WP1–BE and SUOD: State of the Art (SoA), risks and human behavior

T1.2 SoA of earthquake (SUOD) impact on BE and related earthquake-induced modifications due to building/aggregate and aggregate/public spaces interfering conditions. Current risk-reduction strategies analysis. Definition of human behavior including crowding conditions by combining SoA data and real-world events analysis

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Abstract

Earthquake risk assessment at urban scale is mainly based on site hazard, buildings vulnerability and exposure (i.e. in terms of number of individuals exposed to the disaster), but does not consider human behaviours during both the event and the evacuation. Limited efforts towards this goal has been performed by previous studies, by involving limited samples (especially for behavioural analysis). Nevertheless, human interactions in such conditions are influencing element for inhabitants' safety and a paramount topics is to understan how people interact with other individuals and with the Buil Environment, including its modifications due to the earthquake. The development of evacuation software in earthquake conditions needs investigations about these aspects. Starting from a complete state of the art on quantitative and qualitative methods for earthquake evacuation analysis, this work proposes an innovative and complete database for earthquake evacuation models according to literature suggestions, by additionally integrating previous results with new analysis on a wide number of videotapes concerning real events from all over the World. Human behaviors (qualitative aspects) and motion quantities are assessed by codifying step-by-step evacuation behaviors that are activated during the process. Then, motion quantities (i.e. individuals' speed) are investigated, confirming how people prefer moving with an average speed of about 2 to 3m/s (significantly higher than other kinds of evacuation, e.g. fire), especially in the first emergency moments. Finally, fundamental diagrams of pedestrians' dynamics in earthquake emergency conditions are traced for indoor conditions. Results show how, density values being equals, speeds and flows are higher than fire evacuation and general-purpose drill. These data can be used as input parameters for defining and developing new evacuation models, but also for existing models validation.

Keywords

Earthquake evacuation; Human behaviors in the Built Environment; Human behaviours in emergency; Emergency management; Applied social sciences; Urban pedestrians' evacuation

Approvals

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Summary

1. Introduction

The Built Environment (BE) and its occupants have to frequently face outstanding disasters. Numerous researches are developed in the last decades to increase the safety of the BE and contextually to improve the inhabitants' resilience intended as rapid response to emergency situations (Lovreglio et al. 2018; Bernardini et al. 2019). Such studies are mainly relevant while dealing with all the situations in which the disaster conditions can appear in an unpredictable or rapid manner (Sudden-Onset Disasters – SUODs) (PreventionWeb - UNDRR). In case of a SUOD (e.g. fire, terrorist act, earthquake) the individuals' response to BE disaster-induced modifications is mainly critical during the first emergency phases, i.e. the evacuation process (Yang et al. 2011; Bernardini et al. 2019; Lin et al. 2020). In fact, occupants decide how to quickly behave and move while interacting with the surrounding BE and the other individuals, by performing or not, safe behaviors.

Literature underlines the existence of significant differences in disaster reaction between spontaneous behaviors and Civil Defence Bodies (CDB) recommended rules (Bernardini et al. 2019). Hence, understanding (and modelling) evacuees' spontaneous behaviors is essential to find proper strategies (e.g. emergency management, BE layout configurations, interventions on most vulnerable BE elements interfering with evacuees, interactive solutions based on rescuers-damaged population cooperation, individuals' training) to reduce the possibility of risky choices adoption, thus limiting the number of injuries and deaths resulting from SUODs (Bernardini et al. 2019). Current efforts on this goal are mainly focused on understanding behaviors of occupants in indoor SUODs such as fires or terrorist attacks (Chittaro and Sioni 2015; Çakiroğlu and Gökoğlu 2019).

Recent works on the analysis of earthquake evacuation were performed, by underlining the importance of sustainable tools aimed at collecting data about spontaneous human behaviors during such events (Yang et al. 2011; Bernardini et al. 2016b, 2019; Zhou et al. 2018a), which are generally characterized by particular SUODs features which are difficult to be replicate in evacuation drills, such as the presence of debris and smokes, the building damages, the ground shaking (Lovreglio et al. 2018; Lu et al. 2019; Bernardini et al. 2019). Studies tried to codify the behaviours from a qualitative (i.e. adopted choices during the evacuation phases) and quantitative (i.e. motion quantities, related to both individual and group conditions) standpoint, by using several methods and tools exist (Lovreglio et al. 2018), in the view of modelling purposes for simulation (i.e. analysis of risks in BE due to seismic emergency) as well as for training and risk-awareness increasing (D'Orazio et al. 2014a; Bernardini et al. 2016b; Xiao et al. 2016; Zhou et al. 2018a; Lovreglio et al. 2018; Lu et al. 2019). Nevertheless, the existing databases should be updated in order to increase their statistical significance and mainly integrate data about the adopted behaviors, especially in relation to the relation between the evacuees and the BE composing elements and by considering quantitative aspects in motion.

Starting from this point of view, this report traces an overview on the state of the art about earthquake evacuation behaviors (Section 2), by additionally evidencing the tools that can be mainly used to retrieve input for such kind of emergency database. The main behaviors affecting the evacuation process are discussed in relation to the emergency phases as well as to the main BE-characterizing elements, in view of the other deliverables in WP1, T1.2 (i.e.: D1.2.1, to correlate the dependencies with the factors assumed in the risk matrix; D1.2.4 to outline the dependence with the risk-mitigation strategies). In these activities, the attention is focused on pedestrians' emergency behaviors because of (Rojo et al. 2017; Zhou et al. 2018a; Shi et al. 2018; Bernardini et al. 2019; Feng et al. 2020): 1) their impact in such sudden-onset emergency conditions of the BE, i.e. no possibility to have preventive emergency evacuation (e.g. by car or public transportation) and their higher possibility of activation also in view of BE damage levels; 2) the possibility to combine individuals' behavioral aspects in indoor/outdoor scenarios, as well as in the relation between building-spaces in the BE frontiers, especially in complex BEs such as the urban and historical ones.

Then, analysis on real world videotapes are carried out according to consolidated criteria (Johansson et al. 2008; Bernardini et al. 2016b, 2019; Haghani and Sarvi 2018; Zhou et al. 2018a), so as to outline qualitative and quantitative aspects in earthquake evacuation (Section 3). In particular, databases from previous structured works (Bernardini et al. 2019) are integrated by additional analysis on further real-world events videotapes, so as to create a wider sample for the analysis. Results about these activities are traced according to the state of the art-based topics (Section 4).

2. Human behaviors in earthquakes: data collection, analysis methods, aims and current literature outcomes

To outline the current state of the art on Human behaviours in earthquakes, two main sub-topics should be taken into account: the data collection methodologies ("where" and "how" to retrieve the data - Section 2.1); the consolidated aims of researches and behavioral outcomes from literature (Section 2.2).

2.1. Data collection and analysis methods

Among the different methodologies that can be used to trace the human behaviours in earthquake emergencies, critical literature analysis evidences how the most significant and sustainable ones in earthquake context seem to be (Chittaro and Sioni 2015; Shiwakoti 2016; Li et al. 2017, 2018; Feng et al. 2018; Moussaïd et al. 2018; Zhou et al. 2018b; Sukirman et al. 2019; Bernardini et al. 2019; Tsurushima 2020):

1. the analysis of real-world videotapes, e.g. by CCTV (Closed Circuit Television, installed inside or outside private or public buildings mainly for surveillance matters), whose approach was consolidated over the time and allows to evaluate effective emergency situations, or rather during real-world events, without additional biases. Individuals' actions to face the disaster are potentially detected during each evacuation phase, from the moment immediately before and during the earthquake (i.e. in reference to the possible individuals' protection actions and to the organization of strategies to escape towards a safer zone) until the occupants' escape and motion outside buildings, or even until the rescuers' arrival;
2. novel immersive technologies like the Virtual Reality (VR)-based ones, which can ideally reproduce the earthquake-prone BEs with a high level of realism and by considering complexity issues (e.g. BE features, earthquake-induced damages, support to injured people and rescuers requested to the testing individual, support provided to the testing individual by rescuers). Since participants are physically "inside the emergency", their behaviors can be considered as "spontaneously suggested" by their involvement into them, showing that participants feel more focused on the tasks to be solved, resulting from better immersion experience. These tools permit to study occupants' behaviors in realistic scenarios that would be too difficult and dangerous to implement in the real world and they are increasing their level of realisms (i.e. including immersive representation of the earthquake by performing the tests on vibrating platform under participants' seat). Nevertheless, same biases due to the physical interaction with the BE and the other users on the scene remain, and some studies underlines how "it is difficult to reproduce the mental pressure of real evacuations in laboratory experiments".

Additional data collected methodology could concern questionnaires on real world event, e.g. after an earthquake. In particular, one of the fundamental issues in this research is related to the "Did You Feel It" question (Goltz et al. 2020), so as to outline the perception of the earthquake by the population, by additionally using great databases via online surveys[1]. On the contrary, sociological investigations on the adopted behaviors, perception of the surrounding BE and feelings in the evacuation could be better performed by using smaller samples, e.g. by means of direct interviews (Noji et al. 1990; Prati et al. 2013; Tai et al. 2014; Goltz and Bourque 2017; Shrestha et al. 2018). Hence, these techniques could give additional data to the behavioral modeling from a psychological and sociological perspective (including data on the sample characterization of demographic and situational characteristics of the involved population), but they can be conducted only on survivors and could be affected by “memory”-related biases influencing the a-posteriori event perception.

According to this overview, the analysis of real world videotapes is a fundamental data collection methodology to characterize the earthquake evacuation behaviors, as well as it could also provide interesting data for the implementation of the VR-related analysis, thus allowing the definition of qualitative and quantitative aspects in evacuation behaviors. Furthermore, they are often freely available on the internet, by enhancing the possibility to share and analyse them (Moussaïd et al. 2018). Nevertheless, trustworthy videotapes sources should be preferred, i.e. CDB, First Responders and Government organizations, and, secondarily, those from media channels, so as to avoid fake videotapes while ensuring the correspondence between a certain earthquake (i.e. sensible events, so as to take into account the effective users’ perception of ground shaking) and the location (in time and space) of the videotapes (Bernardini et al. 2019). Videotapes posted by end-users on reliable social media channel (e.g. YouTube, Twitter) could be taken into account especially if representing the same scene, so as to confirm the origin of the event (Bernardini et al. 2016b).

Besides the many advantages in selecting real world videotapes as data sources, some main limitations exist and caveats should be underlined.

These sources can be related to videotapes suffering poor resolution quality, inadequate illuminance levels for the scene, ground shaking implying movement for the cameras or not efficient frame, which can reduce the possibility to trace human behaviours in a precise way over time (i.e. quasi-continuous data collecting) and space (i.e. clearly detect each individual in the scene during the whole process; linking data from different videos in the same CCTV system), especially for quantitative purposes (Yang et al. 2011; Bernardini et al. 2016b). In this sense, videotapes with fixed field of view could be affected by limitation in understanding the overall dynamics in the evacuation process (Bernardini et al. 2016b).

Nevertheless, methodologies to detect motion quantities, i.e. speed, density and flows, can be arranged according to the videotapes features, thus having different approximation on the output data (Chen et al. 2012; Boltes and Seyfried 2014; Bernardini et al. 2016b; Gu et al. 2016; Haghani and Sarvi 2018; Shi et al. 2018). Such approximations could be also linked to the necessity of scaling the spaces to trace motion of the individuals. Original space plans are generally unavailable, and space scaling are based on the retrieval of common objects with generally known dimension (e.g.: standard furniture, such as chairs and desks; motor-vehicles, especially if the model can be detected; standard doors such as emergency ones, depending on national main regulations), giving approximation up to 10cm (Bernardini et al. 2016b). Furthermore, most of the videotapes concerns views in perspective, which should be calibrated towards quasi 2D representation by using dedicated tools and specific references into the scene.

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[1] e.g., for the Italian context https://www.hsit.it/ (last access: 10/06/2020)

In such conditions, automatic tracking solutions could be limited applied because of the previous videotapes non-ideal features, while the researchers who perform manual analyses should be adequately trained in recognizing both the behaviours and the position of the individuals, especially in crowd scenes (anyway, in this case, support algorithms and methodologies exist, e.g. implemented in software for behavioural analysis, tracing the silhouette of the evacuees by Canny Edge algorithms, identifying the mass of the evacuees at the hip level rather than at the head level) (Bernardini et al. 2016b; Zhou et al. 2018a).

