Experimental and Real World Applications of Agent-Based Pedestrian Group Modeling

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***Abstract*—The simulation of pedestrian dynamics is a consolidated area of application for agent-based models: successful case studies can be found in the literature and off-the-shelf simulators are commonly employed by decision makers and consultancy companies. These models, however, generally do not consider the explicit representation of pedestrians aggregations (groups), the related occurring relationships and their dynamics. This work is aimed at discussing the relevance and significance of this research effort with respect to the need of empirical data about the implication of the presence of groups of pedestrians in different situations (e.g. changing density, spatial configurations of the environment). The paper describes an agent-based model encapsulating in the pedestrian's behavioural specification effects representing both traditional individual motivations (i.e. tendency to stay away from other pedestrians while moving towards the goal) and a simplified account of influences related to the presence of groups in the crowd. The model is tested in a simple scenario to evaluate the implications of some modeling choices and the presence of groups in the simulated scenario. Moreover, the model is applied in a real world scenario characterized by the presence of organized groups as an instrument for crowd management. Results are discussed and compared to experimental observations and to data available in the literature.**

I. Introduction

Agent–based approaches to the simulation of complex systems represent a relatively recent but extremely successful application area of concepts, abstractions, models defined in the area of autonomous agents and multi–agent systems (MAS). Agent-based models have been adopted to model complex systems in very different contexts, ranging from social and economical simulation to logistics optimization, from biological systems to traffic. Large groups and crowds of pedestrians represent a typical example of complex system: the overall behavior of the system can only be defined in terms of the actions of the individuals that compose it, and the decisions of the individuals are influenced by the previous actions of other pedestrians sharing the same space. Sometimes the interaction patterns are *competitive*, since pedestrians may have conflicting goals (i.e. they might wish to occupy the same spot of the shared environment), but *collaborative* patterns can also be identified (e.g. leave room to people getting off a subway train before getting on). The overall system is characterized by self-organization mechanisms and emergent phenomena.

Despite the complexity of the studied phenomenon, the relevance of human behaviour, and especially of the movements of pedestrians, in built environment in normal and extraordinary situations, and its implications for the activities of architects, designers and urban planners are apparent (see, e.g., [1]), especially considering dramatic episodes such as terrorist attacks, riots and fires, but also due to the growing issues in facing the organization and management of public events (ceremonies, races, carnivals, concerts, parties/social gatherings, and so on) and in designing naturally crowded places (e.g. stations, arenas, airports). Computational models for the simulation of crowds are thus growingly investigated in the scientific context, and these efforts led to the realization of commercial off-the-shelf simulators often adopted by firms and decision makers[1]. Models and simulators have shown their usefulness in supporting architectural designers and urban planners in their decisions by creating the possibility to envision the behavior of crowds of pedestrians in specific actual environments and planned designs, to elaborate what-if scenarios and evaluate their decisions with reference to specific metrics and criteria. Despite the substantial amount of research efforts this area is still quite lively and we are far from a complete understanding of the complex phenomena related to crowds of pedestrians in the environment: one of the least studied and understood aspects of crowds of pedestrians is represented by the implications of the presence of groups [2]. In particular, little work in the direction of modeling and simulating relatively large groups within a crowd of pedestrians encompassing some form of validation (either quantitative or qualitative) against real data can be found in the literature.

The main aim of this work is to present motivations, fundamental research questions and directions, and results of an agent–based modeling and simulation approach to the multidisciplinary investigation of the complex dynamics that characterize aggregations of pedestrians and crowds. In particular, in this paper we will present an agent–based model of pedestrians considering groups as a first–class abstraction influencing the behaviour of its members and, in turn, of the whole system. The model has been tested (i) in a schematic situation that has also been analyzed by means of field

[1] see http://www.evacmod.net/?q=node/5 for a significant although not necessarily comprehensive list of simulation platforms.

experiments to characterize the implications of groups in the overall pedestrian dynamics and (ii) in a real world scenario in which pedestrians were organized in large groups for sake of crowd management.

The paper breaks down as follows: the following section will set the present work in the state of the art of pedestrian and crowd modeling and simulation, with specific reference to recent works focusing on the modeling and implications of groups. Section III will introduce the model that was adopted in an experimental scenario, described in section IV, and in a real world scenario, described in section V. The scenarios will be described and the achieved results will be discussed. Conclusions and future developments will end the paper.

