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Review Article

Panic, Irrationality, and Herding: Three Ambiguous Terms in Crowd Dynamics Research

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Background. The three terms "panic", "irrationality", and "herding" are ubiquitous in the crowd dynamics literature and have a strong influence on both modelling and management practices. The terms are also commonly shared between the scientific and nonscientific domains. The pervasiveness of the use of these terms is to the point where their underlying assumptions have often been treated as common knowledge by both experts and lay persons. Yet, at the same time, the literature on crowd dynamics presents ample debate, contradiction, and inconsistency on these topics. *Method*. This review is the first to systematically revisit these three terms in a unified study to highlight the scope of this debate. We extracted from peer-reviewed journal articles direct quotes that offer a definition, conceptualisation, or supporting/contradicting evidence on these terms and/or their underlying theories. To further examine the suitability of the term herding, a secondary and more detailed analysis is also conducted on studies that have specifically investigated this phenomenon in empirical settings. *Results*. The review shows that (i) there is no consensus on the definition for the terms panic and irrationality and that (ii) the literature is highly divided along discipline lines on how accurate these theories/terminologies are for describing human escape behaviour. The review reveals a complete division and disconnection between studies published by social scientists and those from the physical science domain and also between studies whose main focus is on numerical simulation versus those with empirical focus. (iii) Despite the ambiguity of the definitions and the missing consensus in the literature, these terms are still increasingly and persistently mentioned in crowd evacuation studies. (iv) Different to panic and irrationality, there is relative consistency in definitions of the term herding, with the term usually being associated with '(blind) imitation'. However, based on the findings of empirical studies, we argue why, despite the relative consistency in meaning, (v) the term herding itself lacks adequate nuance and accuracy for describing the role of 'social influence' in escape behaviour. Our conclusions also emphasise the importance of distinguishing between the social influence on various aspects of evacuation behaviour and avoiding generalisation across various behavioural layers. *Conclusions*. We argue that the use of these three terms in the scientific literature does not contribute constructively to extending the knowledge or to improving the modelling capabilities in the field of crowd dynamics. This is largely due to the ambiguity of these terms, the overly simplistic nature of their assumptions, or the fact that the theories they represent are not readily verifiable. *Recommendations*. We suggest that it would be beneficial for advancing this research field that the phenomena related to these three terms are clearly defined by more tangible and quantifiable terms and be formulated as verifiable hypotheses, so they can be operationalized for empirical testing.

1. Introduction

As researchers working in the field of pedestrian dynamics, we have experienced that a presentation of a piece of research on the topic of crowd evacuation, whether to an academic audience or lay audience, barely goes by without researchers being confronted with these questions: How about the effect of panic? How do you model/experiment panic? To a lesser

extent, we also similarly receive questions of this nature during peer review processes. The question is also often accompanied by follow-up questions on irrational behaviour during evacuations and herding phenomena and how we take those into account in our computational models or experimentations.

We have also observed that these debates are often not resolved with a rigorous argument based on facts and empirical evidence and are, rather, addressed with some level of speculation and resorting to intuition. Nevertheless, researchers often concede that these might be limitations of their study and phenomena that they still have not been able to tackle. Sometimes, researchers take a more defensive position facing this question and present counterarguments that are meant to dismiss these phenomena as matters that should not concern us when designing our research experiments or formulating our models.

The question that arises is why, after so many years of research in this field, have these terms remained intractable? Does this stem from a lack of clear definitions and/or a lack of well-conditioned theoretical conceptualisation? Is this a sign that these terms are still not well defined and that they may, to some degree, be misdirecting the research in this field?

The issue of panic constitutes a rather frequent disclaimer at the discussion section of publications on crowd evacuation dynamics and a common ground for criticising the modelling and experimentation efforts in this field [1]. Such disclaimers often appear in wordings such as: These experiments were conducted under nonpanic conditions [2], or the influence of panic has been excluded from the experiment/model [3, 4]. This gives the indication that simulating/modelling panic is going to be a future development in this field something that the research is headed towards, but one that we have not been able to tackle just yet.

What is, however, very clear is that the terms, panic, irrationality, and herding are among the most ubiquitous terms in the crowd dynamics literature. A peculiar characteristic is that they are used as commonly shared language between the scientific literature, the public, and the media to describe collective evacuation behaviour [5]. As stated by Quarantelli [5], "what constitutes panic is illustrated by presentations of anecdotal examples from stories of disaster behavior in journalistic and popular sources". Here, we investigate what level of consensus exists on their definition and meaning. We survey the scientific literature of crowd dynamics and analyse the use of these three terms with the aim of identifying (i) whether the literature offers unified definitions, (ii) how different segments of the literature view these terms and their theories in general, (iii) how well supported they are in various segments of the literature, and (iv) how they can potentially influence experimentation, modelling, and management practices in this field.

2. Methods

The main purpose of the review is to perform a structured literature search on the use of the terms panic, irrationality, and herding in the context of emergency evacuation of crowds. This will help to establish whether unified definitions can be identified, and it will identify possible inconsistencies or contradictions. In performing this analysis, we also aim to provide an overall reflection of how different research fields perceive each of these terms. The literature review puts together studies from a range of disciplines including physical sciences, social sciences, and biological sciences.

The structured literature analysis is mainly performed on direct quotes from peer-reviewed research articles where these terms have appeared. The main criterion for the selection of the underlying studies was that they had to be exclusively in the context of emergency behaviour, and particularly the behaviour of humans within crowds. For example, the use of the term herding in financial or other contexts where the term is frequently used is not considered here.

Using Scopus as our primary database, we performed title-keywords-abstract searches by applying all possible combinations between the terms "pedestrian, evacuation, crowd, escape, disaster, emergency", and the set of three focus terms of this study "panic, irrational, herd" while separating them by the operator "AND". Each search outcome was limited to Articles and Reviews as Document Types, and exclusively Journals as Source Types. No particular date was specified. This search was initially performed in August 2018. It was subsequently updated in January 2019, limiting the outputs to 2018 and 2019 as Year of publication. For each search, the outputs underwent an initial screening to identify the relevant articles. This screening was performed first on the title of the articles that appeared in search outputs and then on their abstract and keywords only if necessary (i.e., only if the title did not give clear indication of whether the study would be potentially relevant to the content of the review). The search was also supplemented by a prior and less systematic search on a personal reference database that includes nearly 2000 selected articles in the context of crowd dynamics, as well as a variety of Google Scholar searches using similar combination of terms used in Scopus.

This process generated a shortlist of nearly 200 articles whose full texts were screened for the purpose of extracting quotes relevant to the context of this review. The full text of each article was searched for the use of the terms 'panic', 'irrational(ity)', and 'herd(ing)' separately. The criteria for choosing quotes where these terms appeared were that the quote has to convey some form of definition on the term, characterise the term (or its underlying phenomenon), or make some comment on the validity of their underlying theory or the commonness of the phenomenon real-life emergencies. We use these broad inclusion criteria to achieve a comprehensive and objective perspective on how these terms are perceived and used in various subdivisions of the literature.

Out of the nearly 200 shortlisted articles whose full texts were analysed for the use of these terms, half of them (101 items) produced at least one quote that met our criteria outlined above. These quotes were extracted from each article and were stored in separate Word files for further subsequent analyses. In the subsequent analyses, mainly for the purpose of keeping this review to a reasonable length, quotes within

studies that had produced more abundant material had to be prioritised. In such cases, where a study had produced several and often lengthy quotes relevant to our review topic, the quotes with similar content were compared together and briefest ones were chosen. Also, for quotes in which more than one of the three terms had appeared, the quote was only categorised in one of the three sections related to these terms by identifying the term that was dominant in the quote (i.e., the term that constituted the primary theme of the quote). This way, we avoided repeating individual quote for the analyses on our three terms.

The selected quotes were subsequently further analysed and categorised. We differentiated between the quotes in terms of whether they offer a definition/characterisation on the term or just comment on the commonness/likeliness of the underlying phenomenon. Where possible we also recorded whether the quote sentiment is in support of the underlying theory or the use of the term, or instead, contradicts or rejects that idea. Also, in order to demonstrate how intertwined these terms are within the scientific literature, we recorded when the quote links (at least) two of the three terms together. We categorised the source study of each quote into one of the three main disciplines, social sciences, physical sciences, and biological sciences. This categorisation is predominantly based on the discipline of journal that has published the study as well as the main theme of the study. In most cases, these criteria aligned with one another, but in cases where one single categorisation was not possible, more than one category was assigned to the source article. This categorisation was primarily meant to indicate whether and how the perception of these three terms varies across researchers from different disciplines. The studies that we surveyed had one (or sometimes more) of these three themes as their main focus: modelling, empirical testing, and conceptualisation. We categorised each quote based on the primary category of its underlying study among these three categories. Often more than one category were applicable to the source study of a quote. In those cases, we allowed belonging to more than one category. The purpose of this categorisation was to identify whether there is a noticeable difference in definition and/or perception of our three terms of interest across studies whose main focus is on modelling compared to empirical studies or those that only conceptualise these phenomena. Although this is a somewhat crude categorisation of studies and should be interpreted as such, we suggest that it facilitates some coarse insights. The quotes that we extracted from individual studies were quite diverse. However, we were able to identify common themes across clusters of these quotes. Therefore, to further summarise and categorise these individual quotes, we identified these common themes and added them as short comments to each quote. In cases where the quote did not fit any of those common themes no comments were added to the quote.

The outcome of the analysis outlined above is summarised and reported in Tables 5, 6, and 7, respectively, for terms panic, irrationality, and herding. For each quote listed in these tables, the source reference from which the quote has been extracted is cited. The table also determines whether the quote links each term to either (or both) of the two other terms. It also determines whether the quote offers any definition or conceptualisation on this term (when applicable) and whether it conveys support for the panic/irrationality/herding theory or challenges/contradicts it (when applicable). Then, in order to identify how these characteristics of the quotes are influenced by the discipline from which the study originated, the source reference of the quote is categorised in one (or, occasionally, two) of the three disciplines: social sciences, physical sciences, and biological sciences. The source reference is also categorised based on the nature of the study. If the study is heavily focused on numerical simulation and modelling without much connection to empirical analysis, then it is categorised as a "modelling" type study. If the study presents noticeable empirical components it is categorised as "empirical testing". If the study only offers conceptualisation on this term or its underlying theory, then it is categorised as a "conceptualisation" study. Occasionally some studies had to be categorised in more than one of the two study types.

In order to establish whether 'herding', as a terminology, is suitable and accurate enough for describing the phenomena that it is meant to embody, it seemed necessary to examine this term based on the findings of empirical studies. Therefore, we decided to perform a supplementary survey on the herding phenomenon in evacuation exclusive to the studies that have experimented this question in one form or another. This supplementary survey is not based on the analysis of the quotes per se, rather than concerns the individual studies, those that have provided experimental findings on herding behaviour in evacuations. In collecting a comprehensive set of references related to this supplementary survey, we first extracted relevant studies from a previous review of the empirical studies in crowd dynamics whose reference database was last updated in April 2017 [6]. In order to identify studies that were published after April 2017 we conducted supplementary search in Google Scholar and Scopus, with the main selection criterion being that the experiment report on some form of empirical testing or experimentation on the topic. In total, 24 articles qualified for this supplementary literature analysis. The supplementary analysis allowed us to focus deeper on the herding phenomenon beyond the use of terminology by assembling all existing empirical findings to date. Our conclusions and recommendations regarding the suitability of the term herding are mostly grounded in this secondary analysis.

3. Quotes on the Term 'Panic'

The original quotes on the term panic have been listed and analysed in Table 5 in Appendix. The extracted quotes on the term panic were subsequently analysed and after identifying the common themes across the quotes; they were categorised into 22 reduced comments. Table 1 lists these reduced comments along with the frequency of their occurrence in the original comments extracted on the term panic. The table also shows how many times each theme has been repeated in studies across the three different disciplines we considered (i.e., social sciences, physical sciences, and

Table 1: Reduced comments on the term panic and their frequency among the original quotes.

No.	Comment	Frq.	Discipline				Study type	
			Soc.	Phys.	Bio.	Mod.	Emp. Test.	Conc.
1	Panic is common occurrence in the face of imminent danger	4	1	3	0	3	1	0
2	Panic is a very pervasive assumption in modelling literature	6	6	0	0	0	1	6
3	Panic is rare occurrence in the face of imminent danger	1	0	1	0	1	0	0
4	Panic is a cause of injuries in crises	13	3	10	0	7	2	6
5	Panic can affect evacuation efficiency, in both beneficial or detrimental ways	1	0	1	0	1	0	0
6	Panic can affect evacuation efficiency	7	1	6	0	4	0	3
7	Panic is manifested as random (erratic) behaviour (chaos)	4	1	3	0	2	0	2
8	Panic is manifested as increased stress (nervousness/fear)	6	2	4	0	4	1	4
9	Panic is manifested as imitative (herd) behaviour	7	1	6	0	7	1	2
10	Panic is manifested as elevated physical competition	9	1	8	0	8	0	3
11	Panic is manifested as non-humanistic behaviour	5	4	1	0	0	1	4
12	Panic can occur without any distinguishable cause	1	0	1	0	1	0	0
13	Panic lacks a clear definition	12	11	1	0	1	4	11
14	Panic is common media language	6	5	1	0	1	2	5
15	Panic can be represented by simple parameters in simulation models	4	0	4	0	4	0	1
16	Panic theory lacks empirical support	27	22	5	0	4	10	23
17	Panic leads to imbalanced utilisation of exits	3	1	2	0	0	0	3
18	Panic leads to exit blockages	6	0	6	0	6	0	2
19	There are various kinds of panic	4	2	2	0	2	2	4
20	Social affiliation theory presents an alternative to the panic theory	7	7	0	0	0	2	6
21	Panic theory has significant implications for crowd management	3	3	0	0	0	0	3
22	What seems to be panic behaviour, may be individual's best perceived course of action	2	2	0	0	0	0	2

"Frq." indicates *frequency*.
"Soc.", "Phys.", and "Bio.", respectively, indicate *social sciences*, *physical sciences*. and *biological sciences*.
"Mod.", "Emp. Test.", and "Conc.", respectively, indicate *modelling*, *empirical testing*, and *conceptualisation*.

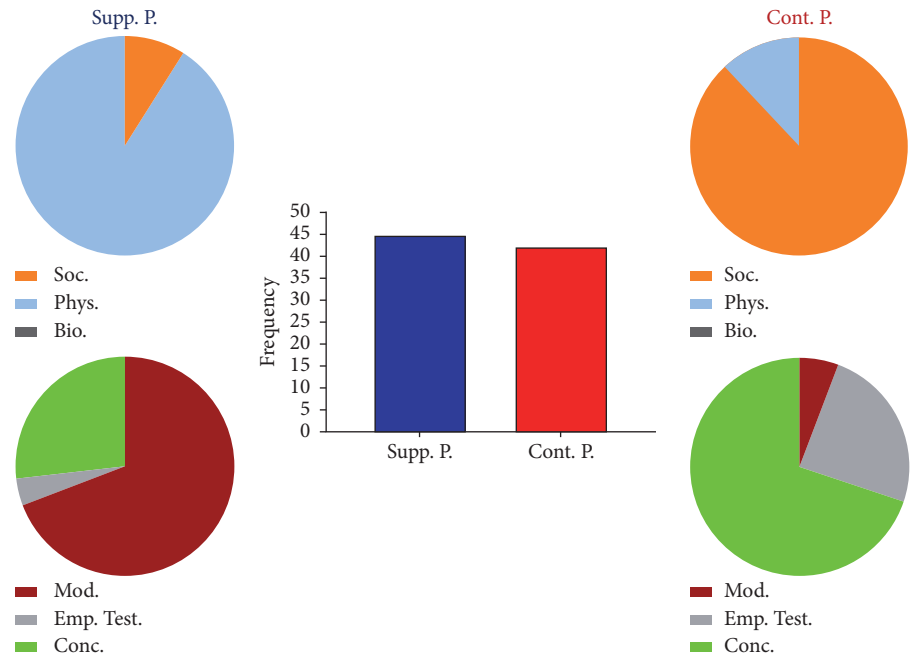

Figure 1: Visualising the frequency of quotes on the term panic that convey support for the theory versus those that challenge it. The pie charts on the left show the frequency of the supporting comments across the disciplines (on the top) and across the study types (in the bottom). Similarly, the pie charts on the right show the frequency of the contradicting comments again across the disciplines (on the top) and across the study types (in the bottom). The column chart in the middle compares the frequency of these comments in total regardless of the discipline or type of the study from which the comments were extracted.

biological sciences) as well as across the three different study types that we considered (i.e., modelling, empirical testing, and conceptualisation). Figure 1 visualises the frequency of the quotes that indicate support for the panic theory versus those that challenge (or contradict) the theory, again across disciplines, and across study types. Figure 2 illustrates the outcome of a temporal analysis on the frequency of the quotes.