Some input characterization parameters concerning the evacuees could be also affected by detection problems, e.g. age, gender, motion abilities, although criteria for the quick identification of the parameters could be applied for higher resolution videotapes (Zhou et al. 2018a).

Finally, about the original CCTV-related sources, guidance notes on the use of images and videos under data protection law should be considered (e.g. for videotapes data publication)[2].

2.2. Human behaviors researches in the state of the art: from aims to results overview

Studies on human behaviors classification through real videos are aimed at defining decisional rules for the prediction of the earthquake emergency response of the single individuals as well as of the crowd, as well as at providing data on the adoption of recommended behaviours by people in emergency behaviours (Yang et al. 2011; Gu et al. 2016; Shi et al. 2018; Bernardini et al. 2019). Such results can be also supported by the other methodologies of data collection, thus providing additional data on psychological and perceptive issues in emergency behaviours (Tai et al. 2014; Lovreglio et al. 2017, 2018; Goltz et al. 2020; Feng et al. 2020).

From a qualitative point of view, these researches generally defined the presence of *common behaviors* between earthquake emergency and other kind of disasters and the presence of *peculiar earthquake emergency behaviors*, essentially due to the specific features of the event (e.g. ground shaking, building damage), which have also been associated to statistical significance thresholds (i.e. 30%) between the analyzed samples (Bernardini et al. 2019). These results are organized according to the three main emergency stages, which essentially relates to (Alexander 1990; Bernardini et al. 2016a, 2019; Rojo et al. 2017; Zhou et al. 2018a; Zhu et al. 2020; Feng et al. 2020):

1. *pre-movement*, which generally refers to the moment of the main earthquake shock, up to the decision to evacuate or not the building. In this sense, such phase is highly affected by pre-earthquake phase characterization (e.g. BE intended use, action carried out by the BE users before the event);
2. *evacuation*, which relates to the movement towards and evacuation target (e.g. building exit in indoor conditions, assembly areas or wide spaces in the built environment in outdoor conditions). This is the main evacuees' response phase, which essentially leads to interaction with the surrounding BEs and their earthquake-induced modifications;
3. *safe area reaching and immediate post-evacuation phase*, which is characterized by the end of the evacuation process and the possibility to return to the initial positions. This stage can by majorly supported by CDB in an active manner (e.g. rescuing trapped and injured people, supporting autonomous survivors).

Moreover, videotapes-based behaviors and their statistical trends have been compared to virtual reality-based, questionnaires-based and evacuation drills-based studies, evidencing differences in the trends which

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[2] e.g. https://www.echr.coe.int/Documents/Handbook_data_protection_ENG.pdf (last access: 31/01/2020)

are not only due to the sample dimension and features (e.g. country, socio-economic issues, gender, age) but also to the substantial differences between real world and simulated/a-posteriori investigation conditions (Yang et al. 2011; Goltz et al. 2020; Feng et al. 2020). In particular, studies comparing *mimic exercises versus reality by real-world videotapes data* demonstrated how crowd behaviors during a seismic event seems not to be in compliance with evacuations reproduced in drills and laboratory conditions, as well as with the recommended evacuation behaviors (Yang et al. 2011; Bernardini et al. 2019). In conditions of scarce illuminance, people in evacuation drills prefer to crawl on the floor (according to the CDB recommendations), while, in real events, even though in presence of a strong ground shaking, individuals tend to hold on to the walls or they looks for other stable objects close to them trying to remain standing (Yang et al. 2011). In overcrowding conditions, especially while moving in proximity of an exit or a bottleneck, laboratory experiments observed how people tend to maintain minimum distances among them and among architectural elements (as for other kind of emergencies). Contrarily, many real-world cases shown how evacuees could tend to occupy the whole available spaces close to the exits, failing the minimum distances proposed by literature. Such differences could be related to stress levels induced by effective emergency conditions in respect to drills (Shiwakoti 2016).

From this point of view, the investigation of emergency preparedness levels of the BE occupants performed through real-life earthquakes videos analysis evaluated if and how much the CDB recommended procedures provided to inhabitants are adopted in case of emergency. Preliminary works were conducted by systematically involving videotapes from a limited number of Countries (e.g. Italy, Japan (Bernardini et al. 2019), China (Zhou et al. 2018a), New Zealand (Bernardini et al. 2019) by comparing data with VR studies (Feng et al. 2020)) and investigating individuals' reaction to the seismic shocks both in indoor and outdoor BEs in correlation with additional factors (i.e.: presence of debris; presence of low obstacles like trees, shelters, street furniture, fences; presence of safety staff members; individuals' number in the scene; intended-use of the BE). Cross-country and specific national guidelines are considered by demonstrating the existence of differences (e.g. cultural ones) between the inquired Countries, while a general low compliance with recommended rules can be generally evidenced, thus suggesting the necessity to better investigate real world events to provide useful data to improve awareness-increasing activities by CDB.

In addition, these studies evidence that the seismic severity and surrounding environmental conditions can strongly affect human reactions and the subsequent safety procedures observance. The activation of the evacuation procedures seems to be registered only over the IV degree of the EMS98 intensity scale (Grünthal 1998). Meanwhile, the increasing of the earthquake severity (e.g. in intensity terms) reduce the delay in the activation of any safety procedure, according to a semi-quantitative approach to evacuation activation (Zhou et al. 2018a). Decision models and trees were also developed (e.g. through machine learning methods, probability-based methods/discrete choice models (Zhou et al. 2018b; Tsurushima 2020)) according to input variables as gender, age, seismic intensity, social context, action, initial location of the individual also in respect to the evacuation target, by mainly focusing on indoor contexts in the BE. Such approaches try to predict, i.e., escape possibility, drop-cover-hold on procedure activation, escape with familiar individuals, continuing performing the original task, assisting other occupants. Nevertheless, studies are still limited in terms of involved videotapes and analysed individuals (e.g. in (Zhou et al. 2018b), 30 videos and 334 individuals; in (Tsurushima 2020), 1 video and 36 individuals) but their capabilities could improve BEs safety management.

Contrarily to the CDB rules which suggest to perform drop-cover-hold on procedures during the earthquake, people in indoor scenarios can generally start the evacuation process immediately, by moving out of the building and being exposed to possible collapse of non-structural buildings parts (Lambie et al. 2017). This result has been also confirmed by post-earthquake questionnaires (Goltz et al. 2020). According to **Errore. L'autoriferimento non è valido per un segnalibro.** results, the attachment to belongings is another collateral effect frequently observed, by leading people to delay their evacuation starting while, in some cases, evacuees can continue their previous activities (especially those connected to personal computers and devices) (Zhou et al. 2018a; Bernardini et al. 2019).

In outside scenarios instead, evacuees are led to stop the evacuation process towards the emergency safe areas immediately where they feel in safer conditions (e.g.: wider spaces, without debris or dust presence, with low overcrowding conditions and away from high and dangerous buildings) (Bernardini et al. 2016b). According to such behaviors, some virtual-reality training tools are aimed at making individuals aware about the outside safe area choice (not prone to landslide and away from electrical and water installations) (Sukirman et al. 2019), while evaluating the possible individuals' tendency to stay away from vulnerable buildings, trees, billboards and streetlights. Similar effects due to evacuation stop/interruption occur when people gather in groups where helplessness and common conditions push people to remain in the first available safe area, without performing completely their safety actions (Alexander 1990; Bernardini et al. 2019).

From a quantitative point of view, two different levels of data can be classified according to different modeling approaches: microscopic aspects of the evacuation process concern the individual's movement features, as reported by Table 4; macroscopic aspects of the evacuation process represent the overall trend of the crowd, as reported by Table 5. Besides the aforementioned models on decision models/trees, a limited number of studies investigates motion quantities during the earthquake emergency (Yang et al. 2011; D'Orazio et al. 2014c; Bernardini et al. 2016b; Gu et al. 2016; Zhou et al. 2018a), by essentially focusing on instantaneous evacuation speed and acceleration, delay time, fundamental diagrams in pedestrians' dynamics, as shown by these tables. Although general caveats to data collection-affecting elements are also discussed in Section 2.1, specific elements are provided by Table 4 and Table 5. Previous researches outcomes are also organized in Table 4 and Table 5 in view of the characterization of conditions for data analysis, of the comparisons to other emergency conditions, and of the input data usability for modeling purposes. Finally, main statistical values from previous works are considered in relevant cases.

Table 1, Table 2 and Table 3 respectively resume the main behaviors retrieved by previous works for pre-movement, evacuation and safe area reaching stages, by focusing on those directly related to the analysis of real world videotapes (Bernardini et al. 2016a, 2019; Lambie et al. 2017; Zhou et al. 2018a; Feng et al. 2020). Each behaviour is organized by:

- providing its definition according to the last structured work on videotapes analysis of earthquakes events (Bernardini et al. 2019), which has been adopted by other further works (also in virtual reality experiments or questionnaires (Feng et al. 2020));
- distinguishing “common” (identified by *) and “peculiar” behaviors, as well as behaviors that can be noticed in other kind of wide scale disasters occurring in BEs, especially those placed in urban areas (e.g. flood, fires (Riad et al. 1999; Bernardini et al. 2017; Veeraswamy et al. 2018));
- outlining their occurrence in respect to indoor and outdoor elements of the BE, in view of D1.1.1 and D1.2.1 general outcomes;
- defining which are the main BE elements affecting the human behaviors, by including the main key aspects from D1.2.1 (i.e., Section 3 for earthquake severity, Section 4 for human exposure and Section 7 for general issues in Risk Matrix for earthquake conditions) and D1.2.4 (i.e., Section 4.5).

It is worthy of notice that, although the traced behaviors are “average” emergency actions in a World-wide perspective and their overall statistical significance is over the 30% limits considering at least one of the original work sources (Bernardini et al. 2016a, 2019; Lambie et al. 2017; Zhou et al. 2018a; Goltz et al. 2020; Feng et al. 2020), significant differences in behaviors adoption among several Countries can exist, thus not leading to the same statistical significance threshold, because of specific local factors (especially about CDB-related recommended behaviors, which can vary depending on the Country) (Bernardini et al. 2019).

Moreover, videotapes-based behaviors and their statistical trends have been compared to virtual reality-based, questionnaires-based and evacuation drills-based studies, evidencing differences in the trends which are not only due to the sample dimension and features (e.g. country, socio-economic issues, gender, age) but also to the substantial differences between real world and simulated/a-posteriori investigation conditions (Yang et al. 2011; Goltz et al. 2020; Feng et al. 2020). In particular, studies comparing *mimic exercises versus reality by real-world videotapes data* demonstrated how crowd behaviors during a seismic event seems not to be in compliance with evacuations reproduced in drills and laboratory conditions, as well as with the recommended evacuation behaviors (Yang et al. 2011; Bernardini et al. 2019). In conditions of scarce illuminance, people in evacuation drills prefer to crawl on the floor (according to the CDB recommendations), while, in real events, even though in presence of a strong ground shaking, individuals tend to hold on to the walls or they looks for other stable objects close to them trying to remain standing (Yang et al. 2011). In overcrowding conditions, especially while moving in proximity of an exit or a bottleneck, laboratory experiments observed how people tend to maintain minimum distances among them and among architectural elements (as for other kind of emergencies). Contrarily, many real-world cases shown how evacuees could tend to occupy the whole available spaces close to the exits, failing the minimum distances proposed by literature. Such differences could be related to stress levels induced by effective emergency conditions in respect to drills (Shiwakoti 2016).

From this point of view, the investigation of emergency preparedness levels of the BE occupants performed through real-life earthquakes videos analysis evaluated if and how much the CDB recommended procedures provided to inhabitants are adopted in case of emergency. Preliminary works were conducted by systematically involving videotapes from a limited number of Countries (e.g. Italy, Japan (Bernardini et al. 2019), China (Zhou et al. 2018a), New Zealand (Bernardini et al. 2019) by comparing data with VR studies

(Feng et al. 2020)) and investigating individuals' reaction to the seismic shocks both in indoor and outdoor BEs in correlation with additional factors (i.e.: presence of debris; presence of low obstacles like trees, shelters, street furniture, fences; presence of safety staff members; individuals' number in the scene; intended-use of the BE). Cross-country and specific national guidelines are considered by demonstrating the existence of differences (e.g. cultural ones) between the inquired Countries, while a general low compliance with recommended rules can be generally evidenced, thus suggesting the necessity to better investigate real world events to provide useful data to improve awareness-increasing activities by CDB.