This work is set in the context of the Crystals project[2], a joint research effort between the Complex Systems and Artificial Intelligence research center of the University of Milano–Bicocca, the Centre of Research Excellence in Hajj and Omrah and the Research Center for Advanced Science and Technology of the University of Tokyo. The main focus of the project is on the adoption of an agent-based pedestrian and crowd modeling approach to investigate meaningful relationships between the contributions of anthropology, cultural characteristics and existing results on the research on crowd dynamics, and how the presence of heterogeneous groups influence emergent dynamics in the context of the Hajj and Omrah. The implications of particular relationships among pedestrians in a crowd are generally not considered or treated in a very simplistic way by current approaches. In the specific context of the Hajj, the yearly pilgrimage to Mecca that involves over 2 millions of people coming from over 150 countries, the presence of groups (possibly characterized by an internal structure) and the cultural differences among pedestrians represent two fundamental features of the reference scenario. Studying implications of these basic features is the main aim of the Crystals project.

II. Related Works

A comprehensive but compact overview of the different approaches and models for the simulation of pedestrian and crowd dynamics is not easily defined: scientific interdisciplinary workshops and conferences are in fact specifically devoted to this topic (see, e.g., the proceedings of the first edition of the International Conference on Pedestrian and Evacuation Dynamics [3] and consider that this event has reached the fifth edition in 2010). A possible schema to classify the different approaches is based on the way pedestrians are represented and managed. From this perspective, pedestrian models can be roughly classified into three main categories that respectively consider pedestrians as *particles subject to forces*, particular *states of cells* in which the environment is subdivided in Cellular Automata (CA) approaches, or *autonomous agents* acting and interacting in an environment.

The most successful particle based approach is represented by the *social force model* [4], which implicitly comprises fundamental proxemical [5] concepts like the tendency of a pedestrian to stay away from other ones while moving towards his/her goal. Proxemics essentially represents a fundamental assumption of most modeling approaches, although very few authors actually mention this anthropological theory [6], [7].

CA based approaches can be roughly classified in ad-hoc approaches for specific situations (like the case of bidirectional flows at intersections described in [8]) and general approaches, whose main representative is the floor-field approach [9], in which the cells are endowed with a discretized gradient guiding pedestrians towards potential destinations.

While particle and CA based approaches are mostly aimed at generating quantitative results about pedestrian and crowd movement, agent based approaches are sometimes aimed at the generation of effective visualizations of believable crowd dynamics, and therefore the above approaches do not necessarily share the same notion of realism and validation. Works like [10] and [11] essentially extend CA approaches, separating the pedestrians from the environment, but they essentially adopt similar methodologies. Other approaches like [12], [13] are more aimed at generating visually effective and believable pedestrians and crowds in virtual worlds. Other approaches, like [14], employ cognitive agent models for different goals, but they are not generally aimed at making predictions about pedestrian movement for sake of decision support.

A small number of recent works represent a relevant effort towards the modeling of groups, respectively in particle-based [15], [16] (extending the social force model), in CA-based [17] (with ad-hoc approaches) and in agent-based approaches [18], [19], [20], [21] (introducing specific behavioral rules for managing group oriented behaviors): in all these approaches, groups are modeled by means of additional contributions to the overall pedestrian behaviour representing the tendency to stay close to other group members. However, the above approaches only mostly deal with small groups in relatively low density conditions; those dealing with relatively large groups (tens of pedestrians) were not validated against real data. The last point is a crucial and critical element of this kind of research effort: computational models represent a way to formally and precisely define a computable form of theory of pedestrian and crowd dynamics. However, these theories must be validated employing field data, acquired by means of experiments and observations of the modeled phenomena, before the models can actually be used for sake of prediction.

III. GA-PED Model

We will now briefly introduce a model based on simple reactive situated agents based on some fundamental features of CA approaches to pedestrian and crowd modeling and simulation, with specific reference to the representation and management of the simulated environment and pedestrians; in particular, the adopted approach is discrete both in space and in time. The present description of the model is simplified and reduced for sake of space, reporting only a basic description of the elements required to understand its basic mechanisms;