One of the most recurring themes in the extracted comments on the term panic concerns the fact that the theory of panic is not well supported by empirical testing [7, 8] (comment #16 in Table 1). Out of nearly 112 comments extracted on the term panic, this theme repeated 27 times. According to Table 1, the majority of such comments originated from studies in the social sciences. Another theme that was very common among the quotes was statements indicating that panic in and of itself is a major cause of injury in emergency incidents and crises and can aggravate the harm caused by the actual crisis [9, 10]. Quotes of this nature were repeated in 13 cases according to Table 1 (comment #4) and the majority of the quotes originated from modelling-type studies published within the domains of physical sciences. Third in this ranking was a noticeable set of quotes that pointed out to a major problem regarding the use of panic in evacuation modelling; the fact that the literature has so far not been able to produce a unified definition for the term panic and that has left the theory of panic largely unverifiable and subject to mere speculation and debate [11, 12]. This comment (#13 in Table 1) was repeated in 12 cases in the quotes extracted on the term panic and again is one of the areas along which the social and physical science studies divide. The vast majority of the quotes that pointed this issue out were obtained from the social science and conceptualisation studies whereas modelling studies have largely downplayed this problem. This highlights a major problem for modelling practice that aim to represent the so-called panic behaviour in their modelling formulations. In the absence of a clear definition on what panic means, efforts to mathematically represent it in the models will largely be subject to the interpretation of the modeller. In addition, even in the domain of social sciences, panic has a very broad definition ranging from aspects such as extreme emotions, groundless fear, uncontrolled flight behaviour, impatience, the quick transmission of excessive fear (i.e., emotional contagion), or the disappearance of normal social bonds [13]. According to Quarantelli [5], early definitions in sociology textbooks and articles view panic as "the crowd in dissolution" or "collective flight based on a hysterical belief" or "dysfunctional escape behavior generated by fortuitous, ever varying circumstances, but involving impending danger". The author also continues to point out that "early approaches to panic were vague in defining the phenomena. However, most formulations view panic as either extreme and groundless fear, or flight behavior". The inconsistency and the variety of the definitions make the practice of integrating them with predictive models (as aimed by physical scientists working in this domain) more arbitrary and rather subjective.

Of those studies that attempted to offer some definitions on the term panic, we found quotes indicating that panic refers to random, unhinged and erratic behaviour [14]

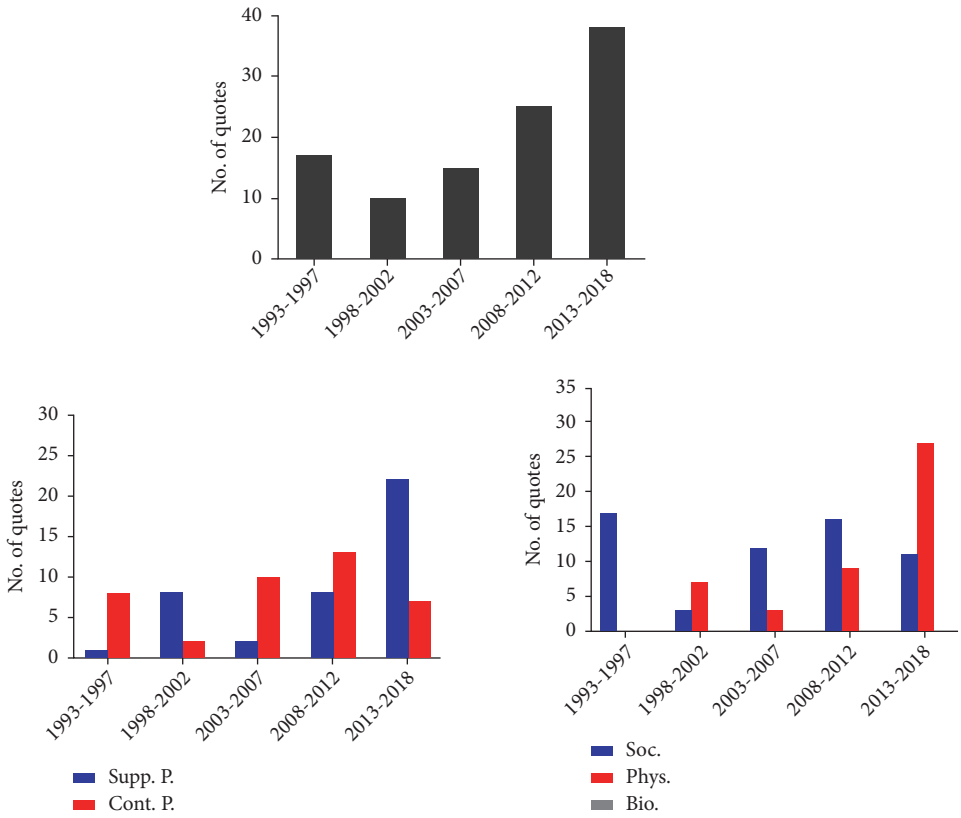

Figure 2: Visualising temporal analyses on quotes that include the term panic. The column chart on the top represents the total number of quotes and the one in the bottom splits the frequency based on whether the quotes support or contradict the theory (chart on the left) and based on the study discipline (chart on the right). To account for the fact that the last time interval includes 6 years as opposed to the rest of the time intervals that include 5 years, the numbers associated with the last interval have been scaled down by a factor of 5/6. The very few studies covered by this review and published prior to 1993 or in 2019 we accommodated in the first and last intervals, respectively.

(comment #7 in Table 1), comments that referred to panic simply as an extreme state of fear or stress during emergencies [11] (comment #8 in Table 1), and also those that described panic manifested as nonhumanistic behaviour [15], imitative behaviour [16], or physically competitive behaviour [17]. It is unlikely that all these conditions can exist at the same time which suggests the theory of panic is not clearly defined and has remained so for many years. The mere fact that modellers try to represent panic using model parameters [18] per se contradicts the idea that panic means people showing random behaviour, because something that is completely random cannot be modelled or predicted. Also, the idea that panic is accompanied by an increased tendency to follow the crowd [19] further contradicts the idea of random behaviour, because following the majority is itself a strategy and is not a random act.

The social identity and the affiliative behaviour theory [13, 15] proposed by social scientists present arguments against the point of view of the mass panic theory as selfish and uncontrolled behaviour. In contrast to the panic theory, social psychologists have in recent years developed and tested a conceptual model of affiliative collective behaviour in emergencies and disasters that explains how "a sense of common fate is the source of an emergent shared social identity among survivors, which in turn provides the motivation to give social support to others affected". [13]

Similarly, the studies that attribute the inefficiency of crowd evacuation behaviour and the occurrence of exit blockages to the increased physical competitiveness caused by panic have also been challenged by recent empirical work that suggests increased physical competition does not necessarily translate to inefficient egress processes [20–22]. Related to this interpretation (or manifestation) of panic behaviour, Heliövaara, Ehtamo, Helbing, and Korhonen [23] have pointed out that "In the literature of social psychology, the pushing behavior is often related to panic. Panic occurs in situations of scarce and dwindling resources and panicking people tend to behave irrationally and adopt a selfish attitude. However, there has been a consensus for decades that actual panic occurs rarely in real crowds and evacuating people tend to behave rationally".

Another common theme that does not come at the top of the list in terms of the frequency of repeating in the quotes but points to an important problem is comment #21 which recognises that "panic theory has significant implications for crowd management" [24]. It pertinently reminds us of the implication that the term panic and the assumptions that it implies may have on how managers and emergency

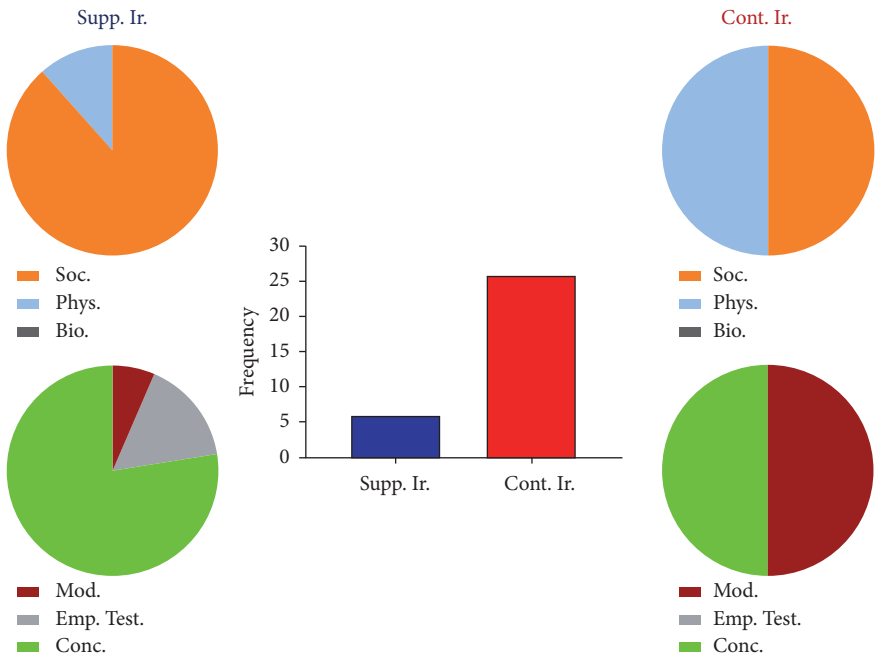

Figure 3: Visualising the frequency of quotes on the term irrationality that convey support for the theory versus those that challenge it. The pie charts on the left show the frequency of the supporting comments across the disciplines (on the top) and across the study types (in the bottom). Similarly, the pie charts on the right show the frequency of the contradicting comments again across the disciplines (on the top) and across the study types (in the bottom). The column chart in the middle compares the frequency of these comments in total regardless of the discipline or type of the study from which the comments were extracted.

responders decide to communicate information to the crowd in incidents of emergency. It recognises that this assumption may be used as a justification to withhold information from the crowd in order to avoid panic and minimise the harm that it may cause. As Heide [25] has pointed out, "The problem with the panic misconception is that the public, the media, and even emergency planners and public officials believe it. Because of this, officials may hesitate to issue warnings because they are convinced that the resulting panic will cause more damage than the disaster itself". He also continues that "this belief has led to recommendations to avoid panic by (1) providing minimal information to occupants in the event of a building fire and (2) carrying on normal activities until the last possible moment". Similar concern has been voiced by Proulx [26] who has stated that "During emergencies, the anticipation of mass 'panic' has been a favoured argument to delay warning the public". This group of studies that pointed to this problem argue extensively that withholding information from potential evacuees cannot reasonably be the best course of action in emergencies [24, 25].

The plots presented in Figure 1 provide an illustration of the divide that exists between social science and physical science studies on how they view the term panic. While the quotes extracted in this review show a relatively balanced split in terms of the number of quotes that support the theory of mass panic versus those that contradict it, a clear difference is noticeable when a comparison is made across the disciplines or across the study types. According to these plots, while the majority of the quotes obtained from studies in the domain of physical sciences (mostly, modelling studies) treat the existence of panic as a proven fact, the situation is completely reverse when one considers the quotes extracted from the studies published by social scientists on this topic. Modelling studies have predominantly tried to represent a partial representation of what is known as panic behaviour in their mathematical formulations using simple parameters (that make agents show more noisy behaviour, or more imitative behaviour or more physically competitive behaviour) while assuming panic and its characterisation as proven by their predecessor studies, whereas social scientists have placed a heavier focus on identifying empirical evidence that supports the idea of collective panic behaviour in mass emergencies and have in most cases failed to observe such evidence [27, 28].

The temporal analysis presented in Figure 2 further highlights this disconnect between disciplines in how they view the term panic. It further illustrates that, despite the increasing debate on the appropriateness of this term in evacuation literature, the term is increasingly appearing in the scientific literature. According to the set of quotes extracted in this review, while the use of the term among these quotes shows a relatively stable pattern that the social science studies in terms of the frequency of mention, its frequency of being mentioned has surged among the modelling studies. It is also interesting to note, at least among the quotes that were extracted here, that there is no mention of the term panic in physical science studies published prior to year 2000.

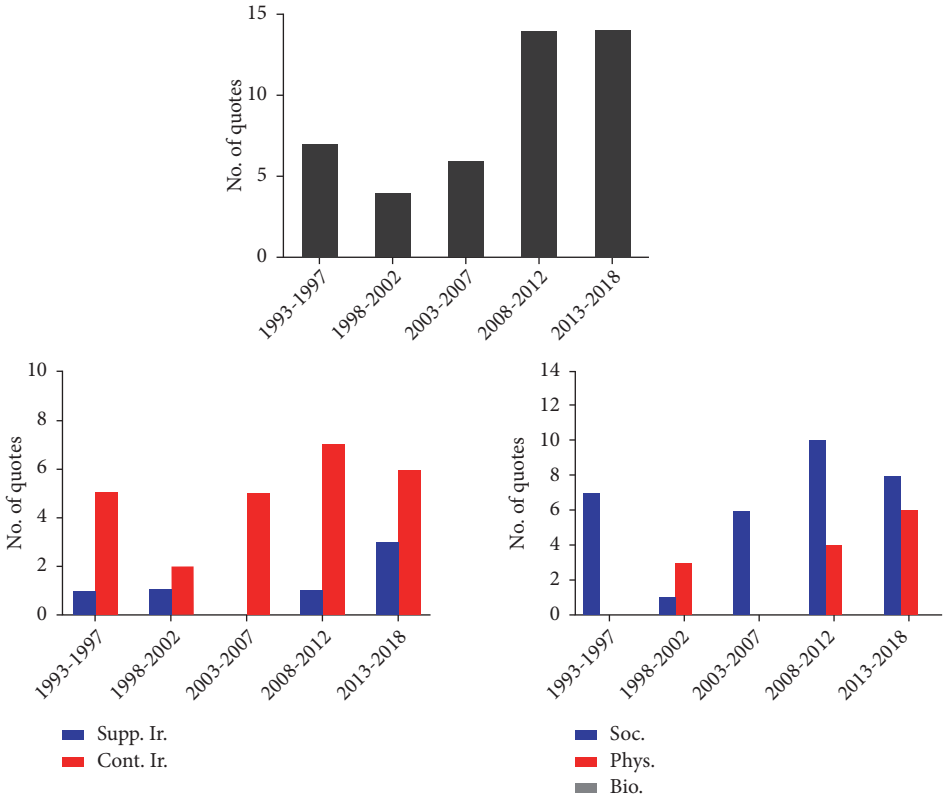

Figure 4: Visualising temporal analyses on quotes that include the term irrationality. The column chart on the top represents the total number of quotes and the ones in the bottom splits the frequency based on whether the quotes support or contradict the theory (chart on the left) and based on the study discipline (chart on the right). To account for the fact that the last time interval includes 6 years as opposed to the rest of the time intervals that include 5 years, the numbers associated with the last interval have been scaled down by a factor of 5/6. The very few studies covered by this review and published prior to 1993 or in 2019 we accommodated in the first and last intervals respectively.

4. Quotes on the Term 'Irrationality'

The original quotes extracted on the term irrationality are listed in Table 6 in Appendix where similar type of categorisation has been conducted to that of the panic term as explained in the previous section. These quotes were categorised subsequently into 11 common themes presented as reduced comments on the term irrationality in Table 2. Figure 3 provides a visual illustration of the frequency of the comments on the term irrationality based on the total set of comments, the discipline of their origin and the type of their study of origin. And Figure 4 provides the outcome of a temporal analysis on these comments based on the year of publication for their study of origin.

The most common theme that was observable among the quotes that were extracted in this work were those that attribute irrationality very closely to panic, by stating that making irrational decisions is one of the aspects of collective panic (comment #1 in Table 2) [29]. In other words, these were the comments which suggest that panic implies irrational behaviour too. According to Quarantelli [5], for example, "present day discussions about panic also revolve around whether or not the behavior is irrational, and whether it is highly contagious or not". We also found a relatively substantial number of quotes challenging the theory of irrationality and stating that the theory cannot be regarded as an accurate and verifiable description of a behavioural phenomenon in the face of threats [15, 30, 31]. This comment was the second most common in the list of reduced comments on irrationality (comment #7).

Another group of statements pointed to a set of very important dimensions which are often neglected in discussions of the topic of irrational behaviour and that includes (1) irrational from whose perspective and (2) irrational relative to which reference point. These statements are collectively reflected in comments #9, 10, and 11. As pointed out by Drury, Novelli, and Stott [24], "To judge a response as irrational requires a frame of reference, but the frame of reference is often unclear in a mass emergency". Therefore, it is not sufficient to merely talk about the rationality of human responses without measuring the effectiveness of the response relative to a proper reference point and that is an element that is often missing from the discussions on this topic. How such a reference point can be set and how the efficiency or rationality or optimality of behaviour can be measured against it is certainly a matter of research in this area [32], but its necessity seems to be indisputable. Further on that issue, a considerable number of studies that were reviewed pointed out that what seems an irrational act may be an individual's best perceived course of action. Drury,

Table 2: Reduced comments on the term irrationality and their frequency among the original quotes.

No.	Comment	Frq.	Discipline			Study type		
			Soc.	Phys.	Bio.	Mod.	Emp. Test.	Conc.
1	Irrational behaviour is a symptom of panic	10	9	1	0	1	1	9
2	Herding is a sign of irrational behaviour	4	1	3	0	3	0	1
3	Choosing familiar exits is a sign of irrational behaviour	1	0	1	0	1	0	0
4	People can maintain rationality during crises	3	0	3	0	2	1	1
5	Irrationality means deciding randomly	1	0	1	0	1	0	0
6	Rationality is associated with evacuation efficiency	7	3	3	1	3	0	5
7	Irrationality is not an accurate theory for evacuation behaviour	9	9	0	0	0	2	9
8	Irrationality theory has significant implications for crowd management	6	6	0	0	0	0	6
9	Measuring rationality requires a reference point	3	3	0	0	0	0	3
10	What seems irrational act, may be individual's best perceived course of action	7	6	1	0	0	2	6
11	Irrationality lacks a clear definition	1	1	0	0	0	1	1

"Frq." indicates *frequency*
"Soc.", "Phys.", and "Bio.", respectively, indicate *social sciences*, *physical sciences,* and *biological sciences.*
"Mod.", "Emp. Test.", and "Conc.", respectively, indicate *modelling*, *empirical testing,* and *conceptualisation*.