In addition, these studies evidence that the seismic severity and surrounding environmental conditions can strongly affect human reactions and the subsequent safety procedures observance. The activation of the evacuation procedures seems to be registered only over the IV degree of the EMS98 intensity scale (Grünthal 1998). Meanwhile, the increasing of the earthquake severity (e.g. in intensity terms) reduce the delay in the activation of any safety procedure, according to a semi-quantitative approach to evacuation activation (Zhou et al. 2018a). Decision models and trees were also developed (e.g. through machine learning methods, probability-based methods/discrete choice models (Zhou et al. 2018b; Tsurushima 2020)) according to input variables as gender, age, seismic intensity, social context, action, initial location of the individual also in respect to the evacuation target, by mainly focusing on indoor contexts in the BE. Such approaches try to predict, i.e., escape possibility, drop-cover-hold on procedure activation, escape with familiar individuals, continuing performing the original task, assisting other occupants. Nevertheless, studies are still limited in terms of involved videotapes and analysed individuals (e.g. in (Zhou et al. 2018b), 30 videos and 334 individuals; in (Tsurushima 2020), 1 video and 36 individuals) but their capabilities could improve BEs safety management.

Contrarily to the CDB rules which suggest to perform drop-cover-hold on procedures during the earthquake, people in indoor scenarios can generally start the evacuation process immediately, by moving out of the building and being exposed to possible collapse of non-structural buildings parts (Lambie et al. 2017). This result has been also confirmed by post-earthquake questionnaires (Goltz et al. 2020). According to **Errore. L'autoriferimento non è valido per un segnalibro.** results, the attachment to belongings is another collateral effect frequently observed, by leading people to delay their evacuation starting while, in some cases, evacuees can continue their previous activities (especially those connected to personal computers and devices) (Zhou et al. 2018a; Bernardini et al. 2019).

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Table 4 and Table 5. Previous researches outcomes are also organized in

Table 4 and Table 5 in view of the characterization of conditions for data analysis, of the comparisons to other emergency conditions, and of the input data usability for modeling purposes. Finally, main statistical values from previous works are considered in relevant cases.

*Table 1. General overview of main emergency behaviors in the pre-movement stage according to literature works in relation to the emergency stages, by including the elements of reference in the BE for individual interactions. "Common behaviors" are identified by *.*

***Behavior*: definition [P: general CDB recommended measures]**	**Building (B) / Open Space in the BE (OS)**	**Relation with Risk-matrix in D1.2.1**	**Relation with DRR in D1.2.4**	**Additional interaction with BE elements**	**Additional exposure-related interaction factors**
*Information seeking**: individuals look around to understand the BE conditions and the state of surrounding individuals (if present)	B/OS	Damage scenario (in B and in OS)		Presence of visible damages in B and OS	
Evacuation procedure for sensible earthquakes: the evacuation generally is adopted for events with an intensity over the IV degree of EMS98 scale	B	Ground Motion Severity; Damage scenario (in B and in OS); Human exposure (BE function and activities-occupancy class)	Risk Perception; Casualties (possibility to autonomously evacuate)		Rescuers and safety staff members; activity carried out by the occupants (i.e. awake or asleep)
Self-protection procedures: Individuals perform drop/cover/hold on strategies during the earthquake shake and the immediate moment after it (in indoor: cover under stable objects, including desks, doors or columns/structural elements of the BE; in outdoor: drop/hold on strategies away from BE elements and other obstacles, including streets furniture) [P]	B/OS	Ground Motion Severity; Damage scenario (in B and in OS)	Risk Perception		Rescuers and safety staff members
*Attachment to things**: people collect belongings and/or continue performed activities (e.g. work) before to start the evacuation process	B/OS	Human exposure (BE function and activities-occupancy class)			
*"Pro-Social" Behaviors**: people interact to perform decisional issues and activate at least one of the following behaviors: 1) *information exchange* to compare information and event perception, during the earthquake and before the evacuation starting (talking, visually communicating); 2) *Social attachment* to provide spontaneous assistance one to each other, including towards elderly and children	B/OS	Human exposure (BE function and activities-occupancy class)	Risk Perception		Presence of more than 1 individual in the space; individuals' features (i.e. age, gender) and group effects (e.g. group ties between family members, social shared identity in widest groups)

*Table 2. General overview of main emergency behaviors in the evacuation stage according to literature works in relation to the emergency stages, by including the elements of reference in the BE for individual interactions. "Common behaviors" are identified by *. ^ refers to a behavior that is partially seen in other kind of evacuation at urban scale (i.e. flood).*

***Behavior*: definition [P: general CDB recommended measures]**	**Building (B) / Open Space in the BE (OS)**	**Relation with Risk-matrix in D1.2.1**	**Relation with DRR in D1.2.4**	**Additional interaction with BE elements**	**Additional exposure-related interaction factors**
Immediate evacuation starting behaviors: during the earthquake individuals can: 1) *run out of indoor spaces*; 2) *move in open spaces in the BE* (although the ground is shaking, to start or continue the evacuation). The choice can depend on the distance to the "safe area" and to social group effects (i.e. herding phenomena)	for 1: B; for 2: OS	Ground Motion Severity	Risk Perception; Casualties (possibility to autonomously evacuate)	Distance to the "safe area"	Presence of more than 1 individual in the space; Group effects (e.g. group ties between family members, social shared identity in widest groups)
Stop/interrupt the evacuation because of ground shaking: individuals can stop moving because of body stability loss (or to prevent it)^	B/OS	Ground Motion Severity	Risk Perception; Casualties (possibility to autonomously evacuate)		
*"Pro-Social" Behaviors**: people interacts in the motion process and activate at least one of the following behaviors: 1) *herding behavior* and related formation of evacuation groups*; 2) remain together because of *group ties**; 3) *information exchange* to compare information on the event (talking, visually communicating).	B/OS		Risk Perception; Population density		Presence of more than 1 individual in the space; individuals' features (i.e. age, gender) and group effects (e.g. group ties between family members, social shared identity in widest groups)
*Information seeking**: individuals look around to understand the BE conditions and the state of surrounding individuals (if present)	B/OS	Damage scenario (in B and in OS)		Presence of visible damages in B and OS	
*Use of personal devices during the evacuation motion**: people interact with smartphones during the evacuation, to gain information/be in touch with other individuals (e.g. telephoning)	B/OS	Human exposure (BE function and activities-occupancy class)	Risk Perception		Personal devices (i.e. mobiles)
*"Curiosity" effect**: people spend time in possible unsafe areas to "see what is happening", by also using mobile devices for not-evacuation-related purposes, e.g. shooting the emergency	B/OS	Damage scenario (in B and in OS); Human exposure (BE function and activities-occupancy class)	Risk Perception		Personal devices (i.e. mobiles)
*Attraction towards safe areas**: people exit/move far from buildings, towards a "*safe area*" (defined as in	B/OS	Damage scenario (in B and in OS)	Risk Perception; Casualties (possibility to		

Table 3)			autonomously evacuate); Network of Paths and Open Spaces; Entry points to the buildings		
Evacuation path selection: people try to gain a "safe area" through the widest and clearest of dust and rubble paths (especially while being in open spaces), by preferring the nearest and more familiar routes (especially in indoor)	mainly OS; applicable to B	Damage scenario (in B and in OS)	Risk Perception; Network of Paths and Open Spaces; Entry points to the buildings		Rescuers and safety staff members
Fear of buildings: individuals try to maintain a safety distance from high and damaged BE elements (i.e. buildings)	OS	Damage scenario (in B and in OS)	Risk Perception	Geometry of the BE layout	
Debris avoidance: evacuees prefer to avoid debris rather than to walk on them (if possible)	mainly OS; applicable to B	Damage scenario (in B and in OS)	Risk Perception		
*Increased guidance effect because of rescuers and possible safety plan/signs influence**: the evacuation process is supported by personnel in the BE (safety staff members, rescuers and first responders) and by the presence of instructions and wayfinding elements, increasing safe behaviors adoption and the reaction to evacuation tasks (e.g. path selection uncertainties reduction)	B/OS		Risk Perception (towards individuals' CDB recommendations awareness and emergency preparedness)	Signage systems; other systems to support the population (including remote-based ones, e.g. interaction with mobile devices)	Rescuers and safety staff members; individuals' risk awareness; emergency preparedness (CDB recommendations); Personal devices (i.e. mobiles)
Helplessness conditions: people tend to remain close to the same place, gathering around it, especially in outdoor, by sharing choices and evacuation interruption, because of the damage levels in the surroundings. People prefer to be close to their initial position (compare to *Evacuation end* in Table 3).	OS	Damage scenario (in B and in OS)	Risk Perception; Entry points to the buildings; Casualties (possibility to autonomously evacuate)		Presence of more than 1 individual in the space; individuals' features (i.e. age, gender) and group effects (e.g. group ties between family members, social shared identity in widest groups)
Attraction towards low obstacles: people can move towards low elements (including trees, shelters, furniture in outdoor) to have support during the motion (i.e. during the earthquake, due to significant ground shaking) and find a "temporary" and easy-to-recognize safety point	OS; in B, they can be related to walls and handrails/furniture	Ground Motion Severity	Risk Perception	BE furniture	

*Table 3. General overview of main emergency behaviors in the safe area reaching and immediate post-evacuation stage according to literature works in relation to the emergency stages, by including the elements of reference in the BE for individual interactions. "Common behaviors" are identified by *. ^ refers to a behavior that is partially seen in other kind of evacuation at urban scale.*

***Behavior*: definition [P: general CDB recommended measures]**	**Building (B) / Open Space in the BE (OS)**	**Relation with Risk-matrix in D1.2.1**	**Relation with DRR in D1.2.4**	**Additional interaction with BE elements**	**Additional exposure-related interaction factors**
Evacuation end for influence of not immediate danger feelings or helplessness conditions: People can be pushed to remain in the "first available safe area, to end evacuation and to not perform personal safety actions". This kind of evacuation choice could be also temporary (e.g. compare to the *Attraction towards low obstacles* and *Helplessness conditions* in Table 2). Major effects can be seen to maintain a close distance with the building in which they were initially placed (i.e. homes)^.	1) B ; 2) OS	Damage scenario (in B and in OS)	Risk Perception; Entry points to the buildings; Casualties (possibility to autonomously evacuate)		Presence of more than 1 individual in the space; individuals' features (i.e. age, gender) and group effects (e.g. group ties between family members, social shared identity in widest groups)
Safe areas definition: people tend to gather in Open Spaces in the BE which are perceived as "safe" because of geometrical (wider than the other surrounding OSs, e.g. large crossroads, squares), low damage visibility and safety distance from "high buildings", significant capacity for the overall OS (possibility to host people without significant crowding conditions)		Damage scenario (in B and in OS); Human exposure (BE function and activities-occupancy class)	Risk Perception; Network of Paths and Open Spaces; Entry points to the buildings; Population density; Casualties (possibility to autonomously evacuate)	Geometry of the BE layout	Presence of more than 1 individual in the space; individuals' features (i.e. age, gender) and group effects (e.g. group ties between family members, social shared identity in widest groups)

Table 4. General overview of main emergency-related quantities concerning the evacuation process at the microscopic scale, according to literature works in relation to the emergency stages.

