Chapter 2
Background Review

This chapter introduces some important aspects of crowd dynamics and crowd evacuation, and discusses regulations concerning evacuation processes as discussed and presented in some countries.

2.1 Theories in Crowd Research

First of all, we define some concepts related to crowds. A crowd represents a large group of individuals in the same environment. Despite that, its formation can occur voluntarily or non-voluntarily, in everyday situations as well as in specific exceptional cases. This is a simple, but very important, concept that we illustrate in Fig. 2.1: people voluntarily become part of a crowd formed by the audience of a music festival (a). On the other hand, an involuntary crowd emerged during the motion of people in a train station (b). Furthermore, we can also highlight, i.e., panic or emergency situations as a trigger for crowd formation, like the evacuation process surrounding the 9/11 events in New York City.

In order to identify a large group of people as a crowd, some criteria are expected to be observed. Challenger (2009) highlights some of them:

- *Size*: There should be a measurable gathering of people.
- *Density*: Crowd members should be colocated in a particular area, with a sufficient density distribution.
- *Time*: Individuals should typically come together in a specific location for a specific purpose over a measurable amount of time.
- *Collectivity*: Crowd members should share a social identity, common goals, and interests, and act in a coherent manner.
- *Novelty*: Individuals should be able to act in a socially coherent manner, despite coming together in an ambiguous or unfamiliar situation.

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(a) (b)

Fig. 2.1 Two different examples of crowds which have emerged in different circumstances: a music festival (**a**) and a train station (**b**). "Ververidis Vasilis/www.Shutterstock.com"

As different events and circumstances can set the stage for crowd formation, some researchers have tried to categorize the different types of crowds. There is no one typical crowd, but a range of crowd types, each with their own characteristics and typical behaviors. Berlonghi (1995-02-01T00:00:00), in 1995, identified five different types of crowds. In order to illustrate each types, we searched the Internet for illustrative examples, shown in Fig. 2.2:

- *Spectator*: A crowd watching an event that they have come to the location to see, or that they happen to discover once there (Fig. 2.2a).
- *Demonstrator*: A crowd, often with a recognized leader, organized for a specific reason or event, to picket, demonstrate, march, or chant (Fig. 2.2b).
- *Dense or Suffocating*: A crowd in which the free movement of people decreases quickly and sometimes can stop. Due to high crowd density, people may be swept along and compressed, resulting in serious injuries and fatalities from suffocation (Fig. 2.2c).
- *Violent*: A crowd attacking, terrorizing, or rioting with no consideration for the law or the rights of other people (Fig. 2.2d).
- *Escaping*: A crowd attempting to escape from real or perceived danger or life-threatening situations, including people involved in organized evacuations, or chaotic pushing and shoving by a panicking mob (Fig. 2.2e).

Our goal is to study the attributes that characterize crowd dynamics in order to understand how crowds are likely to move and behave.

2.1.1 Crowd Dynamics

The observation of crowd evolution in a specific place allows us to observe different aspects. A crowd consists of independent individuals and each one has her own needs and desires, but all of them share the same goal. Such a group feeling is highlighted

Fig. 2.2 The five types of crowds according to Berlonghi (1995-02-01T00:00:00): spectator (**a**), demonstrator (**b**), dense or suffocating (**c**), violent (**d**), and escaping (**e**)

by Osorio (2003), a psychologist, who defines a crowd of people as a human system composed of a set of people able to know each other as individuals, yet share goals and perform a collective action.

The understanding of human behavior is a huge research field in psychology area reaching back into the 1800s. By the beginning of twentieth century, Freud already had spent decades observing human behavior Freud (1922). Supported by studies from LeBon (1895) and Mc Dougall (2009), Freud discusses the behavior of human beings when part of a group and defines a crowd as a temporary entity, consisting of heterogeneous elements that have joined together for a moment.

Other crowd aspects were observed and described by the end of the nineteenth century. One of them was observed by LeBon (1895), who says that when part of a crowd, individuals can perform unusual behaviors which they are not liable to perform alone. In this kind of situation, the individuals can act in collectively and emerge as a new entity. This new entity can make people feel, think, and act in different ways, even being able to perform dangerous behaviors which can result in fatalities.