Novelli, and Stott [24] stated that "Fleeing, fear, screaming or other responses to perceived danger may therefore be entirely reasonable [rational] given the limited information – and limited choices – available to people in the midst of an emergency". In a more recent study, Drury [13] further elaborates on the importance of taking into consideration who judges the behaviour as irrational. He points out that "what appears post hoc and from an external perspective to be an overreaction (such as running frantically following a bomb blast) might be reasonable and proportionate from the perspective of those involved". Similarly, Kelley, Condry Jr, Dahlke, and Hill [33] mentioned that "The individual is no less rational or moral in the panic than in any other situation. He is always in pursuit of his own interests and acts on the basis of his current estimates of where these lie". The comment by Sheppard, Rubin, Wardman, and Wessely [34] stating that "Incorrect decision-making due to incomplete information or insufficient resources is not the same as irrational decision-making and as such is not sufficient to categorise someone as panicking" as well as the conclusion of the study of Heliövaara, Ehtamo, Helbing, and Korhonen [23] stating that "The jams created at bottlenecks along the exit route are often considered to be caused by irrational behavior, a state of psychological panic. However, this study shows that, under threatening conditions, clogging may be caused by crowd members who act rationally according to simple and intuitive assumptions" are also along those lines. Further to that, we also suggest that the research in this area needs to differentiate between what is traditionally known as "social optimum" versus "individualistic optimum" in scenarios where humans interact with one another in their decision-making and particularly those in which they compete for limited resources (which is the case in situations of emergency with the resources being the limited capacity for escape) [35]. In such systems, these two types of optimums often do not coincide with each other. What is optimum course of action from an individual decision-making perspective may not necessarily be the optimum behaviour from a system perspective. We suggest that this is another dimension that needs to be considered in conversations on this topic and in moving towards more operational definitions for rationality.

The plots shown in Figures 3 and 4 demonstrate that, similar to the term panic, the use of the term irrationality in studies of evacuation is increasing according to the quotes collected in this work. These figures, compared to Figures 1 and 2, demonstrate that there were lesser numbers of mentions of the term irrationality compared to that of panic, according to the references that we reviewed. However, there is a relatively higher percentage of the quotes that do not support the theory of collective irrationality in escape scenarios compared to the nearly even split that was identified on the term panic (the column charts in the middle). In other words, irrationality appears to be a less popular and less common term in the studies that we surveyed in this review and is cited much less frequently in modelling studies especially compared to the term panic which appears to be more pervasive. We only had a handful of quotes that supported the theory of irrationality, whereas we extracted a relatively considerable number of quotes, 26 quotes, challenging this idea, and those quotes split evenly between the social and physical science studies according to Figure 3.

5. Quotes on the Term 'Herding'

The original quotes on the term herding have been listed in Table 7 in Appendix. In addition to the analysis on the quotes that have mentioned this term, a detailed analysis was conducted on empirical studies about the herding assumption in evacuations. Figure 5 provides a visual illustration of the frequency of the comments on the term herding based on the total set of comments, the discipline of their origin and the type of their study of origin. And Figure 6 provides the outcome of a temporal analysis on these comments based on the year of publication for their study of origin.

The most common theme across the set of quotes that we analysed was related to the definition of the term herding in evacuation. According to these quotes, herding in evacuation refers to an increased tendency to follow the crowd, or more specifically to imitate the action of the majority [36, 37]. This theme was repeated in 15 quotes out of 72 quotes that were identified on this term (comment #18 in Table 3). Unlike the set of quotes on the term panic and irrationality that did not provide any consensus in terms of the definition and rather added to the mixture on the definition of these terms, the quotes on herding indicated that the majority of studies perceive this term in a roughly similar way. This is of course beside the point of how accurate or suitable this term is for application in evacuation research which is a matter we will discuss below. It merely reflects and describes the current state of the literature and the dominant view on how this term is used and what it refers to.

Another common theme among the quotes we obtained was the use of imbalanced utilisation of exits observed in crowd escape scenarios (regardless of how likely that is to occur) as evidence for herding [17, 38, 39]. This constitutes the reduced comment #20 in Table 3 that was repeated 11 times across all the quotes. The statements reflected by this reduced comment basically assumed that if the crowd shows an imbalance in the utilisation of exits in spaces where there are multiple exit options, then that can be regarded as evidence that individuals within the crowd tend to copy the action of majority. However, whether this imbalanced use of exit capacities stems from an inherent tendency for copying the action of the majority (that individuals made a conscious decision to follow the crowd) or is attributable to other reasons is a matter of debate which will be discussed in more detail in the following sections [40–42].

A considerable body of studies that we reviewed provided comments that indicate herd behaviour, as a feature of escape panic, is a common form of behaviour in evacuations and thus it should be a common assumption for numerical modelling (i.e., numerical models need to produce herding effect in order to be deemed realistic) [18, 43–46]. These are collectively reflected in reduced comments #1, 2, 4, and 6 in Table 3. While we leave examination of the validity of this assumption to our discussion on empirical studies, we only mention here that as opposed to these abundant set of

Table 3: Reduced comments on the term herding and their frequency among the original quotes.

No.	Comment	Frq.	Discipline			Study type		
			Soc.	Phys.	Bio.	Mod.	Emp. Test.	Conc.
1	Herding is a feature of panic behaviour	10	1	7	2	7	3	1
2	Herding is common evacuation behaviour	10	1	7	2	7	3	0
3	Herding is not common evacuation behaviour	3	1	1	1	0	3	0
4	Herding is common modeling assumption	6	0	6	0	5	1	0
5	Pure herding is not an accurate modeling assumption	1	0	1	0	0	1	0
6	Producing herding effects is a common criterion for verifying simulation models	1	0	1	0	1	0	0
7	Herding can be beneficial to evacuation efficiency	1	0	1	0	1	0	0
8	The effect of herding on evacuation efficiency is unclear	3	0	3	0	1	2	0
9	Herding is detrimental to evacuation efficiency	5	0	4	1	4	1	0
10	Mixture of herding and individualistic behavior is beneficial to evacuations	1	0	0	1	0	1	0
11	Stress increases herding tendency	3	0	3	0	1	2	0
12	Stress does not increase imitation tendency	1	0	1	1	0	1	0
13	Herding tendency is moderated by stress level	1	0	1	0	0	1	0
14	Herding tendency is moderated by the crowdedness level	3	0	3	0	0	3	0
15	Herding tendency is moderated by the level of uncertainty	8	0	7	1	4	4	0
16	Herding results from following neighbours	1	0	1	0	0	1	0
17	Herding is not the same as imitation	2	1	1	0	0	2	0
18	Herding means imitating/following others/majority	15	0	12	3	9	6	0
19	Herding is observable in movement initiation	1	0	1	0	0	1	0
20	Imbalanced use of exits is evidence for herding	11	0	7	4	5	6	0
21	Herding theory in evacuation has been influenced by animal models of behaviour	7	0	1	6	1	6	0
22	Herding tendency should be considered in conjunction with individual differences	2	0	2	0	0	2	0
23	Herding theory is in need of empirical testing	1	0	0	1	0	1	0

"Frq." indicates *frequency*.
"Soc.", "Phys.", and "Bio.", respectively, indicate *social sciences*, *physical sciences,* and *biological sciences*.
"Mod.", "Emp. Test.", and "Conc.", respectively, indicate *modelling*, *empirical testing,* and *conceptualisation*.

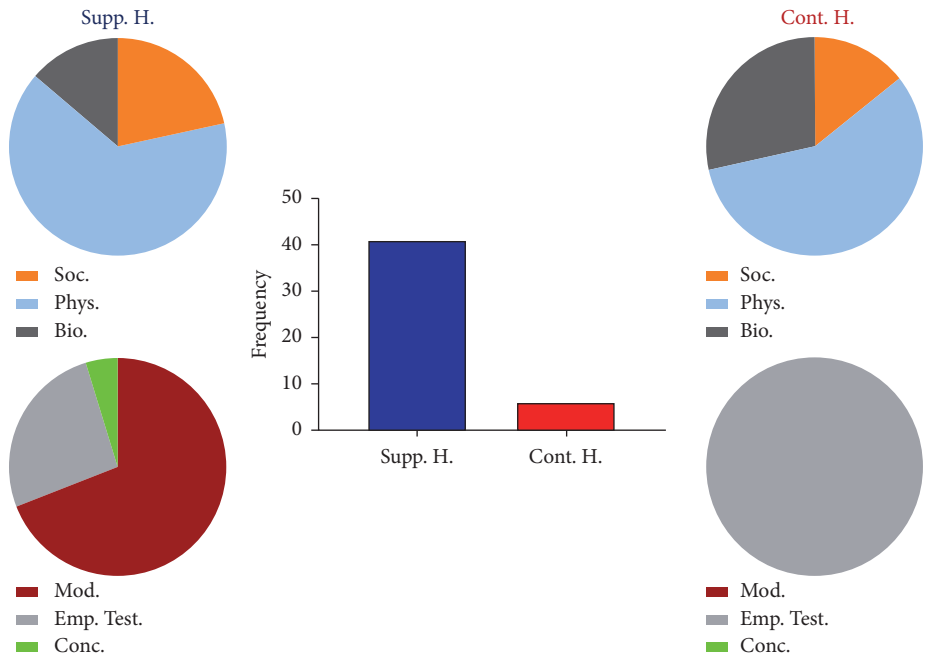

Figure 5: Visualising the frequency of quotes on the term herding that convey support for the theory versus those that challenge it. The pie charts on the left show the frequency of the supporting comments across the disciplines (on the top) and across the study types (in the bottom). Similarly, the pie charts on the right show the frequency of the contradicting comments again across the disciplines (on the top) and across the study types (in the bottom). The column chart in the middle compares the frequency of these comments in total regardless of the discipline or type of the study from which the comments were extracted.

comments, we had quotes that provided a different view and disregarded the assumption that people show herd mentality in escape situations [47] in addition to quotes from studies that recognise that unless people face substantial amount of uncertainty in their surroundings, they will not be likely to take imitative actions [48].

A number of quotes that we extracted considered how herding tendencies influences efficiency of collective crowd egress. These quotes ranged from suggesting that herding behaviour is a detriment to efficient evacuations [37, 49] to those that believe this effect is still unestablished [39, 40, 50] and that there may be scenarios where herding tendencies are beneficial to an escaping crowd [18]. The subset of these quotes that have not been derived from any simulating testing and are more of a speculative nature did not made it clear which aspect of evacuation decision-making they refer to when connecting herding to the escape efficiency. This is basically a distinction that has not thus far been common in the literature. In line with this question, the phenomenon of mixed strategy (i.e., mixture of herding and individualistic behaviour) has been investigated by several numerical studies. A number of those findings reflect on the findings of such studies. These studies have also contributed a mixture of evidence to the literature with some suggesting that a crowd can benefit from mixed strategies [19] and some suggesting that any percentage of herding strategy within the crowd has a negative impact on the evacuation efficiency [51].

The plots in Figure 5 suggest that unlike panic and irrationality, the herding terminology is a much better accepted term in the crowd dynamics literature. We found many quotes that support this theory and this is far more common among the modelling studies published in the physical science domain. However, the temporal analysis in Figure 6 reveals that firstly, the number of quotes on the term herding shows a surge in the more recent publications and secondly, those that contradict or challenge the herding theory (or the terminology) have only emerged within the last five years and that could be attributable to the rapid increase in the empirical studies within that period many of which observed evidence that did not support this theory [41, 48, 52]

6. Experimental Findings on 'Herding'

Unlike the terms of panic and irrationality for which a lack of clear definition was one of the most noticeable aspects of our review, the term herding has a clearer, although largely implicit, definition in the literature. The majority of the quotes indicated that this term is used to describe imitation behaviour or the act of following others. Whether the 'following' specifically means copying the action of the 'majority' was less clear. Nevertheless, given this higher clarity of meaning, the hypothesis of herding behaviour (or as we prefer to say, the role of social influence) has been more operationalizable and this has allowed the hypothesis to be empirically tested in various forms by considerable number of studies mostly published within the last five years. Here, we comprehensively review these studies and their findings to see what we currently know about this behavioural theory. We

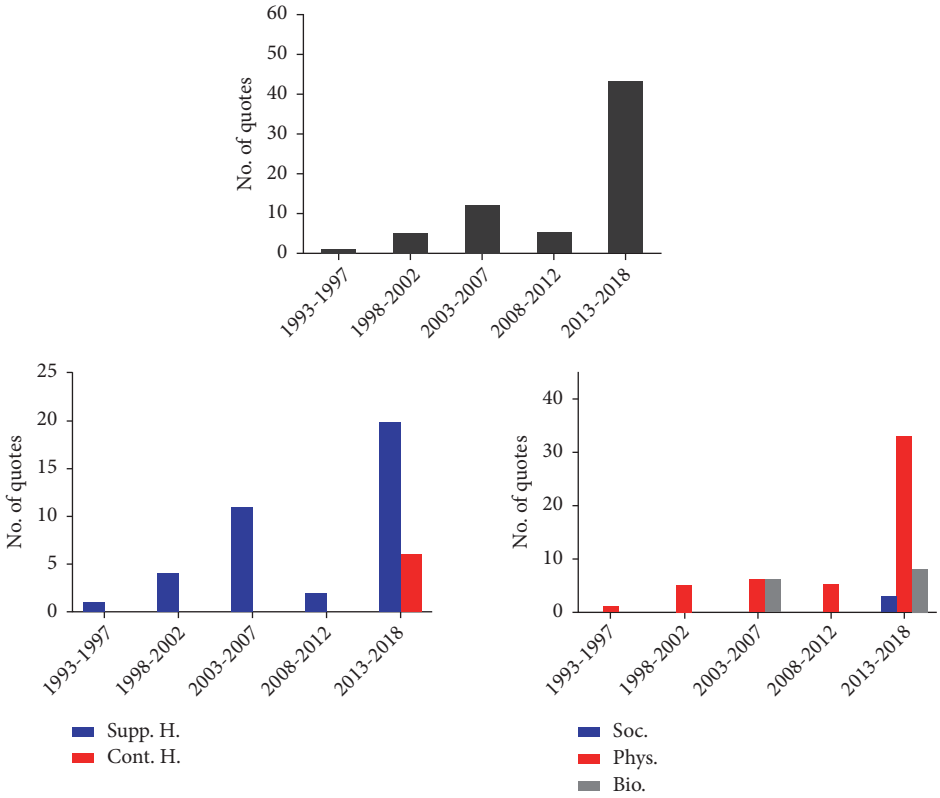

Figure 6: Visualising temporal analyses on quotes that include the term herding. The column chart on the top represents the total number of quotes and the ones in the bottom splits the frequency based on whether the quotes support or contradict the theory (chart on the left) and based on the study discipline (chart on the right). To account for the fact that the last time interval includes 6 years as opposed to the rest of the time intervals that include 5 years, the numbers associated with the last interval have been scaled down by a factor of 5/6. The very few studies covered by this review and published prior to 1993 or in 2019 we accommodated in the first and last intervals, respectively.

also discuss the variety of terminologies that have been used to describe this phenomenon along with their implications.

The set of studies that we reviewed often identify as experiments on peer effect, social influence or neighbour effect in evacuations [53–56] and some directly frame the study as an investigation of herding behaviour [50, 57]. This section provides a comprehensive review of these studies. In total, 24 studies were identified on this topic which have used empirical data of some form. The characteristics of these studies were analysed and subsequently summarised in Table 8 in Appendix. This table shows four main aspects or dimensions of each of these studies: (i) what aspect of the evacuation behaviour was investigated in relation to the peer effect, (ii) what method they used for their data collection (this could be virtual-reality, real crowds, or nonhuman crowd experiments), (iii) did the study find evidence of herding effect (which according to the majority of the body of studies, refers to imitative behaviour), and (iv) what is the main interesting aspect of their findings (this part is provided as a short comment alongside each reference). This analysis is the first to officially recognise that studies and discussions on herding in evacuation should be performed in relation to specific aspects of evacuee's decisions as opposed to discussing the topic in broad terms such as whether people generally show an amplified tendency towards mass behaviour (in all aspects of their decision-making). We have identified and reported the specific aspect of the decision-making that has been investigated in connection with peer influence for each of the studies listed in Table 8 .

6.1. Definitions and Alternative Terminologies for Herding. As mentioned previously, the problem has been framed using a range of terminologies such as imitation [49], allelomimetic behaviour, or allomimetic behaviour [46] (defined as a range of activities in which the performance of a behaviour increases the probability of that behaviour being performed by other nearby animals), social influence [54, 55], peer behaviour effect [53], neighbour behaviour effect [56], follow-the-crowd behaviour [48], and of course, herding or herd-type behaviour [41, 50, 52, 57, 58]. The phenomenon is also referred to by a substantial body of studies as "symmetry breaking" [42, 59–62]. From a linguistic perspective, however, the term does not exactly equate imitation. According to the Longman Dictionary [63], the verb "herd" means "to bring people together in a large group" or "to make animals move together in a group". However, as shown in the previous section, the term is used almost as a substitute for "imitation" in the crowd dynamics literature.