[2] http://www.csai.disco.unimib.it/CSAI/CRYSTALS/

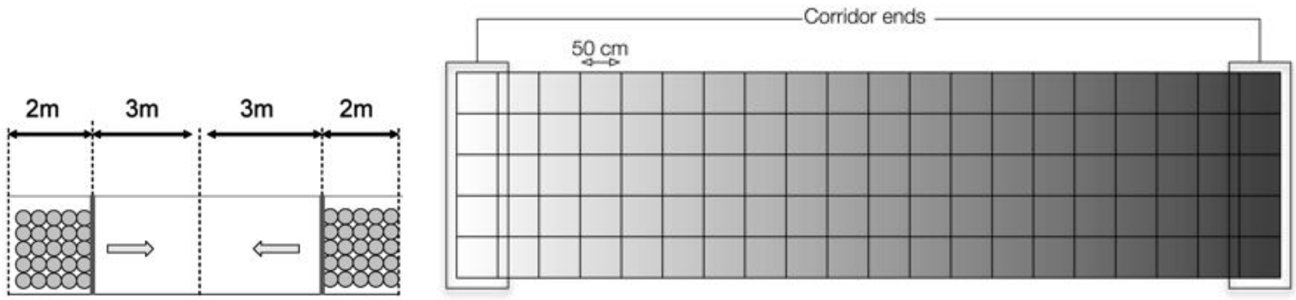


Fig. 1. Schematic representation of a simple scenario: a 2.5 by 10 m corridor, with exits on the short ends and two sets of 25 pedestrians. The discretization of 50 cm and the floor field directing towards the right end is shown on the right.

an extended version of the model description can be found in [22].

A. Environment

The environment in which the simulation takes place is a lattice of cells, each representing a portion of the simulated environment and comprising information about its current state, both in terms of physical occupation by an obstacle or by a pedestrian, and in terms of additional information, for instance describing its distance from a reference point or point of interest in the environment and/or its desirability for pedestrians following a certain path in the environment.

The scale of discretization is determined according to the principle of achieving cells in which at most one pedestrian can be present; traditionally the side of a cell is fixed at 40 or 50 cm, respectively determining a maximum density of 4 and 6.5 pedestrian per square meter. The choice of the scale of discretization also influences the length of the simulation turn: the average speed of a pedestrian can be set at about 1.5 meters per second (see, e.g., [23]) therefore, assuming that a pedestrian can perform a single movement between a cell and an adjacent one (according to the Von Neumann neighbourhood), the duration of a simulation turn is about 0.33 seconds in case of a 50 cm discretization and 0.27 in case of a finer 40 cm discretization.

Each cell can be either vacant, occupied by an obstacle or by a specific pedestrian. In order to support pedestrian navigation in the environment, each cell is also provided with specific floor fields [9]. In particular, each relevant final or intermediate target for a pedestrian is associated to a floor field, representing a sort of gradient indicating the most direct way towards the associated point of interest (e.g., see Fig.1 in which a simple scenario and the relative floor field representation are shown). The GA-Ped model only comprises *static* floor fields, specifying the shortest path to destinations and targets. Interactions between pedestrians, that in other models are described by the use of *dynamic floor fields* [24], in our model are managed through the agent perception model.

B. Pedestrians

Pedestrians in the GA-PED model have a limited form of autonomy, meaning that they can choose were to move according to their perception of the environment and their goal, but their action is actually triggered by the simulation engine and they are not thus provided with a thread of control of their own. More precisely, the simulation turn activates every pedestrian once in every turn, adopting a random order in the agent selection: this agent activation strategy, also called *shuffled sequential updating* [25], is characterized by the fact that conflicts between pedestrians are prevented.

Each pedestrian is provided with a simple set of attributes: $pedestrian = \langle pedID, groupID \rangle$ with $pedID$ being an identifier for each pedestrian and $groupID$ (possibly null, in case of individuals) the group the pedestrian belongs to. For the applications presented in this paper, the agents have a single goal in the experimental scenario, but in more complex ones the environment could be endowed with multiple floor fields and the agent could be also characterized by a *schedule*, in terms of a sequence of floor fields and therefore intermediate destinations to be reached.

The behavior of a pedestrian is represented as a flow made up of three stages: *sleep*, *movement evaluation*, *movement*. When a new iteration starts each pedestrian is in a sleeping state. The system wakes up each pedestrian once per iteration and, then, the pedestrian passes to a new state of movement evaluation. In this stage, the pedestrian collects all the information necessary to obtain spatial awareness. In particular, every pedestrian has the capability to observe the environment around him, looking for other pedestrians (that could be part of his/her group), walls and other obstacles, according to the Von Neumann neighbourhood. The choice of the actual movement destination between the set of potential movements (i.e. non empty cells are not considered) is based on the elaboration of an utility value, called *likability*, representing the desirability of moving into that position given the state of the pedestrian.