We know that a crowd is a congregation of people in the same environment, yet every individual in a crowd is owner of his or her own personal space in the environment. The American anthropologist Edward Hall invented the term *proxemics* Hall (1966) to represent the personal space of each person. Hall noted that the distance between people, when interacting with each other, varies according to their relationship, or level of intimacy. These levels are divided in four possible ranges (see Fig. 2.3): *intimate* [0.00, 0.45] m, *personal* (0.45, 1.20] m, *social* (1.20, 3.60] m, and *public* (3.60, 7.60] m.

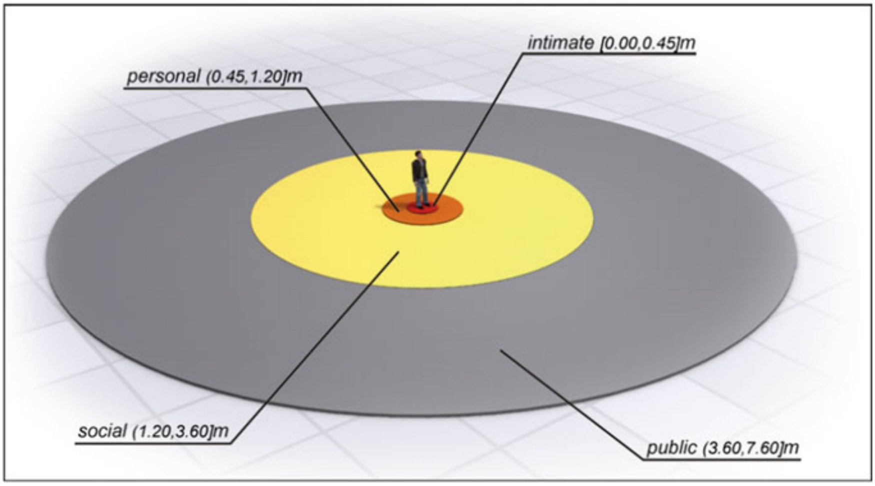

Fig. 2.3 Illustration of a person's proxemics based on Hall's definitions of distances: intimate, personal, social, and public

Knowing the proxemics of the individuals in a group may make it possible to identify the groups' relationship into the crowd Edney and Grundmann (1979). Such aspect is considered because groups of people can perform different behaviors based on its size, place, or even the relationship among the group members.

Still (2000) developed a set of computer programs in order to study, and also reproduce, the behavior of a crowd. His framework, called *Legion*, was based on four rules to determine the flow of human traffic. These rules interact as characters come into proximity with each other's space and associated static and dynamic objects in the environment. The computational result exhibits emergent behavior, specifically, the entities are programmed with one kind of behavior but the group of entities exhibits another, more global, property. Where the group behavior cannot be reduced to the individuals' behavior, a system is defined as emergent (Fig. 2.4).

Still's simulation research focused interest in emergent behaviors from real crowds. These group attributes were observed by other authors Helbing and Molnar (1998) and recognized by international institutions Challenger (2009). Computational crowd simulation should reproduce these behaviors when possible:

(a) Arch Formation

(b) Lane Formation

(c) Corner Effect

(d) Ring Effect

Fig. 2.4 Crowd organization examples

- *Arch Formation*: Arching happens when a large, dense crowd pushes forward toward a narrow exit. In situations like this, the exit becomes clogged and the crowd forms an arch-like shape in front of the exit.
- *Lane Formation*: When people move in the same or opposing directions, they can self-organize to create distinct lanes: one for each direction of movement, or sometimes differentiating by velocities. This self-organization phenomena helps to reduce collisions and increase the lane's overall speed. However, in high density or nervous crowds, any lanes formed may break down due to continuous overtaking maneuvers.
- *Corner Effect*: As crowd members turn corners, they tend to slow down and move further into the corner, becoming more densely packed and appearing to *hug* the corner.
- *Ring Effect*: This phenomena emerges when a crowd is observing a particular event or gathers around a particular point of interest, such as a street artist. In such cases a ring structure emerges, radiating outwards from the point of interest.
- *Speed reduction effect*: This effect arises when many people are populating a specific environment and moving in some direction. If more people arrive, the crowd velocity may decrease.
- *Principle of Least Effort*: When possible, crowd members will typically take the fastest route. They aim to minimize time and work, avoid congestion, and maximize their speed.