Data [unit(s) of measure] - symbol	D: Definition and calculation details (references) C: caveats O: previous outcomes	Characterization conditions, in order of significance of the data	Comparisons to other emergency conditions	Data usability for modeling purposes	Main statistical values (related references)
Instantaneous speed [m/s] - v_i	**D:** referred to a single evacuee in a scene, both moving in free-flow conditions or in specific crowd conditions(Bernardini et al. 2016b; Zhou et al. 2018a) **C:** Paying attention on possible ground shaking affecting the movement and the body stability, which can sensibly alter the final outcomes and cannot be easily measured **O:** higher speeds can be generally seen in outdoors, in lower density conditions and (marginally, due to the sample dimension) for higher earthquake intensity	Indoor/outdoor; number of individuals/crowd density; BE function; earthquake intensity	Average speeds are generally higher than those of fire or general-purpose emergency evacuations.	Individual's speed in free-flow conditions (especially for microscopic motion modeling) (D'Orazio et al. 2014b; Li et al. 2015)	Mean±st.dev. [mode]: indoor, 2.21±0.66 [2.00] (Zhou et al. 2018a) Mean±st.dev.[median]: outdoor, 2.95±0.83 [2.97], indoor with high number of individuals, 2.56±1.14 [2.30], indoor with low number of individuals, 2.54±0.85 [2.58] (Bernardini et al. 2016b)
Instantaneous acceleration [m/s^2] - a_i	**D:** referred to a single evacuee in a scene, both moving in free-flow conditions or in specific crowd conditions (Bernardini et al. 2016b) **C:** compare to instantaneous speed **O:** deceleration (mean trends) for motion in open spaces in the BE suggest the decrease of excitement conditions while moving towards "safe areas"; lower a_i values for lower density	Indoor/outdoor; number of individuals	General trends to zero values thus confirming minimum-effort principle in motion (Zipf 1950)	Limits to individual's speed variations (i.e. in free-flow conditions) between two consecutive simulation moment (Helbing and Johansson 2010; D'Orazio et al. 2014b)	Mean values range: -0.37 (outdoor) to 0.31 (indoor with high number of individuals)
Delay time [s] - t_d	**D:** "time elapsed from the occurrence of the earthquake to the first protection behavior and includes both the recognition time and the response time" (Zhou et al. 2018a) **C:** difficulties in detecting shake starting (needs for videos also in pre-emergency conditions); it can be related to any first emergency activity performed (see Table 1 and Table 2) **O:** higher the earthquake intensity, lower the delay time (up to 0), confirming reactions from	Indoor conditions and earthquake intensity (assumed lower intensity limitations and IV degree in EMS98 (Grünthal 1998)); BE function	Generally lower than fire evacuation average values, but affected by the direct perception of the event rather than on alarm systems (Lovreglio et al. 2019)	Delay for the emergency activities starting, especially for microscopic motion modeling (Li et al. 2015; Xiao et al. 2016)	Mean values range: 22s (IV degree or lower) to 0s (IX degree)

	qualitative studies on earthquake evacuation participation (Grünthal 1998)				
pedestrians' trajectories towards distance with other individuals/obstacles [m] and path choice/evacuation target selection [-]	**D:** continuous tracking of individuals' position during the time in relation to specific elements as well as to the place where the evacuation ends (distances: other people, unmovable obstacles; evacuation target: doors in indoor or "safe areas" in outdoors; "safe areas" in indoors where to stop) (Bernardini et al. 2016b; Zhou et al. 2018a; Tsurushima 2020) **C:** general caveats exist **O:** outdoor scenarios imply higher distance values (also in relation to other individuals); in indoor, the evacuation target and the path choice seem to essentially depend on group effects and distance between the initial individuals' position and the target position	indoor/outdoor (i.e. distances with obstacles in outdoors)	Interaction distances of previous approaches are confirmed (about 3m) (Lakoba et al. 2005)	Decision models for preferred distances between individuals/with obstacles; decision model for evacuation target and path selection	Mean±st.dev.[median]: distance with obstacle in outdoor, 2.37±0.66 [2.51] (Bernardini et al. 2016b)

Table 5. General overview of main emergency-related quantities concerning the evacuation process at the macroscopic scale, according to literature works in relation to the emergency stages.

Data [unit(s) of measure] - symbol	D: Definition and calculation details (references) C: caveats O: previous outcomes	Characterization conditions, in order of significance of the data	Comparisons to other emergency conditions	Data usability for modeling purposes	Main statistical values (related references)
density *d*-speed *v* correlations [pp/m^2, m/s]	**D:** different tracing methods (Zhang et al. 2011; Zhang 2012; Burghardt et al. 2013)**;** correlations according to the Kladek's formula or simplified bilinear/power-based approaches (Nelson and Mowrer 2002; Lämmel et al. 2008) **C:** cross-section identification (especially in outdoor scenarios and in case of open spaces without lateral boundaries) and possibility to apply the specific methods (i.e. microscopic-based ones) in dense crowd conditions **O:** higher densities imply lower speed, as expected for evacuation conditions	indoor scenarios only; BE function in relation to their overall ranges (Zhou et al. 2018a)	Given a certain density, speeds in earthquake evacuation are higher than fire and general-purposes databases		Proposed correlation: $v=2.58m/s\cdot\{1+e^{[-0.8\cdot(1/d-1/5.30pp/m^2)]}\}+0.71m/s$ (Bernardini et al. 2016b)
density *d*-flow *f* correlations [pp/m^2, pp/s]	**D:** the same as for *d-v*; possibility to trace power-based correlations (Zhang 2012) **C:** as for density-speed relation; possibility to work on normalized flow conditions to compare different scenarios; **O:** maximum flows can be obtained at about $2pp/m^2$, but limit no further decrease is noticed	indoor scenarios only	Given a certain density, flows in earthquake evacuation are higher than fire and general-purposes databases		No current proposed correlation, only experimental pairs (Bernardini et al. 2016b)

3. Phases and methods

This work is divided in the following phases:

1. defining a database of real-world videotapes to investigate human behaviors in real earthquakes all over the World (Zhou et al. 2018a; Bernardini et al. 2019) by integrating results to those of previous works carried out by the research group (Bernardini et al. 2019);
2. detecting evacuation behaviours on the videotapes, by organizing them in a "behavioural database" according to previous works approaches (Zhou et al. 2018a; Bernardini et al. 2019) and by focusing on behaviors discussed in Section 2.2 (i.e. Table 1, Table 2, Table 3),;
3. assessing evacuation motion quantities from both an individual and a collective perspective (Johansson et al. 2008; Bernardini et al. 2016b; Lu et al. 2019; Wang and Shen 2019), by focusing on main parameters as discussed in Table 4.

3.1. Characterization of the videotapes database

Videotapes of real earthquake evacuations from all over the World[3] are collected to investigate individuals' response during and after the earthquake shaking, with the aim to integrate previous structured databases (Bernardini et al. 2019) and provide deeper insights on evacuation behaviors while increasing their statistical significance.

Most of those videotapes were available from the Internet and were downloaded to carry out the behavioral analysis as described in Section 3.2. According to previous works, each videotape has to clearly be connected to a specific earthquake in terms of date, location and magnitude (assessed according to USGS database available at http://earthquake.usgs.gov; last access: 06/06/2020), being be confirmed by mass-media channel, civil defense or government agencies. Each videotape has been divided in one or more "scenes" (Bernardini et al. 2019). "Each scene has similar evacuation conditions and involves only an evacuation" (Bernardini et al. 2016b), which can also show the earthquake shaking moment. Criteria for scenes selection (Bernardini et al. 2016b, 2019; Zhou et al. 2018a) are the following ones:

1. possibility to effectively detect evacuees' actions;
2. absence of framing problems, e.g.: deleted frames; inadequate illuminance with the possibility to not continuously track human response; excessive camera shaking/movements;
3. earthquake magnitude ML (Richter Scale) equal or higher than 4 to look for sensible events.

89 "scenes" have been selected and added to the original database, so as to create an overall database of 154 "scenes", which is the current widest one. Since this work would like to integrate a structured existing database (Bernardini et al. 2019), the statistic description of the scenes is provided here in a combined manner. Scenes are firstly organized depending on the Country in which the event occurred and the earthquake magnitude, as reported by Figure 1. Then, the statistic description of the scenes is provided in Figure 2 depending on (Bernardini et al. 2019):

- being *indoor* (buildings) or *outdoor* (linear/areal open spaces in the BE and building annexes/courtyards) scenarios;
- *presence of more than 1 individual in the scenario*, to focus on interactions among the individuals;

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[3] Video from Countries different from those studies in (Bernardini et al. 2019) are preferred to extended the world-wide analysis of the adopted behaviors.

- *building intended use*, by considering offices, schools, other public spaces (including shopping malls, restaurants, transport stations, theatres and linear/areal open spaces in the BE for outdoor scenarios), and dwellings
- for *outdoor* scenarios only: *presence of debris*; *presence of low obstacles*;
- for public spaces (both indoor and outdoor): *presence of rescuers/qualified safety staff members* which can provoke effects on the evacuees' organization.

All the videotapes are available at goo.gl/m1Wh43 and each database element is characterized by an identification code including the Country code and a number (which is reported in the following discussion, e.g. N2 means videotapes 2 from Nepal).

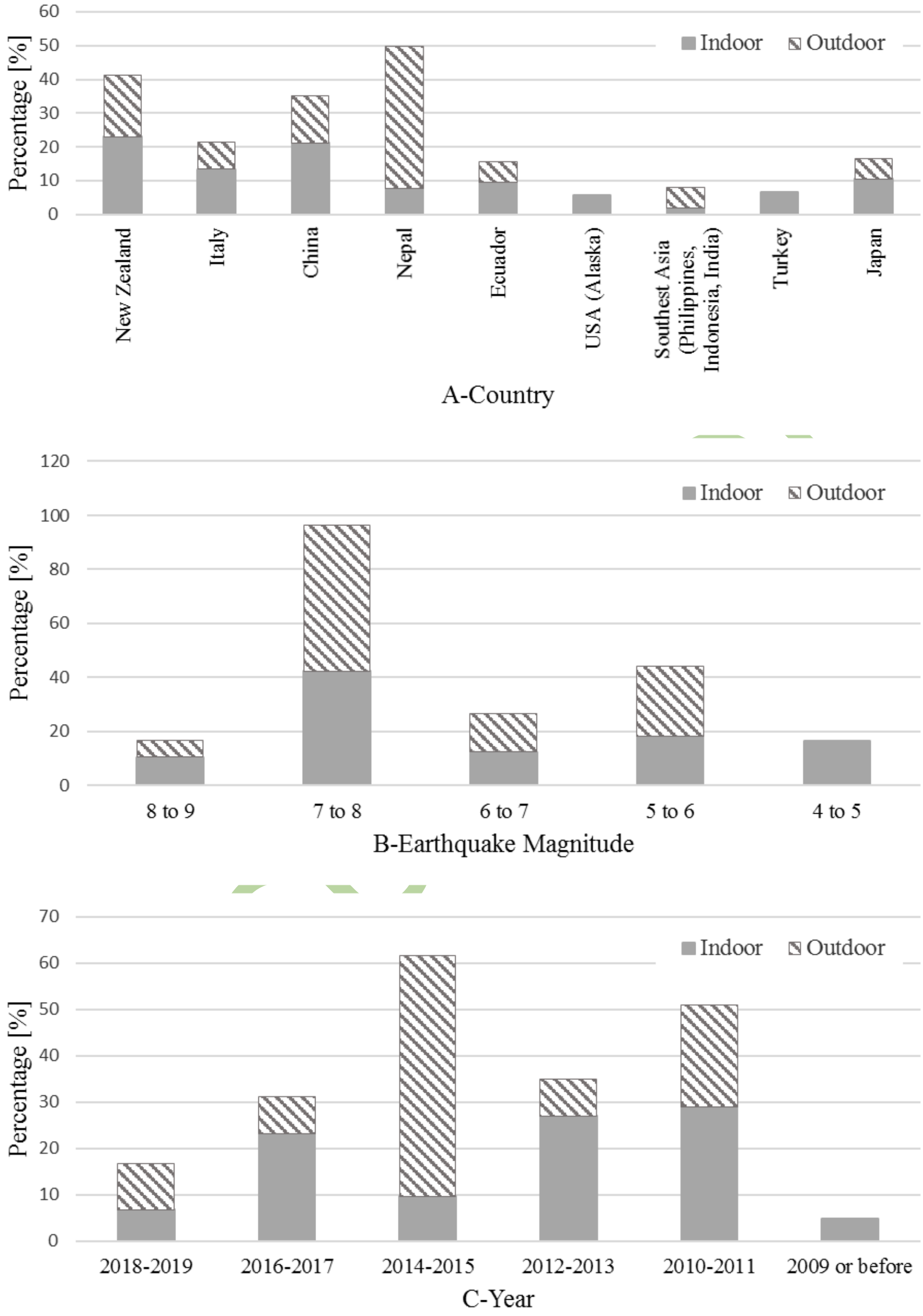

Figure 1. Characterization of the combined “scene” database (original scenes from (Bernardini et al. 2019) and additional scenes retrieved in these activities), by distinguishing indoor and outdoor “scenes”, in reference to: a) Country; b) earthquake magnitude of the referring event; c) year of the event.