Formally, given a pedestrian belonging to a group g and reaching a goal t, the *likability* of a cell $c_{x,y}$ is defined as:

$$li(c_{x,y}, g, t) = w_t \cdot goal(t, (x, y)) + w_g \cdot group(g, (x, y)) - w_o \cdot obs(x, y) - w_s \cdot others(g, (x, y)) + \epsilon. \quad (1)$$

where the functions $obst$ counts the number of obstacles in the Von Neumann neighbourhood of a given cell, $goal$

returns the value of the floor field associated to the target t in a give cell, $group$ and $other$ respectively count the number of members and non-members of the group g, ϵ represents a random value. Group cohesion and floor field are positive components because the pedestrians wish to reach their destinations quickly, while staying close to other group members. On the contrary, the presence of obstacles and other pedestrians have a negative impact as a pedestrian usually tends to avoid them. A random factor is also added to the overall evaluation of the desirability of every cell.

In the usual floor field models, after a deterministic elaboration of the utility of each cell, not comprising thus any random factor, the utilities are translated into the probabilities that the related cell is selected as movement destination. This means that for a pedestrian generally there is a higher probability of moving towards his/her destination and according to proxemic considerations, but there is also the probability, for instance, to move away from his/her goal or to move far from his/her group. In this work, we decided to include a small random factor to the utility of each cell and to choose directly the movement that maximizes the agent utility. A more thorough comparison of the implications of this choice compared to the basic floor field approach is out of the scope of this paper and it is object of future works.

IV. Experimental Scenario

The GA-Ped model was adopted to realize a set of simulations in different starting conditions (mainly changing density of pedestrians in the environment, but also different configurations of groups present in the simulated pedestrian population) in a situation in which experiments focused at evaluating the impact of the presence of groups of different size was being investigated.

A. Experiments

The environment in which the experiments took place is represented in Fig. 1: a 2.5 by 10 m corridor, with exits on the short ends. The experiments were characterized by the presence of two sets of 25 pedestrians, respectively starting at the two ends of the corridor (in 2 by 2.5 m areas), moving towards the other end. Various cameras were positioned on the side of the corridor and the time required for the two sets of pedestrians to complete their movement was also measured (manually from the video footage).

Several experiments were conducted, some of which also considered the presence of groups of pedestrians, that were instructed on the fact that they had to behave as friends or relatives while moving during the experiment. In particular, the following scenarios have been investigated: (i) single pedestrians (3 experiments); (ii) 3 couples of pedestrians for each direction (2 experiments); (iii) 2 triples of pedestrians for each direction (3 experiments); (iv) a group of six pedestrians for each direction (4 experiments).

One of the observed phenomena was that the first experiment actually required more time for the pedestrians to complete the movement; the pedestrians actually learned how to move and how to perform the experiment very quickly, since the first experiment took them about 18 seconds while the average completion time over 12 experiments is about 15 seconds.

The number of performed experiments is probably too low to draw some definitive conclusions, but the total travel times of configurations including individuals and pairs were consistently lower than those not including groups. Qualitative analysis of the videos showed that pairs can easily form a line, and this reduces the friction with the facing group. Similar considerations can be done for large groups; on the other end, groups of three pedestrians sometimes had difficulties in forming a lane, retaining a triangular shape similar to the 'V' shaped observed and modeled in [15], and this caused a total travel times that were higher than average in two of the three experiments involving this type of group.

B. Simulation Results

We applied the model described in Sect. III to the previous scenario by means of an agent-based platform based on GA-Ped approach. A description of the platform can be found in [26]. We employed the gathered data and additional data available in the literature to perform a calibration of the parameters, essentially determining the relative importance of

	Indiv.		Couples		Triples		Groups of 5	
Den.	Sp.	Fl.	Sp.	Fl.	Sp.	Fl.	Sp.	Fl.
0,4	1,54	0,62	1,55	0,62	1,47	0,59	-	-
0,8	1,33	1,06	1,41	1,12	1,32	1,05	1,14	0,91
1,2	1,14	1,37	1,19	1,43	1,12	1,35	0,98	1,18
1,6	0,95	1,52	0,99	1,59	0,93	1,49	0,83	1,32
2,0	0,73	1,46	0,78	1,56	0,74	1,47	0,66	1,32
2,4	0,41	0,98	0,41	0,99	0,44	1,06	0,42	1,00
2,8	0,22	0,60	0,23	0,64	0,25	0,70	0,24	0,66
3,2	0,13	0,42	0,14	0,46	0,16	0,50	0,14	0,46

TABLE I
Simulation Results: values on average speed (meters per second) and flow (persons/m·s), considering different densities (persons per square meter) of pedestrians and different configurations of groups.