Having just described some important aspects related to crowds in general, the next section can now specify some aspects observed in crowds during an egress event.

2.1.2 Crowd Evolution in Egress Situations

As observed by LeBon (1895), when in crowds, people can perform unusual behaviors which can lead to irrational actions. Indeed, we can say that such actions can occur even more likely under panicked egress. It is very easy to look back in history to point out some important involuntary evacuation situations:

1. Atomic bombing of Japan during World War II;
2. Terrorists reach New York in 2001;
3. Hurricane Katrina in 2005.

These are just three examples where evacuations were needed. In such situations, people probably were guided by their simple emotions and responded to the situation performing unusual behavior.

The success of an evacuation event can be related to an understanding of the process. In order to have a safe evacuation there are three important factors: interpretation, preparation, and action Mu et al. (2013). *Interpretation* is the moment when people perceive the real need to evacuate; *preparation* is planning the best route to follow, while *action* guides the individual through the chosen route in order to reach a safe area.

In addition, other specific aspects influence evacuation success, including:

- Building type, such as, office, airport, train station;
- The understanding of occupants' behavior under panic situation;
- Occupants' distribution (by age, gender, and disability); and
- Location of dangerous areas as well as safe places and emergency exits.

Knowledge about such aspects facilitates the execution of a safe egress process. The evolution of a crowd during an evacuation process usually shows behaviors that can evidence the organization and structure of the group. A successful egress is often due to cooperation and coordination among the people Cocking and Drury (2008).

Usually, the group has power to influence its members' motion. Thus the choice of escape route, *made individually*, usually is also influenced by the actions of the other members of the crowd. This aspect can justify the fact that when in egress, people typically move in the same direction as others. In this way, for Cocking and Drury (2008), when united by an emergency situation, a physical crowd (a group of individuals in the same location, each with her own personal identity) may be transformed into a psychological crowd (i.e., a group of people united by a common social identity as members of a particular category).

Additionally other factors (mapped by Challenger (2009)) may influence an evacuation process:

- *Mobility*: An individual who is less mobile is likely to need longer to evacuate in an emergency.
- *Physical Position*: An individual lying down is likely to have a slower rate of reaction and movement than an individual standing up.
- *Density*: Crowd movement will be slower in a more densely packed environment.
- *Alertness*: An individual who is less alert, for instance as a result of tiredness or intoxication, is likely to react more slowly in the event of an emergency.
- *Visibility*: The more visible the signage and emergency exit routes, the more attractive they are likely to be to crowd members and the more likely (and at higher speed) crowd members are to follow those routes.
- *Complexity of the environment*: The more complex the environment, the more indecisive individuals are likely to be and the longer it is likely to take to evacuate.

These factors are usually considered in order to regulate any egress process. Government groups and different professional organizations have worked in regulate egress features and protocols. The next section presents and details some of these regulations.

2.2 Regulations in Evacuation Processes

Nowadays, governments and professionals from different fields work together to define and specify effective measures for optimal evacuation plans. The purpose of an evacuation plan is to guarantee safety when leaving a building or structure, specially when a panic or an emergency situation occurs. An evaluation of egress details is already requested by international organizations as UEFA (Union of European Football Association) or FIFA (Fédération Internationale de Football Association) in specific sites as sport stadiums and arenas, beyond specific regional regulations.

The UEFA expresses specific concerns related to egress processing which must be observed even before the design of a new stadium starts Fenwick et al. (2011). The safe capacity is a mandatory requirement which focuses, as the name suggests, on ensuring maximum safety for spectators. It is widely accepted that all spectators should be able to exit the stadium bowl to a point of safety within a maximum of eight minutes. This value is based on a maximum flow rate through the stadiums exits of 660 people an hour. However, there may be some consideration for specific variations based on the size and design of the venue.