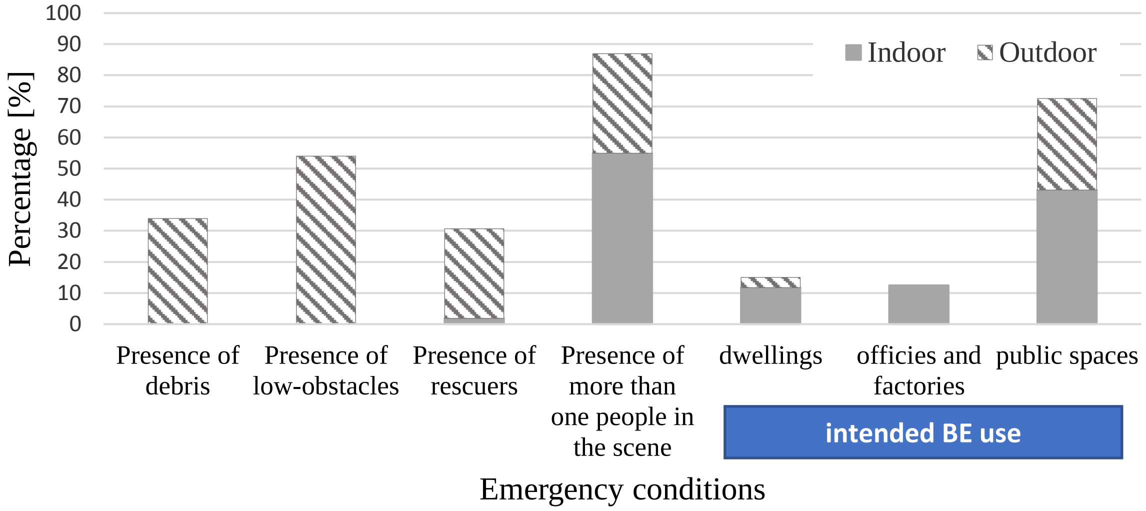

Figure 2. Characterization of the combined "scene" database (original scenes from (Bernardini et al. 2019) and additional scenes retrieved in these activities) in reference to literature-based factors describing emergency conditions, by distinguishing percentage data on indoor and outdoor scenarios.

3.2. Qualitative analysis: methods

For each individual in each "scene", behavioral analyses concern *the observed behaviors* according to the definition given in Table 1, Table 2 and Table 3, so as to increase the statistic significance of the considered database. As suggested by previous works (Lambie et al. 2016; Bernardini et al. 2016b), since additional responses in emergency could exist, other behaviours were pointed out according by evidencing if they reach the 30% threshold of significance. Behaviors are classified between "common to other kinds of evacuation" (if present in other emergency conditions) or "specific of this case" (if currently pointed out in reference to earthquake emergency conditions) (Bernardini et al. 2016b). Each behavior is organized in the related evacuation phase in which it appears and by pointing out the related "reference elements" ("the elements who people refer to activate the behavior") (Lambie et al. 2016; Bernardini et al. 2016b, 2019; Rojo et al. 2017) as well as in the view of Table 1, Table 2 and Table 3.

Once the data from the new "scenes" have been collected, they are also merged to previous works outcomes so as to outline the overall database features. Differences among statistical presence of the data are also discussed.

3.3. Quantitative analysis: methods and scenes

3.3.1. Criteria for scenes selection and analysis

Quantitative analysis on individuals' motion mainly concerns the individuals' speed v_i v_i [m/s] and the related conditions of pedestrians flow and density in view of its significance in respect to current lacks in literature review, differences between different kind of evacuation, applications of modeling purposes (including the development of fundamental diagrams; see methods in Section 3.3.1.2) and relation with evacuation behaviors, as underlined by Section 2.2 and Table 4. Results are offered at Section 4.2.

According to previous works on individuals' tracing in earthquake evacuation (Yang et al. 2011; Bernardini et al. 2016b; Gu et al. 2016), the manual method is chosen because of the videotapes characteristics also evidenced by Section 2.1, i.e.: not uniform backgrounds of the scene; perspective views to be calibrated; frames resolution. Fixed cameras videotapes (both concerning indoor and outdoor scenarios) are evaluated to apply the method and they are investigated according to the surrounding conditions (i.e. being indoor or outdoor scenes; pedestrians' number, i.e. pedestrians' density so as to move towards the application to data for fundamental diagram in evacuation dynamics; BE intended use in case of indoor scenarios). To this end, analysis are performed by using the open source image analysis software "Tracker" (Brown and Christian 2011)[4] according to previous works application and their methodologies (Bernardini et al. 2016b). In particular, videotapes are firstly evaluated in terms of possibility of performing (Bernardini et al. 2016b):

1. a perspective correction (by the Tracker filter) on the original videotape to correct the distorted floor shape in the input frames to a straight-on plane shape (towards planar tracking of pedestrians' motion);
2. the calibration of the spaces dimensions by using real-world dimension through plan data (e.g. for outdoor spaces, basing on Google Maps and Street View) and/or objects with known dimensions (e.g.: chairs, doors, cars), with a general approximation of 10cm;
3. the identifications of boundaries for the individuals' motion along the motion path. In particular, for outdoor scenarios and when physical limits to the movement (e.g. walls, continuous street furnitures) do not exist, the scenes are considered if quais-monodimensional evacuees' motion conditions appear (people move straight forward along a main x or y direction in the tracking plane, by avoding to chaotically vary their position in the orthogonal direction and so tracing ideal lateral limits for the evacuees' flow);
4. in case of high cameras shaking due to the earthquake which does not allow the correct detection of the scene movements, of "de-shaking" processing filter by Deshaker v.3.0 plugin[5].

An Overall Analysis Area (OAA) in the motion path is identified by defining its: a) width depending on the lateral limits definition according to point 3 in the previous list; b) length as a relevant space for the motion with similar width conditions and where the individuals can be clearly visible (i.e. in indoor scenarios, a corridor or a part of it; in outdoor scenarios, the area near to the building exit up to the first area in which people stop the evacuation, such as the middle of the street, so as to trace significant behaviors as reported in Table 2). Then, a point mass is associated to each pedestrian in the considered scene by pointing at hip level to reduce errors in body parts movement (e.g. head movements) in respect to the center of the mass (Bernardini et al. 2016b), during the whole pedestrian's evacuation process in the OAA. Each evacuee is also identified at least in terms of gender (male, M of female F), in terms of general age characterization (child, adult, elderly, disabled) and in terms of hand-assisted motion.

A time step 0.067s (1 or 2 frames according to the analyzed videotapes framing features in this study) is chosen so as to trace the position of the evacuees as continuously as possible, also in view of the use of data for the definition of fundamental diagrams for pedestrians' dynamics (Chen et al. 2012; Burghardt et al. 2013)(Zhang et al., 2011; Zhang, 2012). To investigate continuous pedestrians' flows, the maximum fixed period of time Δt [s] for the analysis is selected equal to about 2.68s (Johansson et al. 2008; Burghardt et al. 2013; Bernardini et al. 2016b). Given two consecutive evacuees i_1 and i_2, evacuation flows are also identified and differently grouped if the time difference between them (i_1 exiting and i_2 entering the OAA) is equal or over this value. The evacuee's membership to an evacuation group is also assessed through *group ties* behaviors and reciprocal support in motion (compare to Table 2 behaviors).

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[4] version 5.1.5, https://physlets.org/tracker/ (last access: 10/06/2020)

[5] version 3.1, https://www.guthspot.se/video/deshaker.htm (last access: 10/06/2020)

Once the individuals' positions have been determined, input data about speed, density, flows and final position where the evacuees stop are assessed from microscopic (see Section 3.3.1.1) and macroscopic (see Section 3.3.1.2) standpoints.

3.3.1.1. Microscopic-related analysis

This work mainly focuses on the analysis of the individuals' evacuation speed v_i [m/s] by considering (quasi) free flowing conditions, that are related to a pedestrians' density in the OAA about ≤0.37 pp/m^2 (Fruin 1971). In such conditions, the pedestrians can freely choose their motion speed without significant conflict for the trajectory selection.

Firstly, for each given scene, v_i outliers are identified according to the Interquartile Range IQR method (fence: 1.5·IQR, (Rousseeuw and Hubert 2011) and boxplot representations are offered. Basic statistics are provided for the whole sample as well as for males and females separated samples. Then, Anderson-Darling tests (Anderson and Darling 1952) are performed to assess the type of distribution of this sample data, by focusing on literature-based ones (Bernardini et al. 2016b), i.e. Normal, Lognormal, and Weibull distributions. Histograms, related distributions and cumulative frequency diagrams are also provided.

Then, the study investigates the v_i trends due to: 1) general elements, i.e. all the sample, gender identification; 2) membership to evacuation groups/flows; 3) characterization for BE conditions, i.e. indoor/outdoor, BE intended use for indoor scenarios; 4) characterization in relation to the distance with buildings and to the overall timing (in respect to the moment of the earthquake), in view of fear of buildings, immediate evacuation and "safe areas" definition behaviors.

The results are also compared to previous works outcomes concerning earthquake evacuation (Bernardini et al. 2016b; Gu et al. 2016; Zhou et al. 2018a) and other kinds of evacuation (Shi et al. 2009; Cuesta and Gwynne 2016) and recent general purpose databases (Bosina and Weidmann 2017), by comparing data for similar boundary conditions.

3.3.1.2. Macroscopic-related analysis: fundamental diagrams

Fundamental diagrams of pedestrians' are carried out according to so called "Method A" described in previous researches (Chen et al. 2012; Burghardt et al. 2013) and adopted in previous analysis on earthquake evacuation (Bernardini et al. 2016b), by taking advantages of the individuals' position tracing activities described in Section 3.3.1. A cross-section (having a certain width b [m] which is constant over the time) is placed in the OAA and analyzed over Δt to evaluate the flow over time $<J>_{\Delta t}$ [pp/s] (depending on the number of individuals crossing the cross-section during Δt), the mean speed $<v>_{\Delta t}$ [m/s] (which depends on the average speed of the pedestrians within a small time interval Δt') and the pedestrian density $<d>_{\Delta t}$ [pp/m^2] (calculated as the ratio of $<J>_{\Delta t}$ and the multiplication between $<v>_{\Delta t}$ and b). In view of the above (compare to Section 3.3.1), Δt=2.68s and Δt'=0.670s (corresponding to 10 frames so as to reduce the fluctuations of speeds due to center of mass positioning (Burghardt et al. 2013)), while b varies from 0.6 to 2.2m in the selected videotapes (compare to Section 3.3.2).

Then, the $<d>_{\Delta t}$ -$<v>_{\Delta t}$ pairs are plotted by merging data from this work and from main previous works outcomes (Bernardini et al. 2016b). Differences among the input conditions in terms of earthquake magnitude/intensity (according to Modified Mercalli Intensity MII scale) and type of building are stressed. Finally, the d-v relationship is proposed according to the revisited Kladek formula (Bruno and Venuti 2008), as shown by Equation (1), for the whole sample:

$$v = \left(v_{F,hf} - v_{min}\right) \cdot \left\{1 - exp\left[-k \cdot \left(\frac{1}{d} - \frac{1}{d_{max}}\right)\right]\right\} + v_{min} \quad if\ 0 \leq d \leq d_{max} \qquad (1)$$

where: $v_{F,hF}$ [m/s] is the maximum speed at the minimum experimental d; v_{min} [m/s] is the minimum experimental speed at maximum density d_{max}; k is the form factor to shape the general trend depending on the sample. v_{min} is added to the first part of Equation (1) to provided a vertical translation of the original Kladek formula due to the experimental trends of no-note maximum density which implies null speeds, as also provided by previous base works (Bernardini et al. 2016b). This formula is selected because of its continuity and compact direct form for practical use. Confidence bounds for the regression are provided at 95%, so as to trace boundary conditions for the d-v relation estimation in which real world cases ideally fall. The goodness of fit is investigated through R^2.

3.3.2. Analysed scenes overview

The analysis method is applied to different real evacuation scenes concerning indoor and outdoor evacuation scenarios.

Concerning indoor evacuation, the videotapes in Table 6 are analyzed, for a total of 153 evacuees. In particular, videotapes:

- N14, NZ34, C28, C29, C32 are mainly used in the fundamental diagram, as discussed in Section 3.3.1.2;
- C28 and 32 are used to respectively define primary and secondary school students' speeds (in running/walking in line conditions), in view of the comparison with previous experimental databases (Cuesta and Gwynne 2016);
- I26 and T21 are used only to detect free-flow speed of individuals, by focusing on disabled (assisted ambulant and assisted wheelchair) to be compared to previous general purposes related databases (Shi et al. 2009).