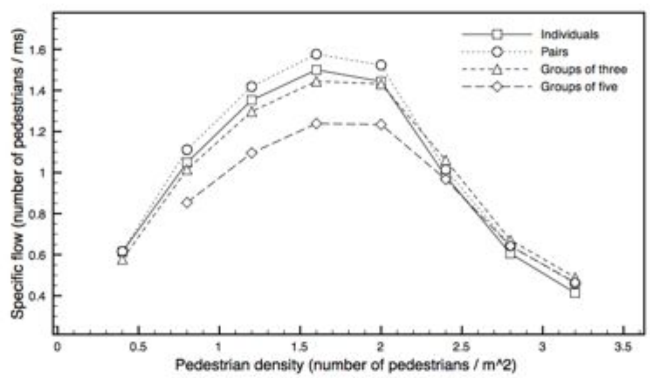


Fig. 2. Fundamental diagram for different configurations of pedestrian based on simulation results in Table I.

(a) the goal oriented, (b) general proxemics and (c) group proxemic components of the movement choice. In particular, we first identified a set of plausible values for the w_t and w_o parameters employing experimental data regarding a one-directional flow. Then we employed data from bidirectional flow situations to further tune these parameters as well as the value of the w_g parameter: the latter was set in order to achieve a balance between effectiveness in preserving group cohesion and preserving aggregated measures on the overall pedestrian flow (an excessive group cohesion value reduces the overall pedestrian flow and produces unrealistic behavior).

We investigated the capability of our model to fit the fundamental diagram proposed in the literature for characterizing pedestrian simulations [27] and other traffic related phenomena. This kind of diagram shows how the average velocity of pedestrians varies according to the density of the simulated environment. Moreover, we wanted to distinguish the different performance of different agent types, and essentially individuals, members of pairs, groups of three and five pedestrians over a relatively wide spectrum of densities. To do so, we performed continuous simulations of the bidirectional pedestrian flows in the corridor with a changing number of pedestrians, to alter their density. For each density value displayed in the graph shown in Figure 2 is related to at least 1 hour of simulated time.

The achieved fundamental diagram represents in qualitatively correct way the nature of pedestrian dynamics: the flow of pedestrians increases with the growing of the density of the corridor unit a critical value is reached. If the system density is increased beyond that value, the flow begins to decrease significantly as the friction between pedestrians make movements more difficult.

An overview on the results of the simulations are shown in Table I in which values on average speed and flow, considering different densities of pedestrians and different configurations of groups are presented.

The simulation results are in tune with the experimental data coming from observations: in particular, the flow of pairs of pedestrians is consistently above the curve of individuals. This means that the average speed of members of pairs is actually higher than the average speed of individuals. This is due to the fact that they easily tend to form a line, in which the first pedestrian has the same probability to be stuck as an individual, but the follower has a generally higher probability to move forward, following the path "opened" by the first member of the pair. The same does not happen for larger groups, since for them it is more difficult to form a line: the curves related to groups of three and five members are below the curve of individuals for most of the spectrum of densities, precisely until very high density values are reached. In this case, the advantage of followers overcomes the disadvantage of offering a larger profile to the counter flow and the combined average velocity is higher than that of individuals.

V. Real World Scenario

A. Environment and observations

The model was also adopted to elaborate different what-if scenarios in a real world case study. In particular, the simulated scenario is characterized by the presence of a station of the Mashaer line, a newly constructed rail line in the area of Makkah. The goal of this infrastructure is to reduce the congestion caused by the presence of other collective means of pilgrim transportation (i.e. buses) during the Hajj: the yearly pilgrimage to Mecca that involves over 2 millions of people coming from over 150 countries and some of its phase often result in congestions of massive proportions. In this work, we are focusing on a specific point of one of the newly constructed stations, Arafat I. One of the most demanding situations that the infrastructure of the Mashaer Rail line must be able to sustain is the one that takes place after the sunset of the second day of the pilgrimage, which involves the transport of pilgrims from Arafat to Muzdalifah. The pilgrims that employ the train to proceed to the next phase of the process must be able to move from the tents or other accommodation to the station in an organized flow that should be consistent with the movement of trains from Arafat to Muzdalifah stations. Since pilgrims must leave the Arafat area before midnight, the trains must continuously load pilgrims at Arafat, carry them to Muzdalifah, and come back empty to transport other pilgrims.

The size of the platforms was determined to allow hosting in a safe and comfortable way a number of pilgrims also exceeding the potential number of passengers of a whole train. Each train is made up of 12 wagons, each able to carry 250 passengers for a total of approximately 3000 persons. In order to achieve an organized and manageable flow of people from outside the station area to the platforms, the departure process was structured around the idea of waiting–boxes: pilgrims are subdivided into groups of about 250 persons that are led by specific leaders (generally carrying a pole with signs supporting group identification). The groups start from the tents area and flow into these fenced queuing areas located in immediately outside the station, between the access ramps. Groups of pilgrims wait in these areas for an authorization by the station agents to move towards the ramps or elevators. In this way, it is possible to stop the flow of pilgrims whenever the number of persons on the platforms (or on their way to reach it using the ramps or elevators) is equal to the train capacity, supporting thus a smooth boarding operation.