According to FIFA, the emergency evacuation time is in part based on the level of risk and the available emergency evacuation routes to places of safety or places of reasonable safety. The organization has published a guideline[1] where they define a set of Stadium Safety and Security Regulations. According to this guide, factors like the type of construction and materials used in the stadium will have an impact on the calculation of the expected time for evacuation. In addition, fire is one of the major risks to be considered when calculating the acceptable egress time. For example, if the risk of fire is high due to the construction of the stadium, the expected evacuation time must be reduced.

The emergency evacuation time is not a fixed value. It is a calculation which, together with the appropriate rate of passage, is used to determine the capacity of the emergency exit system from the viewing accommodation to a place of safety or reasonable safety, during an emergency.

The United States of America considers the *Life Safety Code* (2015), a guideline developed by the NFPA (National Fire Protection Association), which provides details to be followed during a possible building evacuation process. Together with the *Design Handbook* provided by the SFPE (Society of Fire Protection and Engineering) Hurley et al. (2015), building designers can incorporate, during the project phase of a building, egress aspects regarding to features such as sprinklers, exit lights, and alarms.

According to the *International Building Code* International Code Council (2012), every building or structure, new or old, designed for human occupancy, is to be provided with exits sufficient to permit the prompt escape of occupants in case of fire or other emergency. According to the guideline, all exits should discharge directly

[1] http://fifa.com/mm/document/tournament/competition/51/53/98/safetyregulations_e.pdf.

to the street or other open space that gives safe access to a public way. The streets to which the exits discharge must be of a width adequate to accommodate all persons leaving the building. An EAP (*emergency action plan*), according to the guideline, should cover those designated actions that ensure occupant safety from fire and other emergencies:

- Emergency escape procedures and emergency escape route assignments;
- Procedures to account for all individuals after emergency evacuation has been completed;
- The preferred means of reporting fires and other emergencies; and
- Names or regular job titles of persons or departments who can be contacted for further information or explanation of duties under the plan.

Independent of the guideline, it is important to mention that personal behavior can contribute to some emergency or congestion that is not predicted during the egress plan development.

Legislation on crowd management in Brazil is under development, having been given increased attention in the past few years due to some specific events. One motivation has been the unfortunate fatal disaster in the Kiss Night Club.[2] In addition, big sportive events that took place in Brazil (the World Cup and the Olympics) are helping to promote the new legislation.

The ABNT (Brazilian Association of Technical Standards) defined in 2001 the guideline NBR 9077:2001 aiming to specify regulations concerning emergency exits. According to the guideline, the concentration of people when using an emergency exit should be maximum $2 people/m^2$. The Technical Guideline from the government of São Paulo, Brazil Polícia Militar do Estado de São Paulo (2004), defines specific points relating to safety during egress. We summarize some of the most important:

- Individuals should achieve a safe point without walking more than 20 m in outdoor areas and 10 m in indoor areas. Emergency exits can be considered as the safe point.
- The time for a group of people to leave a public indoor area, such as a theater, should not exceed 6 min.
- The concentration of people in stand-up areas should not be greater than $4 people/m^2$.

We opted to present data From São Paulo due the fact the city is considered the most important city in Brazil. Each state or city can provide their own building regulations, in the absence of operative federal regulations.

[2] http://edition.cnn.com/2013/01/28/world/americas/brazil-nightclub-fire.

2.3 Crowd Simulation in Emergency Situations

An important work regarding crowd behavior in egress situations was proposed by Braun et al. (2003). The authors explore the agents' personal characteristics in order to simulate different reactions and behaviors during an evacuation process. Inspired by a physically based approach Helbing et al. (2000), the authors aggregate a set of features to simulate agents and also groups in order to reproduce a heterogeneous crowd. Such features include, among others, aspects such as families representation, dependency level from others, level of agent's altruism, and also desired velocity. The authors keep groups together considering a force composed from the altruism level from agents of the same family. In addition, based on the altruism level, an agent can ungroup from her family in order to help other agents in the process.

The work from ZHU et al. (2008) was developed observing the 2008 Olympic games in China. At that time, the authors developed an approach able to reproduce pedestrian traffic created from delegations of athletes from different countries and also the audience. A case study was performed considering the *National Stadium* and took into account aspects such as the number of pedestrians and their distribution during specific situations (such the final moments of a game).