As a pioneer study in the field of crowd dynamics Helbing, Farkas, and Vicsek [19] discussed the phenomenon and

introduced it to numerical simulations. In their conceptualisations "pure herding behaviour implies that the entire crowd will eventually move into the same and probably blocked direction, so that available exits are not efficiently used". These numerical testings were conducted in relation to a simulated room with two exits. Therefore, we assume that the term herding in its original form was specifically used in relation to exit choice behaviour. And this is in fact a common characteristic of the main body of studies that have so far investigated the herding assumption using empirical methods. They predominantly interpret herding in the context of exit choice making. However, the literature has been increasingly recognising the role of social influence in other aspects of evacuation decision-making and a few studies have looked into this problem in connection with reaction responses of evacuees [55, 58, 64] and exit choice adaptation (or exit choice changing) behaviour [65, 66] of evacuees. Hence, in our analysis of the 24 empirical studies on this topic, we have categorised each item into one (or occasionally two) of these three categories: exit (direction) choice, exit (direction) choice changing, and reaction times. We also identified four general experimental methods that have been adopted to study this topic: human crowd (laboratory or evacuation drill) experiments, virtual-reality experiments, experiments with groups of ants, and experiments with groups of mice (as analogical experiments of human crowds).

In the following subsections, we first investigate the origins of the term herding in crowd dynamics and review the first experiments (predominantly based on social insects) which referred to this notion as the 'symmetry breaking' phenomenon. We subsequently review the findings of empirical studies that investigated the role of the social influence in relation to each of the three behavioural sublayers that identified earlier. We then discuss two questions in subsections that follow: (1) can observations of herding with social insects or animals be reliably extrapolated to humans and (2) is the term herding itself a suitable terminology to be used in crowd dynamics.

6.2. Herding and Symmetry Breaking. The first attempt to empirically test the herding assumption in the context of crowd escape dates back to 2005 (five years after the publication of the pioneer paper in *Nature* [19]) where a study published by *American Naturalist* reported on observing "symmetry breaking" effects in experiments with groups of ants [62]. According to the authors, "The phenomenon of herding is a very general feature of the collective behavior of many species in panic conditions, including humans" and this statement constitutes the main premise of their study. The authors observed in this work that groups of ants confined in a chamber show an elevated level of imbalanced exit utilisation when repelled by an aversive stimulus (a certain dose of repellent chemical) and inferred that as a sign that herding phenomenon exists in collective escape scenarios and that the behaviour is shared across a range of species including humans: "Our experimental results, combined with theoretical models, suggest that some features of the collective behavior of humans and ants can be quite similar when escaping under panic." Another statement that the authors have made in their study is that "It has been predicted theoretically that panic induced herding in individuals confined to a room can produce a nonsymmetrical use of two identical exit doors". In evaluating this statement, we argue on a major factor that seems to have been neglected and that is the differentiation between exogenous and endogenous modelling assumptions in numerical simulation methods. The assumption of herding in Helbing, Farkas, and Vicsek [19] was clearly an exogenous assumption meaning that the authors formulated and imposed this assumption in the formulation of their numerical model. Clearly, when one formulates a certain type of phenomenon in the form of mathematical models and implements that model, observing that phenomenon (formulated exogenously) cannot reasonably be regarded as a proof of that phenomenon. We believe that this is a distinction that in a number of cases like this the literature has failed to make when concluding from numerical studies in this field in general. The conclusion from this study has also been cited as an evidence that greater levels of stress and urgency make humans to be more inclined towards imitating the majority's action in an emergency escape context.

The assumption and terminology of symmetry breaking were subsequently followed up by further studies that adopted the ant experiment technique and often made variations to the type of the aversive stimulus [61]. This includes the study of Chung and Lin [59] where using controlled heat-induced aversive stimulus, they observed that the degree of asymmetry increased linearly with the temperature, and also the study of Li, Huan, Roehner, Xu, Zeng, Di, and Han [60] who investigated the effect of density on the extent of symmetry breaking and observed that the degree of asymmetry increased then decreased by ants' density. The most recent study of this kind has shown that symmetry breaking is associated with the difference in the width of exits in proportional ways, thereby concluding that there are, in fact, some patterns of symmetry in symmetry breaking phenomenon in ant groups [42].

6.3. Herding in Movement Initiation. Laboratory crowd experiments in virtual and real(istic) environments have increasingly furthered the knowledge on the role of social influence within the recent years [67]. The problem of premovement time in particular has received attention in this context. According to Bode and Codling [68], "Social influence occurs when individuals respond to the behaviour of others and it is an important factor that needs to be considered in research on premovement times in evacuations". The virtual-reality experiments of Kinateder, Müller, Jost, Mühlberger, and Pauli [55] and Van den Berg, van Nes, and Hoogendoorn [58] have both provided evidence on the significant role of peer behaviour effect on reaction to threat (or movement initiation) responses of evacuees. They have shown that the presence of passive virtual agent made subjects delay their movement reaction, the more people someone sees leaving, the more inclined this person is to leave, and that seeing people leave has more impact

than seeing people stay. The two experiments have been conducted at different levels of virtual crowd density and they collectively suggested that evacuees' reaction to an emergency signal is impacted by their neighbours' behaviour and the direction of influence is towards taking imitative actions, regardless of whether or not the crowd in dense. In relation to the premovement time response, we only know of one study in nonvirtual experimental setting and that is the study of Nilsson and Johansson [64] who utilised the data from an evacuation drill in a cinema. According to Galea, Deere, Hopkin, and Xie [69], "a subset of data from these trials was later analysed to explore the impact of social influence of close neighbours on response time" and "the authors did report that response time for an individual was related to that of a neighbour, so that participants acted more like their neighbours than to others". They concluded from their analysis that social influence is an important factor in reaction time, especially when cues about dangers are unclear, and that social influence (on reaction time) increases with decreasing distance between visitors.

In terms of the influence of imitation in movement initiation on evacuation efficiency, we do not know of any study that has empirically tested this question, but a recent numerical study has shown that lesser variability in reaction times (which could be achieved when individuals tend to initiate their movement as soon as their peers/neighbours do so) shortens the duration of the evacuation [70]. And this has been shown to be the case across a variety of density levels (up to extreme densities). This suggests that herding in movement initiation could be a beneficial form of behaviour (although we should mention that numerical evidence to the contrary of this finding also exists [71] suggesting that a "staged" evacuation strategy (or waiting strategy) could be more efficient than instant collective response).

6.4. Herding in Exit Choice. As mentioned earlier, a significant portion of the empirical knowledge on the role of social influence has been obtained from experiments that investigated exit choice behaviour. The experiments reported by Bode and Codling [52] adopted a simplified form of virtual-reality setting in which the subjects have a top-down view of a two-dimensional computer-simulated crowd evacuation scene and control and navigate their simulated agent using mouse clicks while interacting with simulated agents. The setting of this study simulates relatively dense crowd escape scenarios. No distinct pattern of herding behaviour was observed in this study. Experiments of direction/exit choice in three-dimensional forms of virtual-reality have been reported in [54, 55, 72, 73] where the experimental setting often simulated a not-heavily crowded scene. As indicated by the analysis in Table 8 , these studies have generally found evidence for social influence in the direction of imitation. The virtual-reality exit choice experiments reported by Lovreglio, Fonzone, dell'Olio, and Borri [50] have been framed and analysed in the form of discrete choice experiments and represent relatively dense crowds. Using mixed logit models, the authors estimated the relative importance of different factors on exit choice. Their findings suggest that on average social influence, measured as the number of people at exits, reduces the likelihood of exits being selected. Therefore, this study suggests that social influence has an effect, but that the effect is the opposite to what is commonly proposed under the herding assumption. The findings in this work also qualitatively match those reported in [74], derived from an independent discrete choice survey, which again does not support the herding assumption. Another aspect that is shared between these two studies and also the virtual-reality studies of Kinateder, Comunale, and Warren [56] and Bode, Wagoum, and Codling [75] is that they have all produced evidence that suggest exit choice making is a multiattribute trade-off (between time-dependant and time-independent factors [75]). While peer behaviour appears to have significant effect on evacuees' exit decision, it is also traded off with a range of other factors.

These findings have demonstrated that one cannot assume that peer behaviour is the sole determinant of exit choices and that is one of the main reasons we suggest that the term herding may not be the most suitable terminology to be used in this context. First of all, it indicates, by implication, that the influence of observing peer behaviour is always to the direction of imitation (whereas, sometimes the opposite is the case) and secondly, it dismisses the role of other contributing factors that compete with peer behaviour effect. It implies a decision-making mechanism that is predominantly governed by social influence. The overall message of the virtual-reality experiments has been that in not-heavily crowded scenes social influence acts to the direction of imitation and in heavily crowded scenarios the direction of influence largely reverses. But in all those cases, one also needs to take into account the effect of other contributing attributes to the decision-making (other than social influence) as well as the role of individual differences in perceiving the social influence [76].

Recent experiments conducted using crowds of volunteers, particularly those from which individual-level exit choice observations were extracted [48], generally confirm the findings of the virtual-reality experiments discussed above. Particularly, the presence of multiattribute trade-off between a set of factors that include peer influence appears to be a recurring theme in all those studies [77]. In highly dense laboratory crowd experiments, the dominant pattern of exit choice behaviour has been avoiding the majority [65]. However, Haghani and Sarvi [48] have shown that when attribute ambiguity is introduced, the peer behaviour can act at a positive direction (meaning people tend to perceive direction chosen by majority more positively or at least, less negatively in relation to the alternatives for which attribute ambiguity exists). Therefore, it has been suggested that the influence of peer behaviour in evacuation contexts is moderated by the extent of decision uncertainty that evacuees face.

In a recent study, Haghani and Sarvi [41] tested the effect of urgency level as well as the density level on the perception of peer behaviour and the results overall suggested that none of these factors lead to an increased tendency to imitate others. Under higher levels of simulated urgency or when faced with a larger total number of people, decision-makers became

actually less likely to follow the direction chosen by the majority. In terms of how imitation in exit choices influences egress efficiency, we currently only can resort to the evidence from numerical simulations that suggest any elevated degree of imitation in exit choice making negatively influences total evacuation times. The suggestion from numerical studies is that, when familiar with the location of exits, a crowd of evacuee is best off avoiding a follow-the-majority strategy [49].

6.5. Herding in Exit Choice Adaptation. The empirical evidence on the role of peer effect in how evacuees change/adapt their decisions is very sparse. The topic of decision adaptation [78–80] within the general framework of evacuee's decision-making [81] is in general highly underrepresented in the crowd dynamics literature. In particular, when contrasted with the growing body of studies that have experimented exit choice behaviour within the recent years [56, 75–77, 80, 82–85] very little attention has relatively been paid to the mechanisms of exit choice changing. Proportionately, much less is known about the influence of peer behaviour on this aspect of evacuee's behaviour compared to the influence on exit choice. Recent studies that have experimented this problem, however, have shown that, in crowded evacuation scenarios (where queues form at exits), observing other people changing their exit decisions is a trigger for the observer to change the initial decision and imitate that action [65, 66]. It has been shown in these experiments that once one evacuee decides to leave a queue formed at an exit and join another queue at another exit, it increases the likelihood of decision changing by others followed by a burst of decision changes. This phenomenon, however, even though it indicates imitation, is not precisely consistent with a definition of herding as "following the majority". It is consistent with a definition of herding as "imitating others" but "others" in this case are often the minority. In such scenarios, at any point in time, there are more people not changing their decisions compared to the number of individuals who decide to change their initial choice. Numerical testing in a recent study [86] has also been shown that certain degrees of imitation in exit choice making enhances the efficiency of crowd evacuations from a system perspective.

6.6. Herding and Extrapolation of Behaviour from Social Insects and Animals to Humans. The findings of the experiment reported by Haghani and Sarvi [41], as outlined earlier, may be regarded as evidence opposite the symmetry breaking. The experiment showed that as urgency increases, people show even less tendency to follow the direction chosen by more people. The stark contrast between this experiment and those of the symmetry breaking experiments with ants could be worthy of note. The symmetry breaking phenomenon has been proven with ants through several independent experiments. However, recent evidence is overwhelmingly suggesting that the phenomenon does not seem to be replicable when tested with humans. This might be only one of the areas where the escape behaviour of insects and humans differ fundamentally and thereby, generalisation across the two should be avoided [87].

An implication of identifying such inconsistent observations between collective escape behaviour of insects and humans may be that, wherever possible, behavioural experimentation in this domain should take place with humans as opposed to alternative animals/insects as proxies for humans. In some research the notion can arise that findings from research using social insects can be extrapolated directly to emergency evacuations involving humans. However, there are fundamental differences between species that go beyond obvious physical distinguishing factors. For example, the genetic make-up of ant colonies is largely homogeneous which is likely to affect the trade-off between individual survival and survival of other colony members. This could explain why entire ant colonies reenter previously evacuated nests in an attempt to save their brood (D. Parisi, personal communication), behaviour that is unlikely to occur at this scale in humans.

An argument in response to our proposition is that such experiments are often conducted to help us replicate the sense of real danger which cannot be possibly considered in experiments with human subjects. It should, however, be noted that in many cases, proxies for life-threating dangers, such as creating the sense of urgency using monetary incentives, could be used within the frameworks of ethical experimentation and without imposing any real danger on participants. This possibility could be taken into consideration as offering a trade-off between using a proxy urgency-inducing treatment with real humans (an accepting a certain level of contextual approximation) as opposed to using real urgency-inducing stimuli with animals/insects (and accepting their fundamental behavioural differences as a very different kind of approximation).

6.7. Is 'Herding' an Accurate Terminology? Previous discussions in Section 5 revealed that the term herding is being used in the literature with lesser degrees of inconsistency in terms of the definition, compared to the terms panic and irrationality. According to the quotes that we extracted, most authors use this term as a reference to the act of (blindly/passively) following others. There are alternative interpretations as well, such as 'synchronisation of actions' or 'congregations of people' or 'large groups moving to the same direction'. But these definitions are not as common as 'copying' or 'imitation' or 'conforming to the behaviour of the neighbours or the majority'. However, in light of the empirical findings that we reviewed in this section, here we argue that, despite this relative consistency in definition, the term herding per se lacks accuracy in conveying the meaning that it is meant to embody.

Firstly, herding is a term that has been originally used in relation to animal groups. In that sense, it implicitly coveys an irrational collective unconsciousness where individuals surrender their own wisdom to the group and copy the group blindly (thus, by a stretch of meaning, it may implicitly convey the meaning of 'acting like a group of animals'). In that sense, the term is indeed linked to the panic/irrationality theory which our review suggested to be not so well supported. A change of terminology may help dissociate this concept from panic/irrationality. Further, the mere use of the

term herding in the scientific literature gives the indication that there are similarities between the escape-from-danger responses of humans and those of animals, thereby, justifying experimentation of animals'/insects' behaviour as a proxy for that of humans. As we discussed earlier in Section 6.5, the emerging empirical evidence has not produced much promising evidence for such analogies. Secondly, our review of empirical findings showed that people exhibit various kinds of tendency towards copying or not copying the actions of others in evacuation contexts. Their behaviour appears to be rather complex. For certain aspects of their behaviour (or under certain contextual circumstances), they show tendency to avoid the action of the majority rather than follow. Also, in some cases, they might show imitative tendency but towards the action of the minority rather the majority. The literature is clearly showing that social influence on evacuation behaviour differs depending on the type of action (e.g., movement initiation, direction choice, and decision changing) and also, depending on certain contextual factors (e.g., how crowded the space is and how familiar the occupant is with the surrounding environment), not to mention the role of individual differences in all that. Therefore, there is a great amount of nuance involved in this phenomenon that the term herding fails to capture. The term gives the indications that when we talk about the social influence, we essentially mean 'following others', whereas, the term social/peer/neighbour influence itself maintains neutrality and flexibility in that regard. It embodies both tendencies to follow or to avoid others, as well as tendencies to follow the majority or the minority. For these reasons, we suggest that while the idea behind exploring the role of social influence in evacuation is legitimately valid and even essential, the problem does not need to be formulated as a question about herding. We argue that this term comes with an unnecessary amount of predisposed connotation (partly inherited from the panic theory) as opposed to the nuance, neutrality and flexibility that is required for describing a rather complex phenomenon like this.

7. Discussion

We have adopted a literature survey approach to investigate, in an open-minded way, if preferred or dominant definitions for the three terms we investigate have emerged over time in the literature. While we cannot claim that our literature search is completely exhaustive, we argue that the number of publications included is sufficiently large to adequately support our findings. We acknowledge that the way we have prioritised comments on the terms we investigate within papers and the way we have grouped or reduced comments and categorised supportive or unsupportive comments, as well as the disciplines that publications belong to, is to some extent subjective. We hope that this qualitative analysis is nevertheless a useful synthesis of the complete body of comments we found which we report in full in the Appendix, Tables 5–7. Given the ambiguity/inaccuracy that we found regarding the use of these terms and the lack of empirical evidence for them (except for "herding" which is comparatively a better-defined concept), it was not possible to perform a quantitative meta-analysis or metasynthesis on the evidence pertaining to "panic" and "irrationality". As the empirical base for research into human crowd dynamics continues to grow [6], such meta-analyses will become an attractive option to test the support for specific hypotheses by incorporating evidence across several studies in a similar way to what has been done in other fields of research [88]. However, we anticipate that such an analysis will not be possible for the three terms we discuss here. The unification of behavioural terminologies and hypotheses could be a major useful step towards shaping the literature in that direction.