*Table 6. Indoor scenarios videotapes overview. * refers to the city where the videotape is recorded according to the data available at the source ("n.a." means that the specific data is unknow). ^ refers to videotapes from the database of* (Bernardini et al. 2019) *which were not assessed in the past from a quantitative point of view.*

Code	**intended BE use**	**Country, city***	**Earthquake**	**Magnitude / MMI***	**Sample**	**Scenes – *b* (range) [m]**
N14	public building: shopping mall	Nepal, Kathmandu	2015/04/25 06:11:25 UTC, Gorkha	7.8 / 8	8	1 – 1.4
NZ34^	dwelling, i.e. supposed to be students' accommodation	New Zealand, Wellington	2016/11/13 11:02 UTC, Amberley	7.8 / 6	10	1 – 0.9
C28	public building: schools	China, Songyuan	2013/10/31 03:04 UTC, Linqiong	5.1 / 4-5	20	1 – 2.2
C29	public building: schools	China, Ya'an	2013/04/20 0:02:47 UTC, Western Sichuan	6.6 / 5	17	1 – 0.8
C32	public building: schools	China, Tangshan (n.a.)	2012/05/28 02:22:56 UTC, Hebei	4.7 / n.a.	91	6 – 0.6 to 2.2
I26	public buildings: hospital	India, Patna	2015/05/12/05 07:05:19 UTC, Kodari	7.3 / 4.5	1	1 – only individual speed (free-flowing)
T21	public buildings: hospital	Turkey, Van	2011-10-23 10:41:23 UTC, Eastern Turkey	7.1 / 7-8	6	5 – only individual

	speed (free-flowing)

Concerning outdoor scenarios, the videotape coded with N2 (i.e. frames ranging from about 2:55 to 3.40) in the videotapes database is considered for quantitative analysis on instantaneous evacuation speeds analysis because: 1) it represents a significant conditions recurring in the outdoor spaces, that concerns the *run out of indoor spaces* behavior and the motion towards the nearest safe areas (i.e. the middle of the facing street); 2) the dimension of the elements in outdoor scenario is ensured by the possibility to correctly apply perspective-correction filters with real-world scaling by Google maps/Streetview data (the location of the event is given by the videotapes and corresponds to 27°42'35.4"N 85°19'01.8"E, Kathmandu-Durbar Marg at Mehandra Statue). It is the only videotapes in the database which reliably allows to respect both the two points.

A unique scene is considered in N2-scene 3, and a view of it is shown by Figure 3. In the videotapes, 33 individuals are traced to derive their speeds in the red area, which corresponds to the exit of a building up to the central fence in the facing road (where people stop at the end of the immediate evacuation process). The whole process last about 40s. Output data are organized in view of Section 3.3.1.1 outlines.

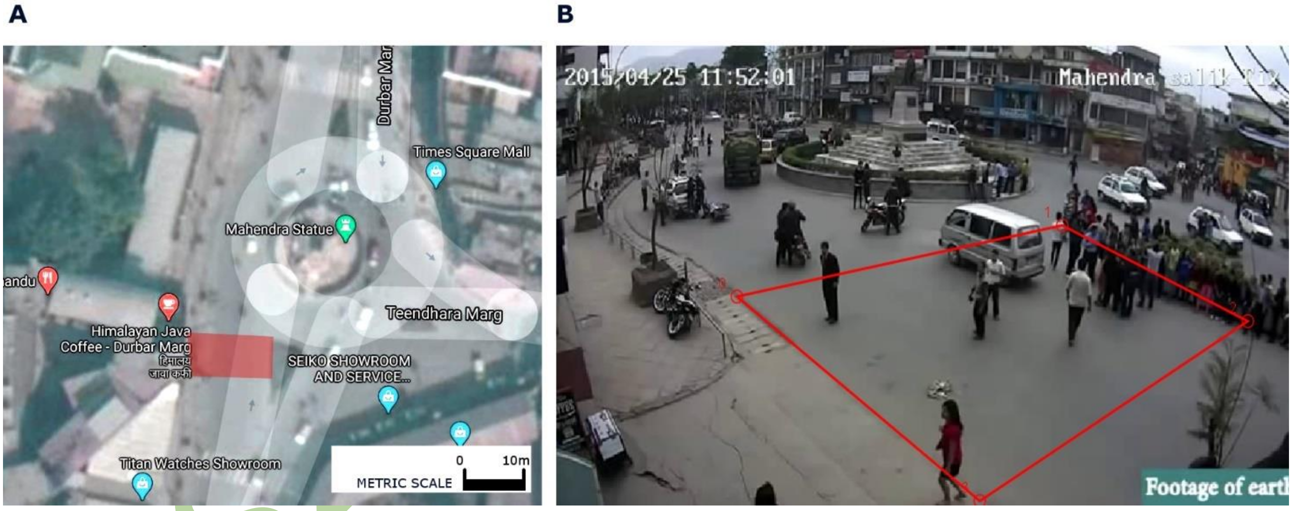

Figure 3. N2-scene 3 videotape scenarios (Kathmandu-Durbar Marg at Mehandra Statue) analysed for quantitative motion issues in outdoor spaces by evidencing: A-its aerial view (source: Google Maps, last access: 10/06/2020), including the red area tracing the monitoring area; B-a view of the videotape in Tracker, with the perspective filter.

4. Results and discussion

4.1. Qualitative analysis: results

Table 7, Table 8 and Table 9 provides the overview of the evacuation behaviours according to the state-of-art general issues, margining the results from the analysis on this work scenes to the ones of previous behavioural databases (Bernardini et al. 2019). In general terms, the analysis on the "new scenes" confirms the general trends evidenced by the original works.

One of the most recurring behaviors is the "*fear of building*", which affect the evacuation from the earthquake shaking up to the end of the evacuation. In particular, people can *run out of the building* in which they are placed (see Figure 4) and then generally move far from the buildings so as to reach an adequate distance from the buildings, e.g. in the middle of the street (see Figure 17) or at the opposite street side (by also ignoring lower walls; see Figure 6).

Only in one case (C2-scene 2), it is noticed that some frightened people try to "invacuate" rather than continue the evacuation process, as shown by Figure 7 (man evidenced with the red arrow): in this case, it can be supposed that the *fear of building* moves people to go indoor to avoid the fall of debris in such a narrow street.

At the end of the exiting process, people prefer to remain near the building (thus leading towards possible *Evacuation end for influence of not immediate danger feelings or helplessness conditions*) in which they are placed, by additionally gathering in groups and allowing physical contact with low obstacles, as shown by Figure 8 and Figure 9. Such *social attachment* behaviors are also noticed in the path choice. In indoor scenarios, family *ties* seem to be a relevant driver for the path choice, by limiting in some cases the herding behaviors, as shown by Figure 10. Moreover, both in indoor and outdoor conditions, during the motion process, people can stop to move in case of high ground shaking (see Figure 11).

Finally, some differences in trends of previous works and current database integration exist. It is noticed that behaviors with a frequency over the 30% threshold in the previous database do not reach the same statistical significance. In particular, *attachment to things* behaviors significantly decrease, as well as the *curiosity effect*. This last behavior could be affected by the level of diffusion of smartphones and cameras over the investigated Countries as well as on the year in which the videotapes are caught. In particular, the Nepalese videos seem to decrease this last percentage, although some cases are still shown in this Country, as shown by Figure 12.

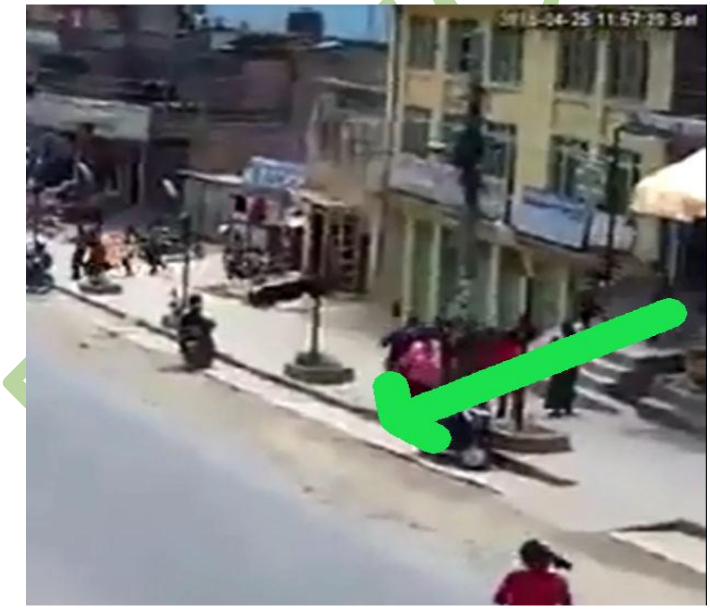

Figure 4. People running out of the building during the earthquake, as shown by the arrow direction (N5).

Figure 5. *“Curiosity” effect: an individual using his mobile phone to catch shoots from the site, as shown by the red area (N2-scene 1).*

Figure 6. “Fear of buildings” and movement towards immediate safe areas in respect to the initial position (red area). In addition, an individual using his mobile phone during the first emergency phases, in the red circle (N10).

Figure 7. “Invacuation” process (moving indoor from outdoor) for the man with the red arrow versus evacuation process (go ahead along the narrow street) for the woman with the green (C2-scene 2).

Figure 8. People grouping (in the red circle) and supporting people in danger or wounded (in the dashed green rectangle) near to the initial indoor position (N7).

Figure 9. People grouping near low obstacles and hanging on them also in absence of ground shaking (in the red circle) (N7).

Figure 10. Family ties conditioning the evacuation direction choice (red arrow) and limiting herding behaviors (green arrow) (E18-scene 3).

Figure 11. People in the red circles stop/interrupt the evacuation because of ground shaking (N8).

Figure 12. “Curiosity” effect: an individual using his mobile phone to catch shoots from the site (N9).

*Table 7. Emergency behaviors in the pre-movement stage by providing frequency for this work, for the reference one (Bernardini et al. 2019) and for the whole merged database. “Common behaviors” are identified by *. ^ refers to behaviors under the 30% threshold.*

***Behavior*: definition**	**Total number of scenes (total number of referring scenes) – related frequency [%]**		
	this work	(Bernardini et al. 2019)	whole database
*Information seeking**	37 (89) - 42	22 (65) – 34	59 (154) - 38
Evacuation procedure for sensible earthquakes	55 (55) - 100	43 (49) – 88	98 (104) – 94
Self-protection procedures	31 (89) - 35	22 (65) – 34	53 (154) – 34
*Attachment to things**	7 (55) – 13^	15 (49) – 31	22 (104) – 21^
*“Pro-Social” Behaviors**: at least one of the following behaviors:	57 (78) - 73	30 (56) – 54	87 (134) - 65
1) *information exchange*	49 (78) - 63	18 (56) – 32	67 (134) - 50
2) *Social attachment*	37 (89) - 42	21 (56) – 38	83 (134) - 62

*Table 8. Emergency behaviors in the evacuation stage by providing frequency for this work, for the reference one (Bernardini et al. 2019) and for the whole merged database. “Common behaviors” are identified by *. ^ refers to behaviors under the 30% threshold.*

***Behavior*: definition**	**Total number of scenes (total number of referring scenes) – related frequency [%]**		
	this work	(Bernardini et al. 2019)	whole database
Immediate evacuation starting behaviors: at least one of the following behaviors	51 (89) - 57	42 (65) – 65	93 (154) - 60
1) *run out of indoor spaces*	48 (89) - 54	39 (65) – 60	87 (154) - 56
2) *move in open spaces in the BE*	12 (34) - 35	11 (16) – 69	23 (50) - 46
Stop/interrupt the evacuation because of ground shaking	40 (89) - 45	20 (65) – 31	60 (154) - 39
*“Pro-Social” Behaviors**: at least one of the following behaviors:	74 (78) - 95	31 (56) – 55	105 (134) - 78
1) *herding behavior*	60 (78) - 77	21 (56) – 38	81 (134) - 60
2) *group ties**	41 (78) - 53	19 (56) – 34	60 (134) - 45
3) *information exchange*	49 (78) - 63	18 (56) – 32	67 (134) - 50
*Information seeking**	37 (89) - 42	22 (65) – 34	59 (154) - 38
*Use of personal devices during the evacuation motion** including:	15 (89) – 17^	31 (65) – 48	46 (154) - 30
*“Curiosity” effect**	9 (89) – 10^	26 (65) – 40	35 (154) - 23^
*Attraction towards safe areas**	25 (34) - 74	12 (16) – 75	37 (50) - 74
Evacuation path selection	12 (37) - 32	6 (13) – 46	18 (50) - 36

Debris avoidance	10 (9) - 111	6 (8) – 75	16 (17) - 94
Fear of buildings	21 (34) - 62	14 (16) – 88	35 (50) - 70
*Increased guidance effect because of rescuers and possible safety plan/signs influence**	24 (30) - 80	4 (5) – 80	28 (35) –-80
Helplessness conditions	51 (89) - 57	40 (65) – 62	91 (154) - 59
Attraction towards low obstacles	10 (15) - 67	4 (12) – 33	14 (27) - 52

*Table 9. Emergency behaviors in safe area reaching and immediate post-evacuation stage by providing frequency for this work, for the reference one (Bernardini et al. 2019) and for the whole merged database. "Common behaviors" are identified by *. ^ refers to behaviors under the 30% threshold.*

***Behavior*: definition**	**Total number of scenes (total number of referring scenes) – related frequency [%]**		
	this work	(Bernardini et al. 2019)	whole database
Evacuation end for influence of not immediate danger feelings or helplessness conditions	19 (37) – 51	6 (13) – 46	25 (50) - 50
Safe areas definition	23 (34) - 68	11 (16) – 69	34 (50) - 68

4.2. Quantitative analysis: results

4.2.1. Microscopic-related results

Concerning indoor scenarios, the attention is focused on the comparison of evacuation speeds for the tested individuals with those of previous works, according to Table 10. Results generally shows how earthquake-related data are higher (about +20% or more) than those of other kinds of evacuation (Shi et al. 2009; Cuesta and Gwynne 2016). This result confirms literature outcomes which general underline an higher reaction level in terms of excitement, and so of evacuation speed, for earthquake conditions.