The main goal envisaged by Fu et al. (2014) was to simulate the normal evacuation process. Their motivation was to reproduce pedestrian behavior in exit selection taking into account a least effort cellular automaton algorithm. Space is represented by a set of 2D cells containing pedestrians or obstacles. The motions and goals used to guide the movements are defined considering a probabilistic approach. Cellular automaton algorithms are used by Ji et al. (2013) for pedestrian dynamics and by Aik and Choon (2012) for reproducing a simple evacuation process. Chu et al. (2014) developed the platform SAFEgress (Social Agent For Egress), in which building occupants are modeled as agents able to choose their actions according to their knowledge of the environment and their interactions with the social groups and the neighboring crowd. According to the authors, results show that both the agents' familiarity with the building and social influences can significantly impact evacuation performance.

Pelechano et al. (2008) have explored different aspects of virtual crowd behaviors. One aspect they studied involved improving a crowd simulation by adding a psychological model Pelechano et al. (2005). A more extensive framework combines *PMFserv* Silverman et al. (2006) (mature models for physiology, stress, perception, and emotion) with the Multi-Agent Communication for Evacuation Simulation (MACES) system Pelechano and Badler (2006). The integration allowed the crowd simulation model to provide events that an agent can perceive, resulting in responsive, reactive, and situated behaviors.

A review of crowd simulation models and selected commercial software tools for high-rise building evacuation was developed by Pelechano and Malkawi (2008). The goal of that work was to study the importance of incorporating human psychological and physiological factors into crowd simulation models. The authors presented an overview of fundamentals that should be applied to simulate human movement to align it closer to real movements of people, where interaction between bodies emerges and flow rates, densities, and speeds become the result of those interactions instead of some predefined values.

Besides agents and environment, some external factors can influence the results of a simulation. Such external factors can include, not exclusively, aspects of fire and smoke propagation, e.g., as discussed by Huang et al. (2010). The authors developed MIMOSA (Mine Interior Model Of Smoke and Action), which integrates an underground coal mine virtual environment, a fire and smoke propagation model, and a human physiology and behavior model. The authors consider the particular effects of smoke and toxic fumes on the agents in the simulation. To accomplish this, each individual agent has a set of physiological parameters dependent on its local environment, simulating a miner's physiological exposure and consequent condition during normal operations as well as during emergencies due to fire and smoke.

Xi and Smith (2015) developed a virtual fire evacuation training system. Their idea was focused on extending a virtual environment development pipeline for building virtual fire evacuation training systems. The authors investigate the best way to integrate 3D building models and fire egress behavior from fire evacuation simulations into a game engine. The aim is to ensure that the behavior of autonomous agents, representing human evacuees extracted from the fire simulator, is faithfully represented in the target virtual environment. A pipeline is presented as example to show the integration of Google SketchUp,[3] FDS+Evac Korhonen et al. (2009) and Unity 3D.[4]

Beyond the analyses of agents' behaviors, it is very important to consider the way environment can contribute (or not) to a possible egress process. This is one of the goals considered in research developed by Berseth et al. (2015b), who observe how the layout of a building affects the flow patterns of its intended users. The authors propose a computational framework for studying the configuration of architectural building elements. Such elements can represent pillars or doors and are studied in order to optimize dense pedestrian flow during building evacuations. One of the aspects considered by the authors was the effect of local collision avoidance strategies used in crowd flow patterns on representative evacuation benchmarks. The benchmarks include variations in the number and placement of pillars, exit door sizes, as well as corridor and crowd flow configurations. Three different steering algorithms (ORCA van den Berg et al. (2009), PPR Singh et al. (2011), and SF Helbing et al. (2000)) were applied in order to observe the resulting optimizations. According to the authors, when the main goal is to study real buildings, it is important to provide approaches validated with the local population. In addition, they conclude that door widths are an important design feature. Door widths had a significant impact on crowd flow patterns, especially for bidirectional traffic, highlighting the importance of selecting the right door width based on the expected crowd interactions.

Also regarding the environment structure, the work presented by Jiang et al. aims to increase environment safety by analyzing better placement of obstacles Jiang et al.

[3]http://sketchup.com.

[4]http://unity3d.com.