Our survey of the crowd dynamics literature illustrated that the three terms that we reviewed do not have an unequivocally accepted definition in the literature. This is particularly the case for the terms panic and irrationality. While these terms are still used in increasing numbers of publications, they are also discussed controversially. And in the case of "irrationality", most publications are explicitly critical of the use of this term. An additional and complicating aspect suggested by our literature search is that the terms are used and treated differently in studies from different broad disciplines of research. This is particularly evident for the term "panic" which seems accepted and used (albeit in different ways) in studies which we classified as belonging to the physical sciences but is mostly opposed in studies we classified as belonging to the social sciences. Based on this, we suggest that at present, the use of the three terms "panic", "irrationality" and "herding" in the scientific literature does not contribute constructively to describing, understanding or even predicting evacuation behaviour.

A recent multidisciplinary effort to define terms frequently used in research on pedestrian dynamics does not include definitions for the terms "panic", "irrationality", and "herding" [89]. Instead, this glossary even includes the suggestion that some terms, including "panic", and "herding" that lack a clear definition or could lead to misunderstandings should not be used. This is in line with what we have found by searching the literature extensively for uses of these three terms, as well as the suggestions of several authors in the field of social psychology. As Quarantelli [5] already concluded in a seminal study titled "The sociology of panic" in 2001, "There are two questions that will loom even larger in the future. One is why despite the research evidence, the idea of "panic" captures the popular imagination and continues to be evoked by scholars of human behavior. A second basic question is whether there is still any scientific justification for the continuing use of the concept in any technical sense in the collective behavior area". Our review suggested that the use of these terminologies has not constructively contributed value to the evacuation dynamics literature and if anything, in some cases, the clear lack of definitions for (at least two of) these terms has ambiguated the research field and hampered the efforts of the researchers. Having reviewed the use of these terms, for example, we were not able to identify a definition for the term panic that can be framed as a testable hypothesis. As a result of this issue in this research domain, assumptions have been made that can neither be verified not rejected and computational prediction models have been formulated that cannot be objectively validated.

These issues do not imply that anything loosely related to the three terms cannot be investigated systematically. Our detailed investigation of empirical evidence related to the term "herding" suggests a constructive way forward. While herding is arguably a vague concept, researchers have specified concrete behavioural phenomena instead, such as imitative behaviour, that lend themselves to scientific investigation via observations, experiments or models. In a similar vein, instead of focussing on the high-level ambiguous term "panic", we suggest it is a legitimate question to ask "how intense levels of urgency, stress or fear influence evacuation behaviour", "how optimality of evacuees' decisions can be measured, quantified or improved", "under what circumstances evacuees make more suboptimal decisions", "how observing peer behaviour influences various aspects of evacuee's decisions" or "under what circumstances evacuees are more/less inclined to imitate actions of others". Importantly, framing these questions in the form of ambiguous terms, such as "panic", "irrationality", or "herding", may act as an impedance in scientifically investigating the topics broadly related to the terms by obfuscating an otherwise operationalizable set of questions. In particular, the imprecise assumptions that can accompany these terms may dissuade or divert research from studying these phenomena at the level of nuance that they require. Therefore, we argue that it would be beneficial for the progress of research in this field that the questions related to the three terms discussed here are clearly stated in terms of verifiable hypotheses and be operationalized for empirical testing.

As an illustration for why the language that is used to describe behavioural phenomena in this context matters and can potentially have a significant influence on shaping and directing the research in this field and even management practices, consider the following examples. The assumption that phenomena related to the term panic are not testable in experimental settings with humans has made many authors favour pure numerical methods over experimentation or favour experimentation with animals or insects over experiments with human crowds [59–62, 90–97]. In terms of management practices, the theory could be cited in crises situations as a reason for withholding information from the crowd by managing authorities in order to save more lives. According to the studies that we reviewed, this is based on the rationale that if people know about a critical situation, it might agitate them, ultimately causing them to panic which will lead to irrational behaviour. In contrast to this line of thinking, several authors like Heide [25] have argued that "Evacuation warnings should not be withheld or delayed for fear of precipitating widespread panic". Similar important implications are also conveyed by the term herding. The term, as we showed in our detailed analysis of quotes, has largely been used in the literature to convey imitative type of behaviour [49]. However, the use of this (largely animalistic) term does not make it clear whether there will be contexts or aspects of behaviour in which people do not tend to imitate. It also depicts a mechanism of decision-making in which peer influence is the only factor or the dominant factor while trivialising the role of other potential contributing factors to human responses.

The research on evacuation dynamics has been actively in progress for several decades. Many scholars from a range of disciplines have been researching this topic and significant progress has been made. However, we argued that, if thus far, this ample effort has not converged to any well-defined and empirically supported characterisation or a well-accepted numerical model for panic, then it may be unlikely that such goal be achieved in the future. This may be an indication that some parts of the literature in this field may be in need a fundamental reformulation. It warrants that some of the concepts or terminologies, including those studied in this review, be revisited and replaced with more proper substitutes. In conclusion, we suggest that instead of framing their investigation under the umbrella of the frequently used, but ambiguous terms, "panic", "irrationality", and "herding", researchers could simply state the precise assumptions or hypotheses underlying their work. In doing so, a more integrative approach between the numerical, empirical, and social science studies could prove useful. Table 4 lists a summary of the conclusions that we drew based on this review regarding the use of each of the three terms, along with our recommendations.

Appendix

A.

See Table 5.

B.

See Table 6.

C.

See Table 7.

D.

See Table 8.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Table 4: A summary of the conclusions and the recommendations associated with each of the three terms.

Panic	*Conclusions*	(i) Panic lacks a formal clear definition (ii) Panic lacks a unified well-defined characterisation (iii) Panic cannot be tested as a verifiable hypothesis (iv) Panic is not theoretically well-conceived (v) Panic is not empirically well supported (vi) Despite lack of clear definition, the term panic persists to be increasingly mentioned in the evacuation dynamics literature, particularly in numerical studies (vii) Alternative theories have been proposed by social scientists challenging the theory of panic (viii) There is a sharp divide between how social and physical scientists see the panic theory and its relevance to disaster research
	Recommendations	(i) The evacuation dynamics literature does not benefit from the use of the term panic as it pushes numerical studies towards unverifiable assumptions and non-testable model formulations (ii) The evacuation dynamics literature does not seem to benefit from the use of the term panic as it pushes empirical studies away from human experiments towards alternatives such as experiments with insects/animals (iii) The question of panic can be substituted by operationalizable questions, such as, how fear and stress influences collective behaviour in disasters
Irrationality	*Conclusions*	(i) Irrationality is an implied notion in the panic theory, thus, same comments largely apply as above (i) Irrationality does not need to be associated with panic (as a feature of panic behaviour). The two can be dissociated. Behavioural rationality could be investigated in its own term without the link to panic (ii) Rationality can be re-framed as (replaced by) optimality of behaviour so it can be measured/tested (iii) Measuring rationality requires clear points of reference (iv) Rationality could be measured at both collective and individual levels, each requiring their own reference points (v) Experimental studies could give insight into how rational (optimal) human evacuation is, and under what circumstances their behaviour becomes more/less rational (vi) Numerical simulation models can further our understanding about how we can enhance collective optimality (rationality) in emergency response
	Recommendations	
Herding	*Conclusions*	(i) Empirical studies do confirm the role of social influence in evacuation behaviour (ii) There is relative consensus on the definition of the term herding, although not perfectly (iii) Herding is an animalistic and rather sensational term (iv) The term herding implies that the direction of social influence is always "imitation" (not always the case, sometimes the opposite "avoiding others" is the case) (v) Herding implies that the direction of social influence is always following the majority (not always the case, sometimes, following the minority is the case) (vi) Herding implies that social influence is the single dominant factor in decision making (not always the case, often people make a trade-off between various factors) (vii) The empirical literature so far has suggested that people do show tendency to imitate when it comes to evacuation movement initiation or decision change initiation. (viii) Some empirical studies have shown opposite tendency to herding when it comes to direction choice making especially in heavily crowded situations (ix) Contextual factors such as the crowding level, the stress level or the level of environmental familiarity have shown to change the magnitude and direction of the social influence
	Recommendations	(i) The term social influence is more suitable than the term herding. (ii) Herding does not need to be associated with panic (as a feature of panic behaviour). The question of social influence can be legitimately investigated in its own terms (iii) The question about the role of social influence should be studied in association with different specific aspects of the behaviour. The effect varies across various behavioural aspects.

Table 5: Original quotes on the term panic.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline			Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
(i) Whenever we (such as pedestrians) perceive a high density or imminent danger in a confined space, we tend to be panic, which can lead to severe injuries even in the absence of real dangers. (ii) Mass behaviors induced by *panic* usually cause great loss, even for human's life	(1) [9]		•		•			•		•			(i) Panic is common occurrence in the face of imminent danger (ii) Panic is a cause of injuries in crises
(i) Results show that moderate *panic* reduces the escape time (ii) Simulation results show that moderate *panic*, meaning that two escape strategies are mixed, reduces the escape time. (iii) In addition, the results indicate that moderate *panic* can improve the efficiency of escape (iv) Finding indicates that panic in specific condition can improve the efficiency of escape, which also can be useful for designing evacuation strategies.	(2) [9]		•		•			•		•			Panic can affect evacuation efficiency, in both beneficial or detrimental ways
(i) Because pedestrians tend to random motion under *panic*, the probability of random moving that can characterize the panic is thus the panic parameter. (ii) When p = 1, it indicates that pedestrian moves in a completely random strategy, that is pedestrian remains at an intense panic	(3) [9]			•				•		•			Panic is manifested as random (erratic) behaviour (chaos)
In situations of escape *panics*, individuals are getting nervous, i.e., they tend to develop blind actionism. Furthermore, people try to move considerably faster than normal, etc. (o.c.)	(4) [11]	•		•				•		•			(i) Panic is manifested as increased stress (nervousness/fear) (ii) Panic is manifested as imitative (herd) behaviour (iii) Panic is manifested as elevated physical competition
"*Panic*: People flight based on a sudden subjective or 'infected' fear; People are moving imprudently; The cause of this movement cannot be recognized by an outsider" (o.c.)	(5) [11]		•	•				•		•			Panic can occur without any distinguishable cause
(i) Up to now, the terminology "*panic*" is highly controversial and usually avoided. In this manuscript, we use "fear"… (ii) There is no precise accepted definition of *panic* although in the media usually aspects like selfish, asocial or even completely irrational behavior and contagion that affects large groups are associated with this concept	(6) [11]	•	•			•		•		•			(i) Panic lacks a clear definition (ii) Panic is common media language
In spite of such measures, empirical knowledge has shown that the real danger comes not from the actual cause but from what is called "unpredictable" or "non-adaptive" behavior of a crowd under *panic*.	(7) [10]				•			•		•			Panic is a cause of injuries in crises
It is shown that the variation of the model parameters allows describing different types of behaviour, from regular to *panic*.	(8) [18]				•			•		•			Panic can be represented by simple parameters in simulation models
The phenomena observed during *panics* can be quite different from those found in "normal" situations. Nevertheless, it is desirable to have a model which is able to describe the whole spectrum of possible pedestrian behaviour in a unified way.	(9) [18]				•			•		•			Panic can be represented by simple parameters in simulation models

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline			Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
In *panic* situations many counter-intuitive phenomena (e.g. "faster-is-slower" and "freezing-by-heating" etc. [o.c.]) can occur.	(10) [18]			•	•			•		•			(i) Panic leads to exit blockages (ii) Panic can affect evacuation efficiency
Crisis circumstances often involve considerable uncertainty, confusion, and *panic*.	(11) [98]			•	•		•				•		Panic is common occurrence in the face of imminent danger
..stress can end up with *panic* [o.c.] and even with aggressive behaviours	(12) [99]			•	•			•		•			(i) Panic is manifested as increased stress (nervousness/fear) (ii) Panic is manifested as elevated physical competition
. . .little study has been carried out to examine these interactions under *panic* situation due to scarcity of data on human *panic*.	(13) [100]				•			•		•			Panic theory lacks empirical support
Crowd safety has emerged as an important issue all around the world as there have been numerous incidents in which crowd *panic* has resulted in injuries and/or death.	(14) [100]				•			•		•			Panic is a cause of injuries in crises
The bulk of the literature is restricted to the study of normal (non-*panic*) pedestrian dynamics or normal evacuation processes.	(15) [100]			•	•			•		•			
The use of term *panic* and emergencies in this study refer to situations in which individuals have limited information and vision (due to high crowd density and short time for egress), and which result in physical competition and pushing behavior.	(16) [100]			•	•			•		•			(i) Panic is manifested as elevated physical competition
In 1954, Quarantelli was the first social scientist to find that there is no proof of the presence of panic in cases of major disasters.	(17) [7]					•		•				•	Panic theory lacks empirical support
An increased stress level is not the same as *panic*, which can be defined as irrational, illogical and uncontrolled behaviour	(18) [7]		•	•	•			•				•	Panic is manifested as random (erratic) behaviour (chaos)
Under the *panic* state the agents cohere closely and almost do not change the target exit. So other alternative exits are ignored.	(19) [101]			•	•			•				•	(i) Panic leads to imbalanced utilisation of exits (ii) Panic can affect evacuation efficiency

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline			Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
People under *panic* are usually willing to move along known routes, even if this means they run towards the fire, which may lead to more fatalities.	(20) [101]		•	•	•			•				•	(i) Panic leads to imbalanced utilisation of exits (ii) Panic can affect evacuation efficiency
Empirical data have shown that usually the escape *panic* can cause more casualties than the actual disaster	(21) [101]		•		•			•				•	Panic is a cause of injuries in crises
Some may lose their own decision-making capacity and the herding behavior may appear for following specific individual. Some may accelerate the speed of movement due to the panic. Some may panic that cannot choose the right exit or even lose destination.	(22) [16]	•	•	•	•			•		•			(i) Panic is manifested as imitative (herd) behaviour (ii) Panic is manifested as elevated physical competition
Panic: Breakdown of ordered, cooperative behavior of individuals due to anxious reactions to a certain event. . . characterized by attempted escape of many individuals from a real or perceived threat. . ., which may end up in trampling or crushing of people in a crowd.	(23) [102]			•	•			•		•		•	(i) Panic is manifested as increased stress (nervousness/fear) (ii) Panic is manifested as elevated physical competition
Critical situations may occur if the arrival flow is much higher than the departure flow, especially if people are trying to get towards a strongly desired goal ("acquisitive *panic*") or away from a perceived source of danger ("escape *panic*") with an increased driving force.	(24) [102]			•	•			•		•		•	There are various kinds of panic
In the worst case, such behavior can trigger a "phantom *panic*", i. e. a crowd disaster without any serious reasons. Under extreme conditions (high densities or panic), however, coordination may break down, giving rise to "freezing-by-heating" or "faster-is-slower effects", stop-and-go waves or "crowd turbulence".	(25) [102]			•	•			•		•		•	(i) There are various kinds of panic (ii) Panic leads to exit blockages
We have proposed a consistent theoretical approach allowing a continuous switching between seemingly incompatible kinds of human behavior (individualistic rational behavior vs. irrational *panic* behavior)	(26) [103]	•	•	•	•			•		•		•	Panic can be represented by simple parameters in simulation models
One of the most disastrous forms of collective human behaviour is the kind of crowd stampede induced by *panic*, often leading to fatalities as people are crushed or trampled.	(27) [19]			•	•			•		•		•	Panic is a cause of injuries in crises
The characteristic features of escape *panics* can be summarized as follows: (1) People move or try to move considerably faster. . .. (2) Individuals start pushing. . .. (3) . . .passing of a bottleneck becomes uncoordinated. (4) At exits, arching and clogging are observed. (5) Jams build up. (6) The physical interactions in the jammed crowd add up and cause dangerous pressures... (7) Escape is further slowed by fallen or injured people acting as 'obstacles'. (8) People show a tendency towards mass behaviour, that is, to do what other people do (9) Alternative exits are often overlooked. . .[o.c.]	(28) [19]	•		•	•			•		•		•	(i) Panic is manifested as increased stress (nervousness/fear) (ii) Panic is manifested as imitative (herd) behaviour (iii) Panic is manifested as elevated physical competition