Table 10. Comparison of individuals' evacuation speeds between this works and the previous reference ones, depending on the specific boundary conditions.

Boundary conditions	This work: mean±st.dev [range] [m/s]	Literature data: mean [range] [m/s]	Literature source	Percentage difference on the mean
Assisted disabled (all)	1.25±0.69 [0.56; 1.94]	1.00 [0.10; 1.77]	(Shi et al. 2009)	+25%
Assisted deambulant	0.95±0.65	0.78 [0.21; 1.40]	(Shi et al. 2009)	+22%
Assisted wheelchair	1.76	1.30 [0.84; 1.96]	(Shi et al. 2009)	+35%
Primary school – running	2.90±0.44 [1.71; 3.51]	2.10 [1.40; 3.10]	(Cuesta and Gwynne 2016)	+38%
Secondary school – running	3.09±0.64 [2.10; 3.93]	2.20 [-]	(Cuesta and Gwynne 2016)	+41%
Secondary school – inline walking	1.20±0.54 [0.69; 2.00]	1.40 [0.90; 2.10]	(Cuesta and Gwynne 2016)	-14%

Concerning outdoor scenarios, Figure 13 traces the distribution boxplot (by including outliers, marked by "+") for the whole sample (Figure 13-A), for males/females separated samples (Figure 13-B) and for the two identified group samples (Figure 13-C). Statistics are shown by Table 11.

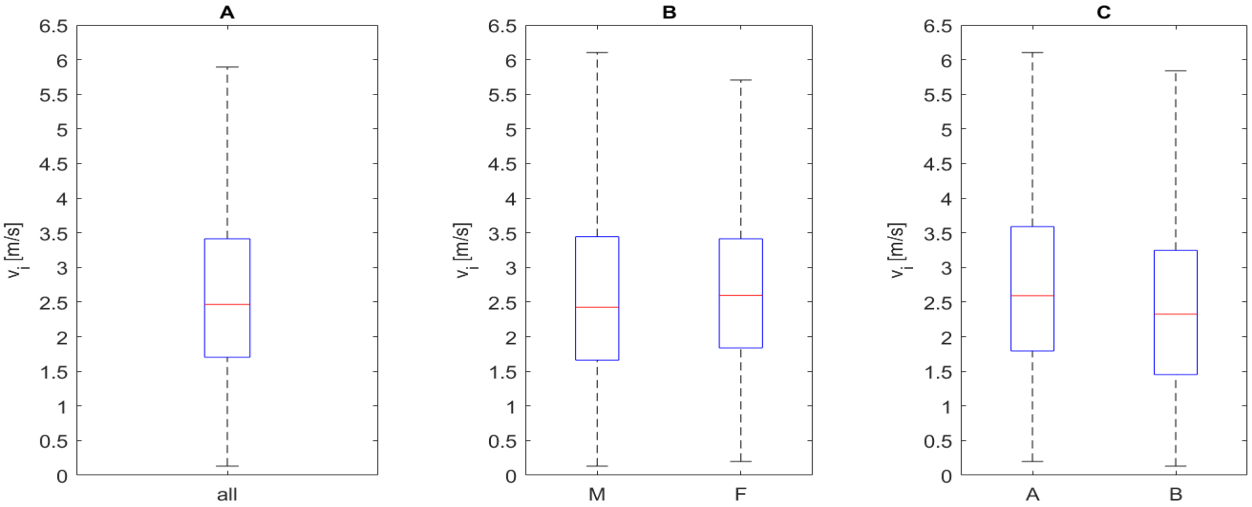

Figure 13. Boxplot analysis (no outliers) for: A-the whole sample; B-males/females; C- groups A and B as separated samples.

In general terms, speed values are close to the ones of previous databases on earthquake evacuation for outdoor scenarios (Bernardini et al. 2016b), with a difference of about -10% in respect to these works arithmetic mean considering outdoor conditions in (quasi) free-flow motion. The distribution of the speed seems to be based on a Weibull distribution (parameters estimate: A (scale)=2.97, std error: 0.03; B (shape)=2.24, std error: 0.04), which is not rejected by the Anderson-Darling test at 99%. The comparison of experimental data with distribution curves is offered by Figure 15 in terms of density and cumulative probability for all the considered distributions. Previous works suggested a normal distribution of speeds in outdoor conditions (Bernardini et al. 2016b), but the current distribution fitting analysis fails in accepting the normality of the experimental data, although a qualitative check of Figure 15 (i.e. Figure 15-A) seems to evidence slight differences between normal distribution density and the histogram. Differences are essentially due to the long right tail of the histogram, but the measurement could be affected by the sample dimension (in this study, 1585 samples; in the reference work, 1382) as well as by subtiles in evacuation behaviors (Shiwakoti et al. 2008). The similarities are also remarked by the cumulative probability chart shown in Figure 15-B).

No substantial differences among male and female sample can be seen, maybe because of the sample dimension. Moreover, in the considered scene, the evacuation is performed in two main groups: the last member of the group A ends its evacuation before that the first evacuees of the group B enter the scene, as also traced by Figure 15. The average speed of the second group (group B, as in Figure 13-C) seems to be -10% smaller than the one of the first one (group A). Figure 15 also shows how the evacuation speed decreases over the time.

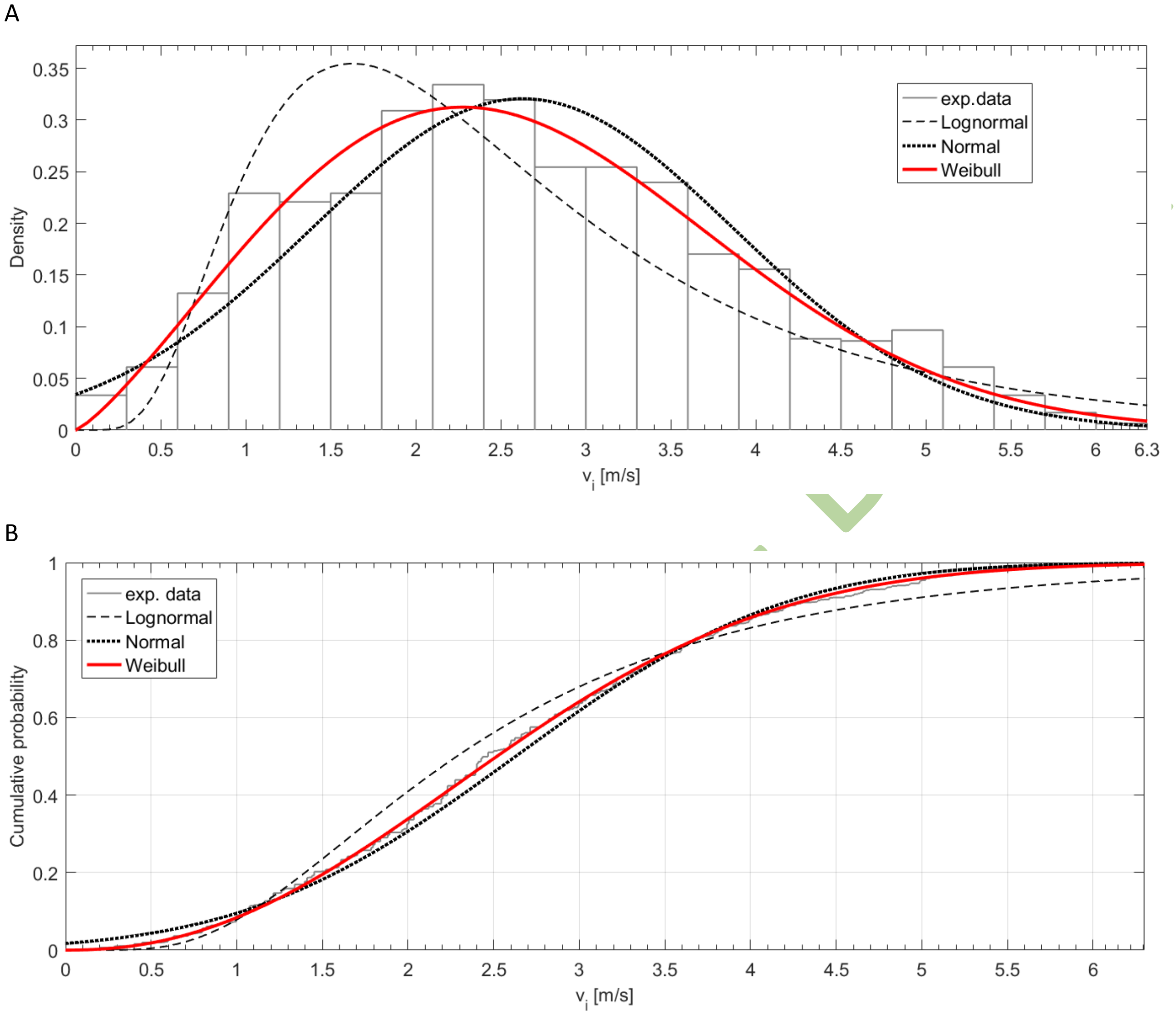

Figure 14. Evacuation speed distribution through lognormal, normal and Weibull distribution based on experimental data, in terms of: A- density (and related experimental data representation through histogram); B- cumulative probability.

Meanwhile, the trend of the speeds seems to decrease with the increase of the distance from the building, as shown in Figure 16-A. The orthogonal distance is defined along the axis orthogonal to the street. Two main phases can be seen: in the first meters on the scene, people seem to adjust their speeds for outdoor evacuation (i.e. while being on the sidewalk, that is in the distances ranges from -3 to 0m), then the evacuation speed decreases (values at 10m are affected by the speed values of the first arriving evacuees). Finally, Figure 16-B shows the distance at which the individual stop their evacuation, thus demonstrating that they prefer to move towards the middle of the road.

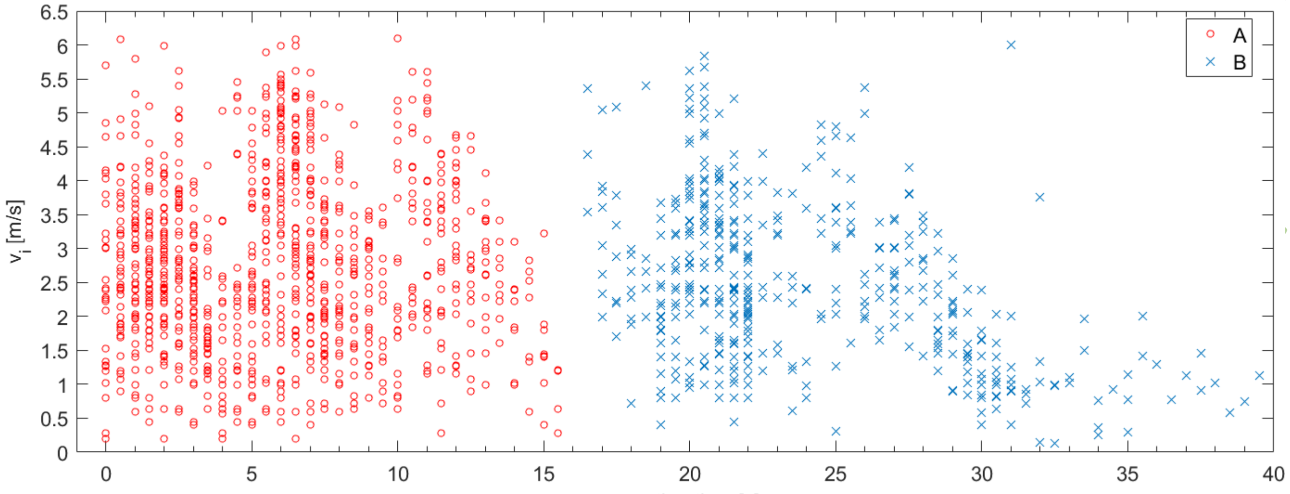

Figure 15. Trend of evacuation speed during the time, by evidencing the two groups A and B.