Three photos and a schematic representation of the real world scenario and the related phenomena are shown in Figure 3: the bottom right photo shows a situation in which the waiting-box principle, preventing the possibility of two flows simultaneously converging to a ramp, was not respected, causing a higher than average congestion around the ramp. This anomaly was plausibly due to the fact that it was the first time the station was actually used, therefore also the management personnel was not experienced in the crowd management procedures.

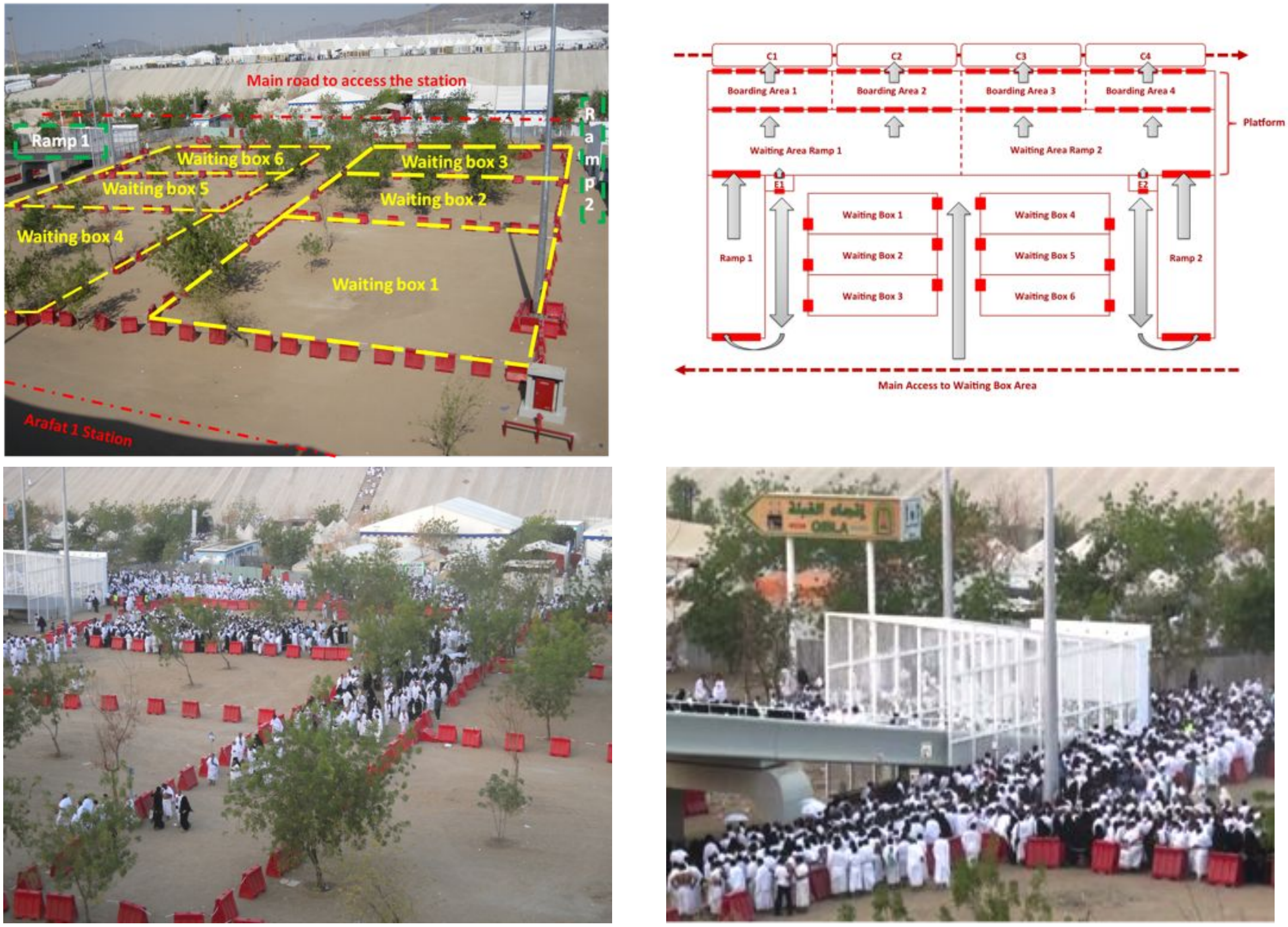


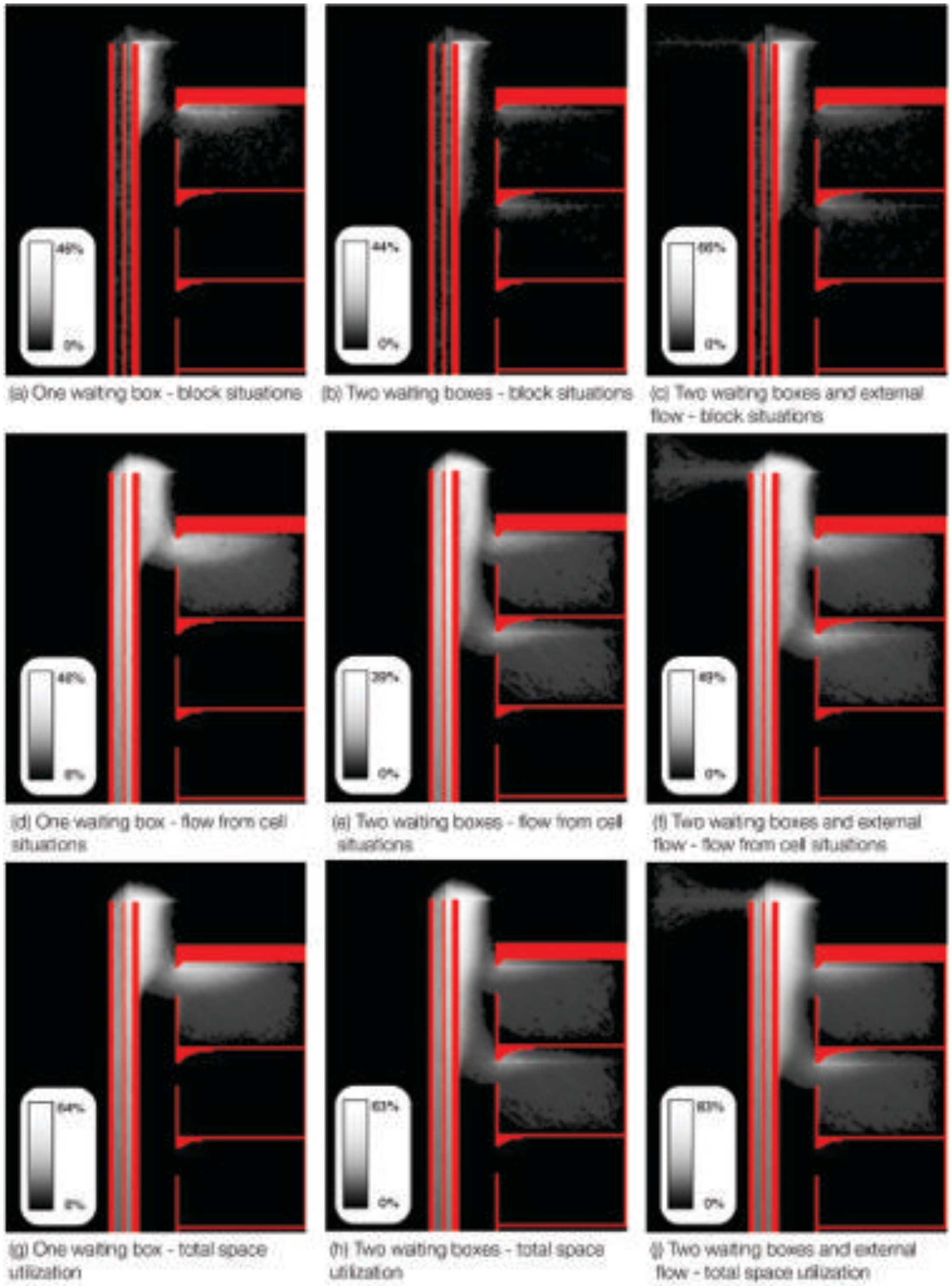
Fig. 3. Photos and a schematic representation of the real world scenario and the related phonomena.

B. Simulation Results

Three different scenarios were realized adopting the previously defined model and using the parameters that were employed in the previous case study: (i) the flow of a group of pilgrims from one waiting box to the ramp; (ii) the simultaneous flow of two groups from two different waiting boxes to the same ramp; (iii) the simultaneous flow of three groups of pilgrims, two as in the previous situation, one coming directly from the tents area. Every group included 250 pilgrims. The goal of the analysis was to understand if the model is able to qualitatively reflect the increase in the waiting times and the space utilization when the waiting box principle was not respected.