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline			Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
In the event of an emergency, unnecessary *panic* can spread rapidly amongst metro passengers, leading to self-evacuation.	(29) [43]				•			•		•			Panic is common occurrence in the face of imminent danger
In a panic, information spreads so rapidly that passengers often self-evacuate.	(30) [43]			•	•			•		•			Panic is common occurrence in the face of imminent danger
Human behavior in an emergency is quite different from that in daily life or even evacuation rehearsal. People in a fire scene are very likely to be affected by people around as a result of uneasiness and *panic*. They would like to be close to the crowd and follow the route of the mass rather than the route made by their own judgment.	(31) [104]	•		•	•			•		•			Panic is manifested as imitative (herd) behaviour
Casualties during crowd evacuation in many unexpected events are closely related to *panic* behaviors.	(32) [105]			•	•			•		•			Panic is a cause of injuries in crises
The evolution of herding people to *panic* people is interpreted by a specific concept of "herding–*panic* threshold," as well as its utility threshold model	(33) [105]	•			•			•		•			Panic can be represented by simple parameters in simulation models
Although the term "*panic*" is a controversial topic, in which some interview data and case studies demonstrate that *panic* is a very rare occurrence in fires. . . the idea of *panic* and the term continue to be used by the public as well as fire experts.	(34) [105]				•	•		•		•			Panic is rare occurrence in the face of imminent danger
In many emergencies. . .*panic* does exist and induces tragic catastrophes, which cannot be attributable to building design or its management	(35) [105]			•	•			•		•			Panic is a cause of injuries in crises
Panicking individuals will block up an exit that they could pass through safely at normal walking speed.	(36) [38]			•	•			•		•		•	Panic leads to exit blockages
Assuming escaping behavior of individuals in emergency is rational rather than out of *panic* according to recent findings in social psychology, we investigate the behavioral evolution of large crowds from the perspective of evolutionary game theory	(37) [8]		•			•		•		•			Panic theory lacks empirical support
In *panic* conditions, individuals' speeds increase above normal, interactions between persons become highly physical and movements are uncoordinated [o.c.]. At exits, clogging and collisions occur, as well as rainbow-like arching structures.	(38) [17]			•	•			•		•			(i) Panic leads to exit blockages (ii) Panic is manifested as elevated physical competition
This model does not account for crushing behaviors and thus limits the interpretation of *panic* in this context.	(39) [106]			•				•		•			Panic is manifested as elevated physical competition
When the *panic* emotion emerges in someone in a crowd, his/her neighboring individuals tend to be infected via what is termed emotional contagion.	(40) [107]			•	•			•		•			Panic is manifested as imitative (herd) behaviour

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline			Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
In order to intervene in and manage a large-scale crowd in which individuals can move freely in the case of large-scale *panic*, some managers or guides should be organized to calm the crowd members	(41) [107]				•			•		•			Panic can affect evacuation efficiency
With such a model, additional characteristics of human behavior in a disaster evacuation scenario could be captured such as erratic action and *panic*.	(42) [14]			•	•			•		•			Panic is manifested as random (erratic) behaviour (chaos)
(i) The "faster is slower" effect induced by *panic* was analyzed. (ii) A state of panic is associated with high values of vd [desired velocity] i.e., individuals try to move faster and faster towards the exit door.	(43) [108]			•	•			•		•			Panic leads to exit blockages
The continuity of both curve (. . .) shows the tendency of people to follow the majority during *panic*.	(44) [1]	•		•	•			•		•			Panic is manifested as imitative (herd) behaviour
. . . the flow rate of pedestrian going out through an exit door of width L is considered a linear function of L [Under normal evacuation conditions (no *panic*)]. . .under *panic* situation, this is no longer valid.	(45) [109]			•	•			•		•			Panic leads to exit blockages
Song et al. distinguished the crowd in panic situations. . .according to people who will (a) select the closest exit, (b) be in total *panic*, and (c) follow the flow of the crowd around them (41). The percentage in each group was 90%, 5%, and 5%, respectively.	(46) [110]	•			•			•		•			
Panicked individuals may have a negative impact on other people and, on the contrary, the calm leadership of certain evacuees may inspire orderly movement of others.	(47) [105]				•			•		•	•		Panic can affect evacuation efficiency
The emotion of the crowd often is in an unreason state. Negative emotions, such as *panic*, may induce disastrous forms of collective human behaviors, e.g., crush and trample	(48) [107]				•			•		•			Panic is a cause of injuries in crises
Panic has been associated with individualistic responses and characterised by "self-preservation at all costs, by 'irrational' animalistic behaviour involving the breakdown of group ties. . . Evidence will be presented to show that this is an inaccurate generalisation	(49) [12]		•	•		•	•					•	Panic theory lacks empirical support
There has been a resistance to psychological studies of human action in fire because of the belief [o.c.] that the term '*panic*' provides a sufficiently accurate description of people's response to hazardous events. Sime [o.c.] has pointed to the essential difficulty associated with the use of the term '*panic*', in that it has "ruled out attempts to examine directly people's experiences of coping in a fire situation".	(50) [12]					•	•					•	(i) Panic lacks a clear definition (ii) Panic theory lacks empirical support
Wood has found that behaviour during fires is influenced by social roles and that different groups within the sample displayed distinctive patterns of response. This would suggest that evacuation is not a random, irrational '*panic*' response even though people are acting under stress.	(51) [12]		•	•		•	•					•	Panic theory lacks empirical support
In the past these factors have been considered the classic situational determinants of competitive flight or '*panic*' behaviour. . .An alternative model of 'affiliative' escape behaviour is examined in the present paper.	(52) [15]					•	•					•	Social affiliation theory presents an alternative to the panic theory
It has been argued that many of the assumptions about escape behaviour in the fire regulations and design literature derive from the notion that when faced by a fire threat, people have a tendency to '*panic*'.	(53) [15]						•					•	Panic is a very pervasive assumption in modelling literature

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline			Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
(i) The *panic* model of escape behaviour assumes that people threatened by entrapment will revert automatically to primitive, highly emotional, irrational behaviour (ii) The panic and physical-science models are inextricably linked through the analogy made between people and non-thinking objects	(54) [15]		•	•			•					•	Panic is manifested as non-humanistic behaviour
(i) The word '*panic*' is frequently used in media accounts and statements of survivors of emergency evacuations and fires, but what does it really mean, is it a phenomenon that actually occurs? (ii) Despite the data demonstrating that panic is a very rare occurrence in fires, the idea of panic and the term continue to be used by the public as well as fire experts	(55) [30]					•	•					•	(i) Panic is common media language (ii) Panic theory lacks empirical support (iii) Panic is a very pervasive assumption in modelling literature
There are various accounts in the literature of 'mass *panic*', all of which assume psychological vulnerability, since they claim that, in the context of threat, the crowd becomes a conduit for inherent tendencies towards dysfunctional behaviour, delusory beliefs and social pathology.	(56) [24]		•	•			•					•	Panic can affect evacuation efficiency
Theories of '*panic*' typically suggest that loss of behavioural control, and hence selfishness and disorder, is generic in emergencies. However, reviews and case studies of emergencies show that cooperation is relatively common within and across crowds.	(57) [24]			•		•	•					•	(i) Panic is a very pervasive assumption in modelling literature (ii) Panic theory lacks empirical support (iii) Social affiliation theory presents an alternative to the panic theory
The concept of '*panic*' has served to justify the restriction of such essential public information – based on a concern that the crowd might '*panic*'.	(58) [24]						•					•	Panic theory has significant implications for crowd management

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline			Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
This general model provides a strong basis on which to refute the '*panic*' description of behaviour. It supports and refines Wood's [16] earlier finding that fire victims do not behave in an irrational manner	(59) [12]		•			•	•					•	Panic theory lacks empirical support
Crowd quakes are a typical reason for crowd disasters, to be distinguished from crowd disasters resulting from 'mass *panic*' or 'crowd crushes. …Accordingly, things can go terribly wrong in spite of no bad intentions from anyone.	(60) [111]				•			•			•		Panic is a cause of injuries in crises
It is widely believed that one of the most disruptive consequences of a terrorist attack… would be public *panic*. Indeed, this is one of the probable goals of the terrorists.	(61) [112]				•		•					•	Panic is a cause of injuries in crises
The results contradict most of the predictions of the mass *panic* model and add to the dominant affiliation and normative approaches. …These results support a hypothesis according to which (emergent) collective identity motivates solidarity with strangers.	(62) [113]					•	•					•	(i) Panic theory lacks empirical support (ii) Social affiliation theory presents an alternative to the panic theory
Images of group *panic* and collective chaos are ubiquitous in Hollywood movies, mainstream media and the rhetoric of politicians. But, contrary to these popular portrayals, group *panic* is relatively rare. In disasters people are often models of civility and cooperation.	(63) [114]					•	•					•	(i) Panic theory lacks empirical support (ii) Social affiliation theory presents an alternative to the panic theory (iii) Panic is common media language
(i) I report evidence showing that *panic* did not cause the death and injury of numerous young people prior to a concert. (ii) I conclude that theoretical models of *panics* or "crazes" within the literature on collective behavior are not very useful in explaining this type of incident.	(64) [115]					•	•				•	•	Panic theory lacks empirical support
Many social scientists would categorize the crowd behavior described above form of panic-usually termed an "acquisitive panic" (o.c.) or "craze" (o.c.). Smelser distinguishes it from the classic panics of escape, e.g., flight from a burning building, in that the latter is a "headlong rush away from something" while the craze is a rush "toward something [the participants] believe to be gratifying.	(65) [115]			•			•				•	•	There are various kinds of panic
Although many collective behavior theorists discuss the phenomenon, systematic studies of *panic* are uncommon. Researchers conducting such studies generally conclude that *panic* is a rare form of crowd behaviour. Quarantelli and Dynes (1972) report that they have found few instances of *panic* after years of disaster research.	(66) [115]					•	•				•	•	There are various kinds of panic
Although not in complete agreement, writers on *panic* before Mintz had tended to emphasize perceived danger and mutual influence (suggestion, contagion, mimicry) as the key factors in the development and spread of incoordinated and nonadaptive "*panic*" behavior	(67) [33]	•		•			•				•	•	(i) Panic is manifested as increased stress (nervousness/fear) (ii) Panic is manifested as imitative (herd) behaviour
Intense fear is shown not to be important because even in its absence there occurs "behavior analogous to that occurring in *panics*	(68) [33]					•	•				•	•	
The notion of 'mass *panic*' shares with classical 'crowd science' the assumption that the crowd is less intelligent and more emotional than the lone individual (o.c.) and hence reactions to an emergency will be disproportionate to the actual danger.	(69) [116]		•	•			•				•	•	Panic is a cause of injuries in crises
In the field of mass emergency and disaster research, the notion of mass *panic* has been largely discredited by the finding of orderly, meaningful mass behavior in disasters. However, some influential practitioners, including crowd modellers in the fields of engineering and design, still draw upon the notion.	(70) [116]			•		•	•				•	•	(i) Panic is a very pervasive assumption in modelling literature (ii) Panic theory lacks empirical support

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline				Study type		
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
The term '*panic*' is a commonsense cliché. The term is often used when what in fact is being described is simply flight from the source of danger.	(71) [116]			•		•	•				•	•	Panic lacks a clear definition
Analyses of 9-11 refer to the relative absence of *panic* (o.c.), the calm and orderliness of the evacuation (o.c.), and the frequency of helping and acts of 'mundane heroism' amongst strangers (o.c.).	(72) [116]					•	•				•	•	Panic theory lacks empirical support
Shared identity in an emergency crowd enhances expressions of solidarity and reduces '*panic*' behaviour and. . .such a shared identity can arise from the shared experience of the emergency itself	(73) [27]					•	•				•	•	Social affiliation theory presents an alternative to the panic theory
It is suggested that the 'mass *panic*' approach is correct to suggest a discontinuity between everyday and mass emergency behaviour, but wrong in its account of what that behaviour is.	(74) [27]					•	•				•	•	Panic theory lacks empirical support
[Keating] pointed out that people did not *panic*, did not become animals, and did not abandon their ties to others. Instead they continued to be social actors . . .	(75) [117]			•		•	•					•	Social affiliation theory presents an alternative to the panic theory
Collective solidarity can mitigate fear and negative emotions, thus reducing the risk of *panic*.	(76) [118]						•				•		Social affiliation theory presents an alternative to the panic theory
The mass *panic* approach describes individuals as acting in a purely selfish manner.	(77) [118]			•			•				•		(i) Panic is manifested as non-humanistic behaviour
Indeed, participants referred to 'orderly' behaviour, and cooperation, even when they said the threat of death was present. '*Panic*' was therefore being used as a description of events that was not consistent.	(78) [28]					•	•				•	•	(i) Panic theory lacks empirical support (ii) Panic lacks a clear definition
(i) More empirically oriented studies have consistently reported little collective *panic*, as well as a great deal of solidarity and pro-social behavior during mass emergency situations. (ii) Many studies in the fields of sociology and social psychology have systematically questioned the existence of mass panic in disasters and mass emergency contexts.	(79) [119]			•		•	•					•	(i) Panic theory lacks empirical support (ii) Social affiliation theory presents an alternative to the panic theory

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline				Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
Defining 'mass *panic*' in a scientifically sound manner has long been recognized as a difficult task.	(80) [119]						•					•	Panic lacks a clear definition
Panic in crowds is still an important theoretical postulate of scholars interested in the modeling of collective behavior	(81) [119]						•					•	(i) Panic is a very pervasive assumption in modelling literature
[People] report having been in a state of *panic* to describe their lack of information about an event. This is even the case when they in fact stayed calm and behaved in a rational and prudent fashion.	(82) [119]		•			•	•					•	Panic theory lacks empirical support
As usually defined, individual *panic* would include a "reaction involving terror, confusion, and irrational behavior, precipitated by a threatening situation often including physical symptoms as well, and *panic* as a social phenomenon is defined as simply an aggregate of such responses"	(83) [120]		•	•			•					•	(i) Panic is manifested as increased stress (nervousness/fear) (ii) Panic is manifested as elevated physical competition
[As opposed to *panic*] I prefer the term unregulated competition as the descriptive label.	(84) [120]						•					•	Panic lacks a clear definition
In this emergency situation, the survivors of the bombings came together to tend to the injured and find a way of evacuating safely. In contrast to portrayals of crowds as *panicking* and acting selfishly to evacuate, research has shown that the opposite occurred.	(85) [121]			•		•		•		•	•		Panic theory lacks empirical support
There is good reason to think that the behaviour of human crowds is quite similar to these animal groups and that studying humans might help elucidate the origins of crowd *panic* and other dangerous instabilities that can lead to injury or loss of life.	(86) [122]				•			•				•	(i) Panic is manifested as non-humanistic behaviour (ii) Panic is a cause of injuries in crises
While mass *panic* (and/or violence) and self-preservation are often assumed to be the natural response to physical danger and perceived entrapment, the literature indicates that expressions of mutual aid are common and often predominate, and collective flight may be so delayed that survival is threatened.	(87) [123]					•	•					•	Panic theory is not empirically well supported
(i) The term "*panic*" refers to inappropriate (or excessive) fear and/or flight. (ii) Whether defined as inappropriate or as highly intense fear or flight, instances of *panic* are difficult to identify in practice	(88) [123]			•		•	•					•	Panic theory is not empirically well supported
Rushing for exits in a structural fire may be the only rational course of action to take. Hence, the decision to label instances of collective flight as *panic* is arbitrary.	(89) [123]		•	•		•	•					•	What seems to be panic behaviour, may be individual's best perceived course of action

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline			Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
Studies are revealing several misconceptions about the types of responses that emergencies evoke in people. For example, a number of widely-held beliefs among the public and the media have been shown to be incorrect, such as that looting, mass *panic*, and selfish behaviour are common in disasters, and should be abandoned in favour of realistic, proactive emergency knowledge.	(90) [124]					•	•				•	•	(i) Panic theory lacks empirical support (ii) Panic is common media language
The review of the existing research literature, together with our own studies, support the view that mass *panic* is a myth, and that crowd behaviour in disasters and emergencies is meaningful rather than irrational; and that such behaviour is characteristically orderly and co-operative rather than disorderly and individualistic.	(91) [125]		•	•		•	•				•	•	Panic theory lacks empirical support
Mass *panic* is said to occur when a crowd has only limited opportunity for escape from impending danger. It supposedly explains the high numbers of avoidable fatalities in emergency evacuations.	(92) [31]						•					•	Panic is a cause of injuries in crises
Mass *panic* occurs when a group of persons fleeing from imminent danger find their escape route impeded or blocked. Under these circumstances they lose all sense of judgment and discretion. They become impervious to communication or direction, trample over one another, and fail to seek other exits of escape even if available. For these reasons mass *panic* rarely occurs in outside disaster circumstances.	(93) [29]		•	•	•		•					•	(i) Panic is manifested as non-humanistic behaviour (ii) Panic leads to imbalanced utilisation of exits
From around 200 accounts of the World Trade Center survivors published in the media, *panic* was seldom mentioned instead many emphasized the calm and altruistic behaviour of the evacuees.	(94) [126]					•	•					•	Panic theory lacks empirical support
The popular image of disaster has often centered on the theme of personal chaos. Such an image is frequently documented by isolated anecdotes used to prove the universality of such behavior. This image suggests that individuals *panic* and that individuals lose their concern for others.	(95) [25]			•		•	•					•	(i) Panic is manifested as random (erratic) behaviour (chaos) (ii) Panic is manifested as non-humanistic behaviour
The issue of *panic* in disasters is frequently clouded by a lack of understanding of what the term means. The word is often very loosely and incorrectly used to describe virtually any type of fear, flight, or uncoordinated activity.	(96) [25]			•			•					•	Panic lacks a clear definition
The problem with the *panic* misconception is that the public, the media, and even emergency planners and public officials believe it. Because of this, officials may hesitate to issue warnings because they are convinced that the resulting *panic* will cause more damage than the disaster itself. (i) This belief has led to recommendations to avoid *panic* by (1) providing minimal information to occupants in the event of a building fire and (2) carrying on normal activities until the last possible moment. (ii) Evacuation warnings should not be withheld or delayed for fear of precipitating widespread *panic*.	(97) [25]						•					•	(i) Panic theory has significant implications for crowd management (ii) Panic is common media language
Governments and commentators perceive the public to be prone to *panic* in response to terrorist attacks. . .Evidence from five such incidents suggest that the public is not prone to *panic*, although people can change their behaviours and attitudes to reduce the risk of themselves being exposed to a terrorist incident.	(98) [34]					•	•					•	Panic theory lacks empirical support

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline				Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
We suggest that although the public may change their behaviours or attitudes, in ways that might be viewed as irrational by public authorities,. . .these actions tend to have an internal logic and as such are amenable to change. Assumptions of *panic* may therefore be counterproductive.	(99) [34]		•			•	•					•	What seems to be panic behaviour, may be individual's best perceived course of action
During an emergency evacuation, for instance, the presence of heightened anxiety and distress among the evacuees combined with a fear of dying is not sufficient to label them as *panicking*	(100) [34]					•	•					•	Panic lacks a clear definition
Despite considerable effort by many individuals found in this article's reference list, the myth of mass panic stubbornly refuses to die.	(101) [127]					•	•					•	Panic is a very pervasive assumption in modelling literature
During emergencies, the anticipation of mass '*panic*' has been a favoured argument to delay warning the public. Such delays have contributed to subsequent flight behaviour and the crush of people who had only a few seconds left to react once the situation unexpectedly got out of hand.	(102) [26]						•					•	Panic theory has significant implications for crowd management
Perhaps the most frequently used term in connection with disasters and crises is the word "*panic*". . .an observation by Jordan unfortunately still is true today. As he noted: "The literature on panic research is strewn with wrecked hulks of attempts to define '*panic*.' When these definitions are placed side by side. one is confronted by chaos.	(103) [128]						•					•	Panic lacks a clear definition
Panic flight was so rarely found that eventually the very concept of "panic behavior" was deemed useless for fire research purposes	(104) [128]					•	•					•	Panic is a rare occurrence
To conclude, collective *panic* flight in disasters is such a rarity that it is not a major problem and has very little overall negative consequences compared with other bad effects.	(105) [128]					•	•					•	Panic theory lacks empirical support
While some current researchers continue to use the word "*panic*" in imaginative ways (o.c.), we personally think the term should be dropped as a social science concept. . .A major move in such a direction would free social scientists from the ambiguities and imprecisions of continuing to use a word drawn from popular discourse.	(106) [128]					•	•					•	Panic lacks a clear definition
In stress situations, one aspect of social behavior that has been subjected to little experimental investigation is *panic* behavior. . .By far the great majority of the literature consists of post hoc impressionistic reflections that contain little substantive material amenable to systematic, analytic interpretation.	(107) [129]						•					•	Panic theory lacks empirical support

Table 5: Continued.