(2014). In order to reach this goal, the authors developed a genetic algorithm based on social-forces. According to them, simulation results indicate that appropriately placing two pillars on both sides but not in front of a door can maximize escape efficiency. In order to validate results, they performed an experiment using 80 participants. Results indicated that human actions corresponded well with the simulations.

Motion information is also considered by Rodriguez et al. (2013), who investigate the use of tools from robotics control to improve the design of buildings. The authors apply methods of optimization and roadmap-based motion planning to determine how placement of agents and common design features, such as pillars and doors, can affect the flow of human traffic through a building. Some experiments had objectives to explore pedestrian flow rate optimization via pillar placement, evacuation time via door placement, and the optimization of agent meeting points.

After having defined an ideal environment, it is also interesting to define the ideal parameters for possible steering algorithms. This aspect is also discussed by Berseth and collaborators Berseth et al. (2014). The authors present a methodology for automatically fitting the parameters of a steering algorithm. The goal is to minimize any combination of performance metrics, across any set of environment benchmarks in a general, model-independent fashion. Named *SteerFit*, the framework can optimize steering algorithms according to different criteria: distance, time, or energy consumption of an agent, its computational performance, similarity to ground truth, user-defined custom metrics, or a weighted combination of any of them. The framework was applied in order to fit parameters for three steering algorithms: ORCA van den Berg et al. (2009), PPR Singh et al. (2011) and SF Helbing et al. (2000). According to the authors, the parameter fitting can be used to improve the performance of a specific algorithm. The optimization also can be considered as an analysis tool able to produce a detailed view of an algorithm's behavior relative to its internal parameters.

Beyond the simulation of one egress path, it is interesting to observe different ways that people leave an environment. One alternative for egress plan generation is the use of matheuristic, which decomposes the problem being solved into a master and a set of subproblems. The work of Pillac et al. (2014) presents an evacuation algorithm that follows recommended evacuation methodologies, which divides the evacuated area in evacuation zones, each being instructed to leave at a specific time and following a predefined route. According to the authors, the *Conflict-Based Path-Generation Heuristic* specifies evacuation routes for each evacuation zone and uses a lexicographic objective function that first maximizes the number of evacuees reaching safety and then minimizes the total evacuation time. The algorithm was evaluated taking into account real-scale, massive flood scenarios in the Hawkesbury-Nepean River, Australia. The simulation considered 70,000 agents who required evacuation from the area.

One of the main points to be considered when simulating crowds is the validation of results. The best strategy, in this case, is to compare data from simulation with real-life experience. Chapter 5 discusses many techniques currently used to extract data from crowds in video sequences that can be used to this end. One work in the area is by Murphy et al. (2013): they present EvacSim, a multi-agent building evacuation simulation. Here, the authors detail pedestrian model elements that govern microscopic agent movement such as personal space preservation, obstacle avoidance, and moving together as a crowd. In order to validate the EvacSim pedestrian model against real-world pedestrian data, the authors made a comparison of flow rates, density, and velocity for corridor entry and for merging groups, considering data from simulation and the real world in a controlled environment.

Guy et al. (2012) developed a statistical similarity measure for aggregate crowd dynamics. The method aims to measure the similarity between a given set of observed, real-world data and a visual simulation technique for aggregate crowd motions of many individual agents. This metric uses a two-step process to quantify a simulator's ability to reproduce the collective behaviors of the whole system, as observed in the recorded real-world data. Wang et al. (2016) propose a new approach based on finding latent path patterns in both real and simulated data in order to analyze and compare them. Unsupervised clustering by nonparametric Bayesian inference is used to learn the patterns, which themselves provide a rich visualization of the crowd's behavior. To this end, they present a new Stochastic Variational Dual Hierarchical Dirichlet Process (SV-DHDP) model. The fidelity of the patterns is then computed with respect to a reference, thus allowing the outputs of different algorithms to be compared with each other or with real data.

2.4 Summary

This chapter presented a literature analysis regarding theories of crowd dynamics and evolution, and further discussed the regulation of egress situations in different countries. In addition, we presented the state of the art in crowd evacuation techniques. The next Chapter presents current crowd simulation technologies, including some commercially distributed, and CrowdSim, which is the software used in Chap. 4 to explain and discuss case-studies.

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