The environment was discretized adopting 50cm sided cells and the cell space was endowed with a floor field leading towards the platform, by means of the ramp. The different speed of pedestrians in the ramp was not considered: this scenario should be therefore considered as a best case situation, since pilgrims actually flow through the ramp more slowly than in our simulation. Consequently, we will not discuss here the changing of the travel time between the waiting boxes and the platform (that however increased with the growth of the number of pilgrims in the simulated scenario), but rather different metrics of *space utilization*. This kind of metric is tightly related to the so called *level of service* [28], a measure of the effectiveness of elements of a transportation infrastructure; it is also naturally related to proxemics, since a low level of service is related to a unpleasant perceived situation due to the invasion of the personal (or even intimate) space.

The diagrams shown in Figure 4 report three metrics describing three different phenomena: (i) a situation in which an agent in a cell of the environment was willing to move but it was unable to perform the action due to the excessive space occupation; (ii) a situation in which an agent actually moved from a cell of the environment; (iii) the "set sum" of the previous situations, in other words, the situations in which a cell was occupied by agent, that either moved out of the cell or remained stuck in there. More precisely, diagrams show the relative frequency of the above events on the whole simulation time. The three metrics are depicted graphically following the same approach: the background color of the environment is



(a) One waiting box - block situations (b) Two waiting boxes - block situations (c) Two waiting boxes and external flow - block situations

(d) One waiting box - flow from cell situations (e) Two waiting boxes - flow from cell situations (f) Two waiting boxes and external flow - flow from cell situations

(g) One waiting box - total space utilization (h) Two waiting boxes - total space utilization (i) Two waiting boxes and external flow - total space utilization

Fig. 4. Space utilization diagrams related to the three alternative simulated scenarios.

black and obstacles are red; each point associated to a walkable area (i.e. a cell of the model) is painted in a shade of gray according to the value of the metric in that specific point. The black color is therefore associated to point if the environment in which the related metric is 0; the white color is associated to the point in which the metric assumes the highest value in the scenario (also shown in the legend). For instance, in all diagrams in the third row the points of space close to the ramp entrance are white or light gray, while the space of the waiting area from which the second group starts is black in the first column, since the group is not present in the related situation and therefore that portion of space is not actually utilized.

The difference between the first and second scenario is not apparent in terms of different values for the maximum space utilization metrics (they are actually slightly lower in the second scenario), but the area characterized by a medium-high space utilization is actually wider in the second case. The third scenario is instead characterized by a noticeably worse performance not only from the perspective of the size of the area characterized by a medium-high space utilization, but also from the perspective of the highest value of space utilization. In particular, in the most utilized cell of the third scenario, an agent was stuck about 66% of the simulated time, compared to the 46% and 44% of the first and second scenarios.

This analysis therefore confirms that increasing the number of pilgrims that are simultaneously allowed to move towards the ramp highly increases the number of cases in which their movement is blocked because of overcrowding. Also the utilization of space increases significantly and, in the third situation, the whole side of the ramp becomes essentially a queue of pilgrims waiting to move towards the ramp. Another phenomenon that was not highlighted by the above diagrams is the fact that groups face a high pressure to mix when reaching the entrance of the ramp, which is a negative factor since crowd management procedures adopted in the scenario are based on the principle of preserving group cohesion and keeping different groups separated. According to these results, the management of the movement of group of pilgrims from the tents area to the ramps should try to avoid exceptions to the waiting box principle as much as possible.

VI. Conclusions

The paper has discussed a research effort aimed at investigating the implication of the presence of groups in pedestrian and crowd dynamics. In particular, the paper has shown a sample situation in which data coming from experimental observations were used to calibrate and validate a simulation model that correctly captures some aspects of the impact of groups in the overall system dynamics. The validation was performed considering both travel times and other data gathered in actual experiments and also by comparing the achieved fundamental diagram with existing results from the literature. In addition, a real-world case study was also described: this work considered a train station in which different policies for crowd management were compare adopting space utilization metrics. The achieved results are in tune with observations carried out on the field and the model is able to reproduce phenomena related to group behaviours in pedestrian simulation.

Future works are aimed at modeling and simulating more complex group structures, such as hierarchical group structures (e.g. families, friends, elderly with accompanying persons inside larger groups) and their implications on overall system dynamics, validating results both quantitatively and qualitatively with specific reference to the morphology assumed by the group in medium and high density situations.

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