Quotes	Qu. Ref. No	Implications of the quote			The source study								Comments/ Interpretations
							Discipline			Study type			
		Links to H.	Links to Ir.	Def./ Cha. P.	Supp. P.	Cont. P.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
For ethical reasons, however, there is a serious lack of experimental data regarding crowd *panic*. While *panic* has recently been studied in animal experiments with mice and ants [o.c.], there is still an evident lack of data on critical conditions in human crowds.	(108) [130]							•		•	•		Panic theory lacks empirical support
Mass-emergencies are very popular in the news, whether we watch news on TV or read a newspaper. In most of these news we are able to read that people were fallen in *panic* or a mass-*panic* occurred. This is a simple, but often used explanation why people died in such situations. But is that the truth?	(109) [131]					•	•				•	•	Panic is common media language
Several researchers in the field of engineering or sociology have written special papers (e.g. [3]) or books (e.g. [4, 5]) about the phenomenon of *panic*, but a complete definition of *panic* cannot be found in the literature.	(110) [131]						•				•	•	Panic lacks a clear definition
Based on this short overview the authors want to point out that the terms "*panic*", "stampede" and "crush" are very language specific, thus one has to read articles in one's native language and at least in one foreign language to ensure, that both language specific views are considered.	(111) [131]						•				•	•	Panic lacks a clear definition
This and other definitions are used to investigate 127 cases of mass-emergencies. The results show, that *panic* behavior in case of mass-emergencies does not as often occur as suggested.	(112) [131]					•	•				•	•	Panic theory lacks empirical support

"Qu./Ref. No." means *Quote/Reference number.*
"Links to Ir." means *(The quote) links Panic (P.) to Irrationality (Ir.).*
"Links to H." means *(The quote) links Panic (P.) to Herding (H.).*
"Def. Cha. P." means *(The quote) defines/characterises Panic.*
"Supp. P." means *(The quote) supports (the theory of) Panic.*
"Cont. P." means *(The quote) contradicts (the theory of) Panic.*
"Soc. Sci." means *(The source of the quote) is a study in Social Sciences.*
"Phys. Sci." means *(The source of the quote) is a study in Physical Sciences.*
"Bio. Sci." means *(The source of the quote) is a study in Biological Sciences.*
"Mod." means *(The source of the quote) is a study with a main focus on Modelling.*
"Emp. Test." means *(The source of the quote) is a study with a main focus on Empirical Testing.*
"Conc." means *(The source of the quote) is a study with a main focus on Conceptualisation.*
Note that individual studies can belong to multiple categories (e.g. multiple disciplines).

Table 6: Original quotes on the term irrationality.

Quotes	Qu. Ref. No.	Implications of the quote					The source study							Comments/Interpretations
							Discipline			Study type				
		Links to H.	Links to P.	Def./ Cha. Ir.	Supp. Ir.	Cont. Ir.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.		
Here we want to apply this model to a simple evacuation process with people trying to escape from a large room. Such a situation can lead to a panic where individuals apparently act *irrationally*.	(1) [18]		•		•			•		•				Irrational behaviour is a symptom of panic
They think that the transition between the "*rational*" normal behavior and the apparently "*irrational*" panicbehavior is controlled by a single parameter, the "nervousness", which influences fluctuation strengths, desired speeds, and the tendency of herding.	(2) [11]	•	•					•		•				Herding is a sign of irrational behaviour
We aspire to give answers to the following specific questions what is the impact between choosing the escape route based on familiarity as opposed to *rationally* following the fire exits.	(3) [10]			•				•		•				Choosing familiar exits is a sign of irrational behaviour
We do not want to imply that individuals would always behave *irrational* in emergency situations. It has been observed that, even in such situations individuals can behave highly self-controlled, coordinated, *rational*, and social	(4) [103]			•		•		•		•		•		People can maintain rationality during crises
Recent researches in social psychology about herding effect in emergency [o.c.] indicate that, escaping behaviors among individuals are *rational* actions instead of crowd panic and a series of phenomena including herding effect are the result of *rational* choices in behaviors for escaping agents.	(5) [8]	•	•			•		•		•				People can maintain rationality during crises
Most microscopic simulation models [o.c.] in the field of emergency evacuation up to now are generally based on the assumption that panic instead of *rational* actions induces herding effect.	(6) [8]	•	•					•		•				Herding is a sign of irrational behaviour
Irrationality: Accounting for the idea that individuals in a crowd lose *rational* thought	(7) [99]			•	•			•		•				
(i) High herding causes a crowd of high *rationality* (especially in normal circumstances) to become more "vying" in behaviour. (ii) The high-*rationality* crowd is shown to spend more evacuation time than a low-*rationality* crowd in emergency situations.	(8) [36]		•	•				•		•				Rationality is associated with evacuation efficiency
Persons with high *rationality* deal with various situations according to their precise judgment, while persons of low *rationality* choose strategy at random.	(9) [36]			•				•		•				Irrationality means deciding randomly

Table 6: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to H.	Links to P.	Def./ Cha. Ir.	Supp. Ir.	Cont. Ir.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
Computer simulation results show that. . .(2) in an emergency situation, individual hyper-*rationality* among evacuees diminishes evacuation efficiency; (3) the imitation effect enhances cooperation among evacuees, yet reduces evacuation efficiency.	(10) [37]	•		•				•		•			(i) Rationality is associated with evacuation efficiency (ii) Herding is detrimental to evacuation efficiency
The underlying behavior could be called "*irrational*", as all of these effects decrease the chances of survival compared to normal pedestrian behavior.	(11) [103]			•				•		•		•	Rationality is associated with evacuation efficiency
For a low level of panic, a great number of individuals are still able to choose autonomously the best exit but, as soon as their stress level increases, more and more persons imitate other persons around them, discarding any *rational* behaviour.	(12) [17]	•	•	•	•			•		•			Herding is a sign of irrational behaviour
Gabriel Tarde (1901) (cited in van Ginneken, 1992). . .suggested that by mere proximity people become a crowd, and hence subject to uncritical imitation and hence *irrational* behaviour.	(13) [132]	•		•	•		•					•	Herding is a sign of irrational behaviour
Despite the evidence, a number of myths about disasters persist in public discourse, some of which suggest that collective behavior in emergencies is maladaptive, *irrational*, and even pathological.	(14) [31]		•		•	•	•					•	Irrationality is not an accurate theory for evacuation behaviour
The idea that the majority of people in such circumstances are acting '*rationally*' at least in their own terms contrasts with the conventional escape model which assumes everyone is panicking	(15) [15]		•			•	•					•	Irrationality is not an accurate theory for evacuation behaviour
Over several decades, studies specifically looking at panic behaviour in fires have consistently shown that non-adaptive and *irrational* behaviours are actually a rare occurrence	(16) [30]		•	•		•	•					•	Irrationality is not an accurate theory for evacuation behaviour
Although evacuees might be anxious, and frequently use the word 'panic' to describe their own or others' reaction to events, they do not behave in an *irrational* or antisocial manner.	(17) [30]		•			•	•					•	Irrationality is not an accurate theory for evacuation behaviour
One important impact of the rejection of the concept of panic is that management authorities should envision the building occupants as allies during a fire rather than a mass of *irrational* people who need to be controlled	(18) [30]		•			•	•					•	Irrationality theory has significant implications for crowd management
However, many studies on human behaviour in fire and crowd disasters have showed that even under extremely critical conditions people do not panic but they behaved quite *rationally* helping each other	(19) [50]		•			•		•			•		People can maintain rationality during crises
There are various definitions of 'panic', a distinguishing feature of all of them is the crowd's supposed *irrationality*, which is linked to the 'contagion' of emotion.	(20) [24]		•	•			•					•	Irrational behaviour is a symptom of panic

Table 6: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to H.	Links to P.	Def./ Cha. Ir.	Supp. Ir.	Cont. Ir.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
To judge a response as *irrational* requires a frame of reference, but the frame of reference is often unclear in a mass emergency.	(21) [24]						•					•	Measuring rationality requires a reference point
Fleeing, fear, screaming or other responses to perceived danger may therefore be entirely reasonable [rational] given the limited information – and limited choices – available to people in the midst of an emergency	(22) [24]			•		•	•					•	What seems irrational act, may be individual's best perceived course of action
A leading example of supposed *irrational* crowd behaviour 'panic', which is generally conceptualised as *irrational* flight in which fearful people may end up hurting or killing themselves and others.	(23) [133]		•	•			•					•	
Myth of *irrationality*: crowds may cause people to behave *irrationally* or to engage in panic *irrational* flight.	(24) [133]		•	•		•	•					•	Irrational behaviour is a symptom of panic
Renzetti and Curran. . .claim that while people may copy one another or look to others for indications of how to behave, this does not mean that they lose their *rationality* when in a crowd or similar type of collectivity.	(25) [133]	•				•	•					•	Irrationality theory has significant implications for crowd management
(i) Couch (o.c.) argued that some crowds may appear irrational in that they do not support the ideas "supported by the established institutions of the day." (ii) Couch's analytic approach suggests that the concept of irrationality and its counterpart, rationality, may have "limited applicability for sociological analysis".	(26) [133]			•		•	•					•	Irrationality theory has significant implications for crowd management
In buildings people choose the route they know or when not familiar with the building their exit route is the way they entered the building. Although it might not be the most optimal route, this does not imply *irrationality* or randomness. . . .[This] can be considered a risk assessment.	(27) [134]			•		•	•					•	What seems irrational act, may be individual's best perceived course of action
The notion of *irrationality* is often used when people are not behaving in what is seen as the most effective way to achieve a goal, like fleeing out of a building while not following the emergency exits. However, the effectiveness of behaviour is compared to an ideal way of acting. It thus depends on whoever defines the effective or ideal way how and when the label "*irrational*" is used	(28) [134]			•		•	•					•	(i) Rationality is associated with evacuation efficiency (ii) Measuring rationality requires a reference point
The fact is that people in crowds do not behave *irrationally*, i.e. do not encounter a cognitive shut-down. Actually, the available evidence supports the opposite: individuals behave *rationally* given the information they have and they pursue goals effectively	(29) [134]					•	•					•	(i) Irrationality theory has significant implications for crowd management (ii) Measuring rationality requires a reference point

Table 6: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to H.	Links to P.	Def./ Cha. Ir.	Supp. Ir.	Cont. Ir.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
Panic has been associated with individualistic responses and characterised by "self-preservation at all costs, by '*irrational*' animalistic behaviour involving the breakdown of group ties (i.e. 'non-social' behaviour: ignoring of group members, or 'antisocial' behaviour: kicking, trampling)" [o.c.]. . .this is an inaccurate generalisation; however, this type of description has implications for the ways in which motivation to escape is explained.	(30) [12]			•		•	•					•	Irrationality theory has significant implications for crowd management
Mintz suggested that ineffectual escape in an evacuating crowd is due to individual calculation of costs and benefits, rather than to a contagious outburst of mass *irrationality*, as assumed by the early mass panic models.	(31) [113]					•	•					•	(i) What seems irrational act, may be individual's best perceived course of action (ii) Irrational behaviour is a symptom of panic
The several sociological and social psychological theories of collective behavior which consider panic. . . they make very different assumptions about the process producing the competition, variously attributing it to *irrational* behavior produced by fear and social contagion	(32) [115]		•				•				•	•	Irrational behaviour is a symptom of panic
The individual is no less *rational* or moral in the panic than in any other situation. He is always in pursuit of his own interests and acts on the basis of his current estimates of where these lie.	(33) [33]		•			•	•				•	•	What seems irrational act, may be individual's best perceived course of action
The concept of panic is vague and deciding what is *rational* and people think is *rational* is tricky business	(34) [135]		•			•	•				•	•	Irrationality lacks a clear definition
The concept of mass panic is also still influential in crowd modelling (o.c.), where its *irrationalist* assumptions have implications for the design of public spaces and evacuation procedures.	(35) [27]		•				•				•	•	Irrationality theory has significant implications for crowd management
(i) Popular representations of crowd behaviour in disasters are often characterised by *irrationalist* discourses, in particular 'mass panic' despite their rejection by current scientific research (ii) It is concluded that the term 'panic' is so deeply embedded in popular discourse that people may use it even when they have reason to reject its *irrationalist* implications.	(36) [28]		•			•	•				•	•	Irrationality is not an accurate theory for evacuation behaviour
One classical way of defining panic is to refer to an excessive and groundless feeling of fear which make people take an *irrational* and inappropriate course of action in an attempt to secure themselves.	(37) [119]		•	•			•					•	(i) Irrational behaviour is a symptom of panic (ii) Rationality is associated with evacuation efficiency

Table 6: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to H.	Links to P.	Def./ Cha. Ir.	Supp. Ir.	Cont. Ir.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
There are two possible ways that *irrationality* may be involved. First, definitions of panic often include exaggerated beliefs about threat and overreactions and so on. Second is the idea that the act of escape may be self-defeating.	(38) [119]		•	•			•					•	(i) Irrational behaviour is a symptom of panic (ii) Rationality is associated with evacuation efficiency
A common assumption regarding individual behavior in emergency is that. . .they panic and react in an antisocial and/or *irrational* manner: they show self-preserving behavior and little or no concern for their neighbors. . . a great deal of solidarity and pro-social behavior has been reported in such situations.	(39) [119]		•	•		•	•					•	Irrationality is not an accurate theory for evacuation behaviour
In the accounts, rather than the *irrational* panic or small group behaviour that has been suggested in previous simulations of crowd behaviour, survivors often described people forming orderly queues, acting calmly despite the emergency situation	(40) [136]		•	•		•	•				•	•	Irrationality is not an accurate theory for evacuation behaviour
The judgment of panic is usually made retrospectively, especially if serious loss of life occurred. But what may be considered inappropriate, excessive, *irrational* or highly intense by others may not be so judged by participants themselves.	(41) [123]		•			•	•					•	What seems irrational act, may be individual's best perceived course of action
Early accounts of 'mass panic' similarly suggested that collective behaviour was *irrational* because it was governed by primitive bio-psychological processes.	(42) [132]		•	•			•					•	Irrational behaviour is a symptom of panic
The most well-documented of these is "mass panic." This refers to an exaggerated or *irrational* fear that is said to spread through "contagion," leading to escape behaviors that are over-hasty, unthinking, and unrestrained by social rules.	(43) [31]	•	•	•			•					•	Irrational behaviour is a symptom of panic
In its more limited and correct usage, panic denotes *irrational* behavior in which judgment and consideration of reality factors are so poor that self-destructive activity may occur.	(44) [29]		•	•	•		•					•	(i) Irrational behaviour is a symptom of panic (ii) Rationality is associated with evacuation efficiency
In fact, 'panic' in the form of *irrational* behaviour is rare during fires and researchers have long ago rejected this concept to explain human behaviour in fire.	(45) [126]		•			•	•					•	Irrationality is not an accurate theory for evacuation behaviour

Table 6: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study							Comments/Interpretations
							Discipline				Study type			
		Links to H.	Links to P.	Def./ Cha. Ir.	Supp. Ir.	Cont. Ir.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
Incorrect decision-making due to incomplete information or insufficient resources is not the same as *irrational* decision-making and as such is not sufficient to categorise someone as panicking	(46) [34]		•			•	•					•	What seems irrational act, may be individual's best perceived course of action
Sime (1980) has fully explained the arguments to consider the concept of 'panic' as a poor and ineffective explanation of human behaviour in fire. In fact, 'panic', in the form of *irrational* behaviour, is rare in a majority of fires.	(47) [26]		•			•	•					•	Irrationality is not an accurate theory for evacuation behaviour
(i) It is possible to argue that the choice to herd can be result of a *rational* decision (i.e. a choice "procedurally reasonable in light of the available knowledge and means of computation") (ii) Herding behaviour can be the result of a *rational* decision-making process instead of an "*irrational*- panic" decision	(48) [50]	•	•					•			•		What seems irrational act, may be individual's best perceived course of action

"Qu./Ref. No." means Quote/Reference number.
"Links to P." means (The quote) links Irrationality (Ir.) to Panic (P.).
"Links to H." means (The quote) links Irrationality (Ir.) to Herding (H.).
"Def. Cha. Ir." means (The quote) defines/characterises Irrationality.
"Supp. Ir." means (The quote) supports (the theory of) Irrationality.
"Cont. Ir." means (The quote) contradicts (the theory of) Irrationality.
"Soc. Sci." means (The source of the quote) is a study in Social Sciences.
"Phys. Sci." means (The source of the quote) is a study in Physical Sciences.
"Bio. Sci." means (The source of the quote) is a study in Biological Sciences.
"Mod." means (The source of the quote) is a study with a main focus on Modelling.
"Emp. Test." means (The source of the quote) is a study with a main focus on Empirical Testing.
"Conc." means (The source of the quote) is a study with a main focus on Conceptualisation.
Note that individual studies can belong to multiple categories (e.g., multiple disciplines).