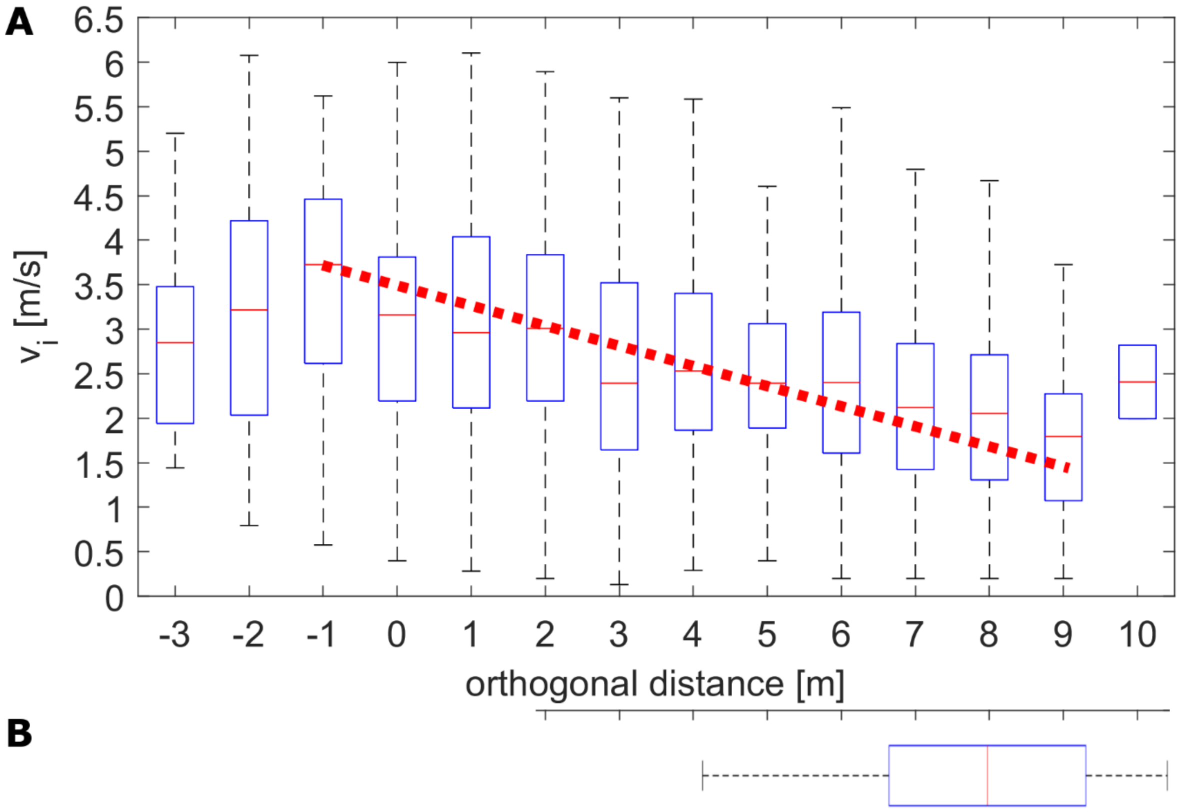

Figure 16. Effects of distance from the building: A- trend of evacuation speed in respect to the orthogonal distance, that is orthogonal to the street axis (negative values are on the sidewalk; 0m corresponds to the end of the sidewalk, while 9m is near to the fence in the middle of the street). The general trend of speed is qualitatively traced by the dotted red line; B-boxplot of the distance where the evacuation stops.

Table 11. Summary of basic statistics for quantitative analysis on instantaneous evacuation speed v_i [m/s] for outdoor scenarios, depending on the classification criteria.

Statistics	**Whole sample**	**Males**	**Females**	**A**	**B**
Sample dimension	1585	1261	324	1112	473
vi data [m/s]					
Minimum (IQR-based)	0.13	0.13	0.20	0.20	0.13
Q1	1.70	1.66	1.84	1.80	1.45
Q2 (median)	2.47	2.43	2.60	2.59	2.33
Arithmetic mean	2.63	2.62	2.66	2.70	2.45
St. dev	1.24	1.26	1.18	1.26	1.19
Q3	3.41	3.44	3.41	3.59	3.25
Maximum (IQR-based)	6.10	6.1	5.84	6.10	6.00

4.2.2. Macroscopic-related results: d-v correlations

Equation 2 traces the Kladek formula for the whole sample as reported by Figure 17:

$$v = (3.29 - 0.71)\cdot\left\{1 - exp\left[-0.91\cdot\left(\frac{1}{d}-\frac{1}{5.30}\right)\right]\right\} + v_{min} \quad if\ 0 \leq d \leq 5.30pp/m^2 \qquad (2)$$

The 95% confidence bounds are assigned to *k* values of 0.84 (lower bound) and 0.97 (upper bound). Equation 2 has an R^2 of 0.92. Differences among the considered d-v pairs boundary conditions (i.e. MMI of the event, earthquake magnitude, BE intended use) are quite slight, as shown by Figure 18. In particular, data on lower earthquake magnitude (Figure 18-B) and for school-related scenarios (Figure 18-C) seems to be more scattered, but this can due to the differences in the *b* values in the scenes. *v* values for school-related scenes seem also to be higher than the other BE intended use being *d* equal: this result could be affected by the presence of emergency staffs (i.e. teachers) who support the students' evacuation, according to previous general outcomes on the rescuers' improvement of the evacuation conditions (Bernardini et al. 2019). Nevertheless, all the subsamples show the expected trend and confirm that earthquake-related speeds are higher than those of other kinds of emergency (and evacuation drills) because of the related emergency conditions (Bernardini et al. 2016b).

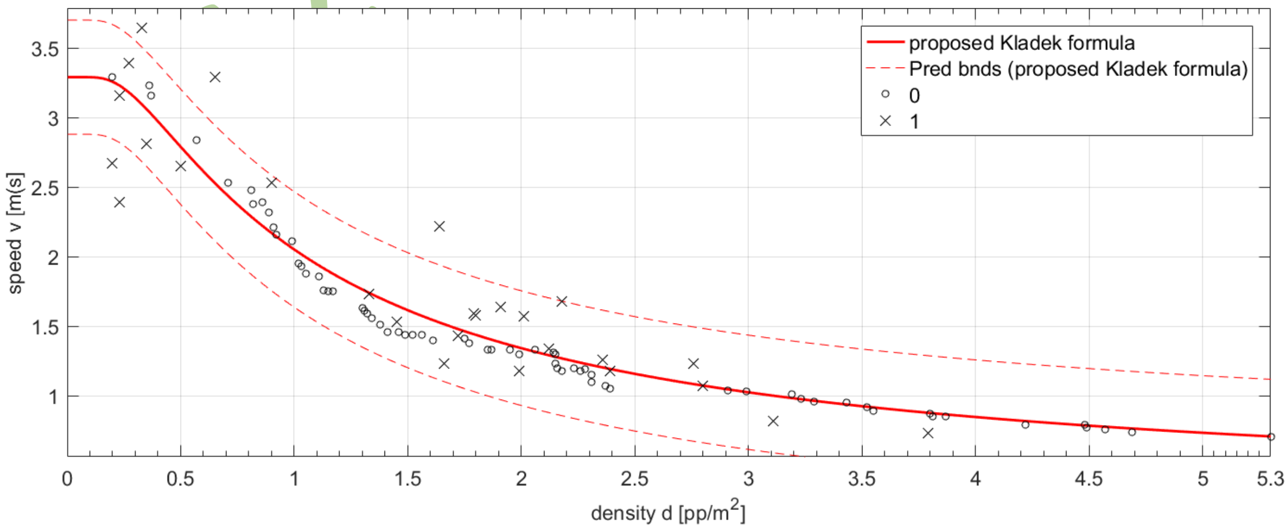

Figure 17. Experimental density-speed pairs for indoor evacuation conditions, based on data from this work and the previous reference study (Bernardini et al. 2016b), and related Kladek formula-based relation (including 95% confidence prediction bounds regression, displayed by dashed curves).

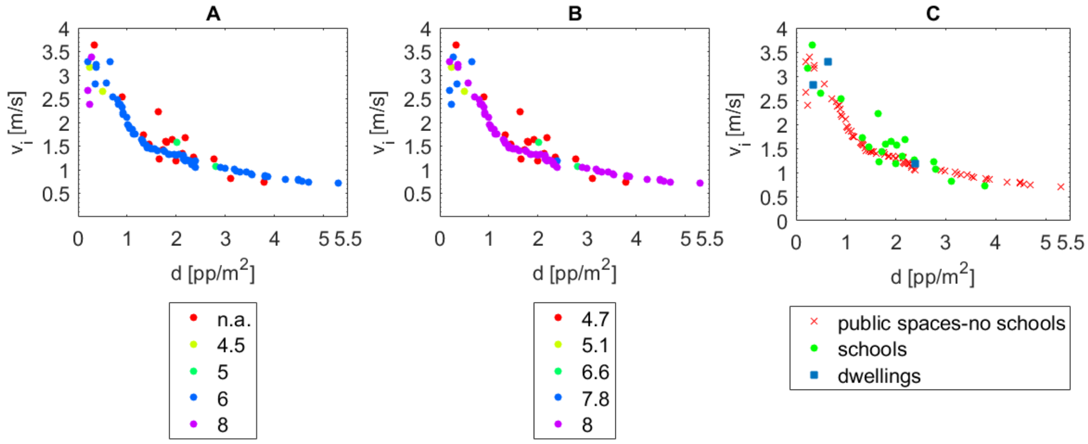

Figure 18. Experimental density-speed pairs for indoor evacuation conditions, based on data from this work and the previous reference study (Bernardini et al. 2016b) by outlining the pairs depending on : A-MMI of the event; B-earthquake magnitude; C-BE intended use.

5. Conclusions and remarks

This work provides insights on earthquake evacuation behaviours starting from the analysis of literature works and integrating them with analysis on real world videotapes of earthquakes from all over the World. In particular, the integration of the results of this work with a previous research of the UNIVPM group ensures the definition of the largest database available at today, thus providing bases for future modelling of earthquake evacuation in the Built Environment, since it focuses both on indoor and outdoor conditions. Such choice enables researchers to adopt the data to define the reaction of individuals from the indoor scenario (inside the building surrounding the Open Spaces in the BE) up to the outdoor Open Spaces in the BE.

Results firstly evidences how earthquake behaviours and motion quantities should be studies since they are different from those of other evacuation kinds. In particular, specific behaviors due to the relation with buildings are observed, which influence the evacuation procedure from a qualitative (e.g. people tend to stay far from buildings and debris) and quantitative (e.g. motion speeds are higher for lower distances with the buildings) perspective. From this point of view, such outcomes evidence the general microscopic rules to be implemented in simulators about evacuation choices (qualitative aspects) and the motion quantities (i.e. by focusing the attention on evacuation speeds).

Fundamental diagrams of evacuation dynamics concerning density-speed relation are also traced (by focusing on indoor scenarios, because of the difficulty of having videotapes with significant crowd conditions in outdoors along a limited-width path) and allows to define macroscopic-rules for the simulation.

Future works should merge the results of this study by creating operative models for earthquake evacuation simulation which should jointly combine the earthquake characterization (e.g. ground shaking), the vulnerability of the buildings and so the possible earthquake-induced damage levels and the movement of people (from a microscopic point of view, but by also applying macroscopic and group-based criteria).

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