigation, organized by intentional model and chronologically arranged by events occurrence during the time. According to i* rules, agents are represented in the circles, tasks in rectangles, activities in hexagons, goals in ellipses; boundaries for agents are represented by dashed curves, dependencies by arrows, contemporary dependencies by linked lines.

Then, people decide to move towards *safe areas*, where they can minimize hazard because of *D, V, M* and the possibility to reach rescuers' aid (thanks to support of *evacuation procedures, rescuers and leaders*). The used path depends on the configuration of *open spaces in the urban fabric and ground elevation* (which also influence the floodwaters spreading) and on social effects (and so the presence of surrounding pedestrians), as well as on the *"curiosity" effects*. Building exits, directional street changes, crossroads, squares and other plano-altimetric variations in the urban fabric (e.g.: bumps, bends, significant variation of the street width) can be mainly considered as decision points for evacuation path choice. In these positions, in fact, *pedestrians* can consider the conditions of surrounding possible paths. When an evacuee is placed at a decision point, he/she decide the path to be used in the number of possible usable (and visible) ones. Equation 3 tries to link the path choice probability to these factors.

$$P_{s,e}=f\left(\frac{M_{e}}{M_{e,\max}},\frac{D_{e}}{D_{e,\max}},\frac{V_{e}}{V_{e,\max}},\frac{i_{channel,e}}{i_{channel,e,\max}},O_{e},\frac{N_{e}}{N},CUR,\frac{t_{e,s}}{t_{e,s,\max}},m_{e}\right)\in\left[0,1\right] \tag{3}$$

A time-dependent parameter is introduced for including individuals' time evacuation estimation by using a certain path [10,21,26]. Floodwaters-related (*D, V, M*), street slope ($i_{channel,\ e}$) and evacuation time values are divided by maximum critical ones for the possible usable paths ($_{max}$), in order to scale these values in the 0-1 non-dimensional interval. For $i_{channel,\ e}<0$ (downhill street), the whole parameter is generally considered as null. *"Curiosity" effects CUR* can be considered as not-dependent from the path since they are an individual's aptitude: a random variation can contemplate similar risk-increasing behaviours. Memory effects and *increased guidance effects* represent interaction with urban layout and possible assistance elements, as for other evacuation model [30,31]. People would tend to choice max $P_{s,e}$ value. While moving, each *pedestrian* adjusts his own velocity (*calculate motion*) because of his/her interaction system. The modified SFM should consider: flood-dependent components of speed based on Fig. 3-b considerations, due to V_e modifications; repulsive forces with *moving elements*; attractive forces with *unmovable obstacles*. Equation 4 resumes these interactions and common SFM terms in the overall motion law [30,29].

$$\vec{\ }_{i}(\ )\quad(\ _{g},\ _{rep,j},\ _{rep,w},\ _{attr,gr},\ _{attr,w},\vec{\ }) \tag{4}$$

O_g has been modified for considering the M influence on the preferred motion speed V_e, as shown by Equation 5.

$$\vec{O}_g(t) = f(\vec{r}_i(\text{[illegible]}), M, \text{[illegible]}) \tag{5}$$

The *fear of moving elements* is defined in terms of repulsive forces against next floating elements (distance with the individual lower than a critical value $D_{w,max}$) whereof barycentre C_w moves during the time. Nevertheless, $F_{rep,w}$ should maintained in order to avoid overlapping phenomena and all the obstacles. The *attraction toward unmovable obstacles* is included in SFM by proposing a related attractive force: as suggested by noticed behaviours at Fig. 3-a, this force should take into account the floodwaters characterization (e.g.: in terms of D, V) since effects of attraction (i.e.: D_w) seems to depend on the risk level. Equation 6 provides a theoretical view of these issues. The *hydrodynamic simulation* would allow to evaluate possible *stability problems* [17,18]: extreme floodwater flow conditions (D·V>1.20 m^2/s) can be proposed as *pedestrians*' motion limit, and force *i* to *stop the evacuation*.

$$\vec{F} \text{[illegible]} \vec{r} \text{[illegible]}$$

$$\vec{F}_{attr,w} = f(\vec{r}_i, \vec{r}_w, \text{[illegible]}) \text{[illegible]} \|\vec{r}_i \text{[illegible]} \vec{r}_w\| = \text{[illegible]}_{w,\max} \text{[illegible]} \vec{r}_{C_w} \text{[illegible]t} \tag{6}$$

The current model should be supported by future researches aimed at enriching the experimental behaviours dataset, by evaluating specific phenomena related to flooding types and social/geographical backgrounds. Laboratory experimental activities could be carried out to enlarge the test sample for speed-floodwaters relationship characterization. The, the next steps will concern the proposed model implementation in a microscopic-based simulation tool. To combine the model with flood-inundation simulation data, a microscopic description of flood parameters should be preferred. After its validation (e.g.: by comparing real World data and simulator outputs), the software could be used so as to perform evacuation safety analyses in existing urban scenarios and then support local authorities, civil protection bodies and safety planners when dealing effective risk-reduction strategies. Similar solutions could be linked to: emergency plan development and safety area definition, including possible spontaneous ones; interventions aimed at floodwaters spreading modification (e.g.: basins within the urban fabric); architectural components development (e.g.: street furniture, raised elements), which could provide physical support to people in dangerous floodwaters conditions; implementation of comprehensive alarm and guidance systems by including Smart City components as sensors and actuators (e.g.: personal devices applications or interactive street furniture). The tool application will can be also extended to both existing and new city areas.

6. Conclusions

This work would like to introduce the analysis of the "human" factor in flood-induced evacuation analysis, so as to investigate the safety performance of built environment (mainly, urban ones) and the critical issues for damaged populations. The first step to reach this goal is offered by this paper: behaviours adopted by pedestrians' in evacuation phases are provided by means of real-World videotape analysis and then organized in a related agent-based behavioural model. This representation allows tracing interactions between evacuating pedestrians, environment and floodwaters during the time, by adopting a microscopic approach. Moreover, criteria for describing the evacuation motion and choices are offered according to empirical data, for each evacuee involved in the process.

Acknowledgements

This work was supported by the MIUR (the Italian Ministry of Education, University, and Research) Project SHELL, Smart Living technologies (grant number: CTN01 00128 111357), part of the national cluster TAV (CTN01 00128) – Research Objective OR4 "Safety & Security Manager".

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