Table 7: Original quotes on the term herding.

Quotes	Qu. Ref. No.	Implications of the quote			The source study								Comments/Interpretations
							Discipline			Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
(i) The behaviour here is typical for panic situations, e.g. the *herding* tendency dominates. (ii) Such a behaviour is relevant for panic situations where this *herding* tendency becomes important and has been observed empirically (o.c.)	(1) [18]	•			•			•		•			(i) Herding is a feature of panic behaviour (ii) Herding is common evacuation behaviour
We found a non-monotonic dependence of the evacuation times on the coupling constants. These times depend on the strength of the *herding* behaviour, with minimal evacuation times for some intermediate values of the couplings, i.e., a proper combination of *herding* and use of knowledge about the shortest way to the exit.	(2) [18]				•			•		•			Herding can be beneficial to evacuation efficiency
(i) A large value of k_D implies a strong *herding* behaviour which has been observed the case of panics. (ii) The behaviour here is typical for panic situations, e.g. the *herding* tendency dominates.	(3) [18]	•		•				•		•			(i) Herding is a feature of panic behaviour (ii) Herding is common evacuation behaviour
Models of pedestrian crowds have generated a number of surprising or counterintuitive predictions. For example, panic should induce "*symmetry breaking*" in which some available exits or escape routes from enclosed spaces are jammed while others go under-utilized.	(4) [100]	•		•	•			•		•			(i) Herding is a feature of panic behaviour (ii) Herding is a common modelling assumption
We hypothesize that, under time and monetary pressure, subjects would increase their tendency to follow their neighbours as suggested in an early model of crowd panics [o.c.], which would give rise to the observed *herding* pattern under high stress.	(5) [40]	•		•	•			•			•		(i) Stress increases herding tendency (ii) Herding results from following neighbours

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
When the panic happens, the agents want to evacuate as quickly as possible and may try to choose the closest exit. At the same time, they may have the *herd* mentality.	(6) [101]	•			•			•		•			Herding is a feature of panic behaviour
Herding is stronger under high stress than under low stress. . .[but], pedestrians had a higher probability of following their neighbours when stress was high, simply because the neighbouring individuals were more numerous due to the increased density level. *Herding*, therefore, resulted from the crowdedness and not from a change in the individual tendency to imitate neighbours.	(7) [40]			•				•			•		(i) Stress increases herding tendency (ii) Herding tendency is moderated by the crowdedness level (iii) Herding is not the same as imitation
It remains unclear to what extent pushing, overcrowding and peer imitation [herding] can affect the efficiency of egress. The main obstacle to answering these questions is the scarcity of detailed empirical data.	(8) [40]							•			•		The effect of herding on evacuation efficiency is unclear
Although people often display obvious *herding* behavior, their judgment may not be to follow the crowd.	(9) [47]				•	•	•				•		Herding is not the same as imitation
Many studies (o.c.) have reported that *herding* behavior often occurs in relatively large number of people in panic situations.	(10) [47]	•			•		•				•		(i) Herding is a feature of panic behaviour (ii) Herding is common evacuation behaviour

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote				The source study							Comments/Interpretations
							Discipline			Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
(i) Because *herding* behavior is not the dominant preference of people, peacetime training of how to escape an acute crisis would be critically important. (ii) We present novel evidence showing that people prefer searching for an exit and avoiding smoke rather than following the crowd [*herding*] regardless whether with intuition or deliberation when the crisis situation was activated. (iii) Reliable and consistent evidence shows that when facing a crisis (e.g., fire), searching for an exit and avoiding smoke are preferred by people rather than following the crowd [*herding*]	(11) [47]					•	•				•		Herding is not common evacuation behaviour
Herding coefficient. . . α indicates an evacuee's tendency to emulate others' strategies, and (1-α) reflects the degree to which evacuees prefer to choose their own strategy based on personal experiences.	(12) [36]			•				•		•			Herding means imitating/following others/majority
Most individuals (90% of total individuals in subway station) select the evacuation exit that is closest to them, while others totally panic (5% of total individuals in subway station) and follow the flow of the crowd around them [*herding*] (5% of total individuals in subway station).	(13) [16]	•		•	•			•		•			Herding is a feature of panic behaviour
While we can thus rule out the *herding* effect in our experiment, we should point out that in different scenarios tendencies to follow others could be more prominent. For example, consider the case of an environment in which the exit routes are less clear than in our experiment or even entirely unknown.	(14) [52]			•		•			•		•		(i) Herding means imitating/following others/majority (ii) Herding is not common evacuation behaviour (iii) Herding tendency is moderated by the level of uncertainty

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
The direction that more pedestrians moving to is more attractive. Such behavior is the *herding* behavior.	(15) [137]			•	•			•		•			Herding means imitating/following others/majority
The excessive herding behavior can reduce the evacuation efficiency.	(16) [137]							•		•			Herding is detrimental to evacuation efficiency
Our study just investigates the fundamental collective effects which fluctuations, increased desired velocities, and *herding* behaviour can have, independently of whether all criteria of panics are fulfilled or not.	(17) [103]	•		•	•			•		•		•	
…possible mechanisms underlying the effects of escape panic (regarding an increase of the desired velocity, strong friction effects during physical interactions, and *herding*).	(18) [19]	•			•			•		•		•	Herding is a feature of panic behaviour
In case of an evacuation, people may also be influenced by the behavior of other people, and copy this. . .Ariely considers this to be *herding* behavior	(19) [58]			•	•			•			•		Herding means imitating/following others/majority
The models showed that people were inclined to stay at the concert area but when they saw others leaving, they were inclined to leave as well. The results seem to imply that *herding* is impulsive	(20) [58]			•	•			•			•		Herding is observable in movement initiation
The effect of *herding* behaviour might be different when people are in a known environment. . .Collecting data in known environments could provide insights on this.	(21) [58]							•			•		Herding tendency is moderated by the level of uncertainty

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
Knowing how much stress people experience, could show differences in the effect of *herding* on evacuation choices	(22) [58]							•			•		Herding tendency is moderated by stress level
Herding effect (i.e., *herding* behavior), considered as a common phenomenon in various fields such as emergency evacuation of large crowds, has caught much interest of scholars.	(23) [8]				•			•		•			Herding is common evacuation behaviour
For large population to escape from danger in a closed building with two symmetrically located exists or paths, *herding* effect means that the great majority of people adopt the same one in escaping, leaving the other one vacant.	(24) [8]			•	•			•		•			Herding means imitating/following others/majority
(i) *Herding* effect usually means inefficient utilization of resources, thus often leading to inferior outcomes in real life. (ii) Asymmetric utilization of escaping exits in emergency due to *herding* effect will decrease evacuation efficiency and bring disastrous consequences	(25) [8]			•	•			•		•			Herding is detrimental to evacuation efficiency
Herd behaviour is manifested, with underutilisation of other exits.	(26) [17]			•	•			•		•			Imbalanced use of exits is evidence for herding

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study							Comments/Interpretations
							Discipline			Study type				
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.		
As evacuees choose to follow others during a game, *herding* behavior will occur in the evacuation process.	(27) [37]			•				•		•				Herding means imitating/following others/majority
We use the hypothesis of *herd* behaviour to model the passenger decision-making process that leads to self-evacuation	(28) [43]			•	•			•		•				Herding is common modeling assumption
In an emergency, passengers on the periphery of the event are usually unaware of the details of the situation. Rather, these passengers usually adopt a *herd* mentality and evacuate immediately for their security.	(29) [43]				•			•		•				(i) Herding is common evacuation behaviour (ii) Herding tendency is moderated by the level of uncertainty
We first introduce a new microscopic model characterized by an exploration phase and an evacuation phase. The main ingredients of the model are an alignment term, accounting for the *herding* effect typical of uncertain behavior, and a random walk, accounting for the need to explore the environment under limited visibility.	(30) [44]				•			•		•				(i) Herding is common modeling assumption (ii) Herding tendency is moderated by the level of uncertainty

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study							Comments/Interpretations
							Discipline				Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.		
The crowd control technique investigated in the previous sections relies on the fact that pedestrians actually exhibit *herding* behavior in special situations	(31) [44]				•			•		•				Herding is common evacuation behaviour
A prototype system has been developed, which is able to demonstrate some emergent behaviors, such as competitive queuing, and *herding* behaviors.	(32) [39]				•			•		•				Producing herding effects is a common criterion for verifying simulation models
Herding behavior is often observed during the evacuation of a crowd in a room with two exits—one exit is clogged while the other is not fully utilized.	(33) [39]			•	•			•		•				Imbalanced use of exits is evidence for herding
One well-known example of social proof under emergency situations is the *herding* behavior—when under highly uncertain and stressful situations, an individual tends to follow others almost blindly.	(34) [39]			•	•			•		•				(i) Herding means imitating/following others/majority (ii) Stress increases herding tendency (iii) Herding tendency is moderated by the level of uncertainty
Sometimes *herding* behavior helps people to exit safely, and at other times, the *herding* behavior may lead people to a dead end or cause the blockages of some exits even though other exits are not fully utilized.	(35) [39]				•			•		•				The effect of herding on evacuation efficiency is unclear
Building designers often assume that a crowd would exit evenly among multiple exits of a room in case of an emergency; however, *herding* behavior invalidates such an assumption.	(36) [39]			•	•			•		•				Imbalanced use of exits is evidence for herding

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study							Comments/Interpretations
							Discipline				Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.		
In this paper the evacuation crowd system is abstracted into a dynamic complex network composed of three types of people, namely calm people, panic people, and *herding* people, as well as their interactions.	(37) [105]	•			•			•		•				Herding is common modeling assumption
If other people's behaviors show a high level of irrationality, such as screaming, rushing, colliding, pushing, etc., which provide salient evidence about panic emotion. . .one who has a certain *herding* level will tend to be "infected" and also present irrational panic behavior	(38) [105]	•	•	•	•			•		•				Herding is common evacuation behaviour
The evacuation of pedestrians from a smoke-filled room with two exits can lead to *herding* behaviour and clogging at one of the exits.	(39) [38]			•	•			•		•				Imbalanced use of exits is evidence for herding
During evacuation. . .Exit behaviors such as following leaders or *herding* to an exit are commonly observed.	(40) [138]				•			•		•				Herding is common evacuation behaviour
The agents choose their actions and evacuation routes by considering individual preferences, as well as the roles and the behaviors of the members in the social group and other neighboring agents [*herding*].	(41) [138]							•		•				Herding is not the sole determinant of the behaviour
In addition to static and dynamic fields, the extended model adopts the smoke and *herding* fields to reflect pedestrian's smoke-avoiding behavior and *herding* behavior.	(42) [137]				•			•		•				Herding is common modeling assumption

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
The direction that more pedestrians moving to is more attractive. Such behavior is the *herding* behavior.	(43) [137]			•				•		•			Herding means imitating/following others/majority
Study of collective behavior of mice has received increasing attention in the field of evacuation. Based on mice, scale-free behavior [o.c.], *herd* mentality [o.c.], learning experience [o.c.], etc. have been investigated.	(44) [90]				•				•		•		Herding theory in evacuation has been influenced by animal models of behaviour
Helbing et al. proposed the ignorance of available exits model, which suggested that neither simple individualistic nor *herding* behavior is optimal for escaping	(45) [59]								•		•		Mixture of herding and individualistic behavior is beneficial to evacuations
Pure *herding* behaviour infers that the whole crowd eventually moves in the same direction while other available exits are not efficiently used.	(46) [59]			•					•		•		Imbalanced use of exits is evidence for herding
Some studies have suggested that the direction of influence is such that we tend to copy the decision of the majority, and this tendency is often referred to as "*herd* behaviour".	(47) [53]			•				•			•		Herding means imitating/following others/majority
Herd behaviour has been assumed by a considerable body of literature (mostly theoretical studies) as a common default behavioural feature of pedestrian evacuees.	(48) [45]							•			•		Herding is common modeling assumption
Results also suggested that a simple *herd*-model may not suffice as a default universal assumption for realistic replication of evacuees' directional choices	(49) [45]					•		•			•		Pure herding is not an accurate modeling assumption

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study							Comments/Interpretations
							Discipline			Study type				
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.		
The symmetry breaking [*herding*] observed in nature is fascinating. This symmetry breaking is observed in both human crowds and ant colonies. In such cases, when escaping from a closed space with two symmetrically located exits, one exit is used more often than the other.	(50) [60]			•	•				•		•			(i) Imbalanced use of exits is evidence for herding (ii) Herding theory in evacuation has been influenced by animal models of behaviour
(i) We study the efficacy of allelomimesis [*herding*] as an escape strategy of mobile agents (pedestrians) that aim to leave a two-exit room within the shortest possible time. (ii) Allelomimesis is the act of copying one's kindred neighbors. (iii) Allelomimesis provides a simple yet versatile mechanism for studying the egress behavior of confined crowds in a multi-exit room.	(51) [46]			•				•		•				(i) Herding is common modeling assumption (ii) Herding means imitating/following others/majority
It is not hard to see that allelomimesis [*herding*] is a plausible mechanism for driving the emergence of herd behavior in crowds and animal groups.	(52) [46]			•	•			•		•				Herding theory in evacuation has been influenced by animal models of behaviour
When orientation and visibility is poor, such as in smoke-filled rooms or overcrowded areas, only the local information is accessible to each pedestrian. The situation encourages pedestrians to base their decisions on what they know, thus copying the actions of their immediate neighbors, which may result to *herding*.	(53) [46]			•	•			•		•				(i) Herding means imitating/following others/majority (ii) Herding tendency is moderated by the level of uncertainty

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
The assumption of *herd*-like behaviour does not necessarily apply to all contexts of evacuations and it should be considered in conjunction with the moderating role of context-specific factors, particularly the level of information available to individual evacuees.	(54) [48]							•			•		(i) Herding is not common evacuation behaviour (ii) Herding tendency is moderated by the level of uncertainty
We found that the ants demonstrated the phenomenon of "symmetry breaking" [*herding*] in this stress situation.	(55) [61]								•		•		Herding theory in evacuation has been influenced by animal models of behaviour
Blind copying promotes *herding* behavior in animal groups often with dire consequences to participants.	(56) [91]			•					•		•		Herding theory in evacuation has been influenced by animal models of behaviour
A binary logit model is proposed showing that the occurrences of HB [*herding* behaviour] are affected by both environmental and personal factors. In particular, the model shows that the personal aptitude to HB can have a key role in selecting an exit.	(57) [50]							•			•		Herding tendency should be considered in conjunction with individual differences
Three types of interactions among evacuees have been identified: *HB* (i.e. following others' behaviour), cooperative behaviour (i.e. working or acting together for the common/mutual benefit) and competitive/selfish behaviour	(58) [50]							•			•		Herding tendency should be considered in conjunction with individual differences
HB occurs whenever a decision-maker prefers, among different options, to follow other people's choices. As regards to the exit choice, this can be explained by the decision of the evacuee to choose an exit just because other evacuees had selected it, instead of striving to identify the exit that would provide them with the best evacuation conditions.	(59) [50]			•				•			•		(i) Herding means imitating/following others/majority (ii) Imbalanced use of exits is evidence for herding
The literature argues that *HB* could have both positive and negative effects depending on the evacuation conditions	(60) [50]							•			•		The effect of herding on evacuation efficiency is unclear

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
the degree of uncertainty can make the difference in the choice since the higher the uncertainty the more decision-maker could manifest *HB*.	(61) [50]							•			•		Herding tendency is moderated by the level of uncertainty
The model shows that the probability of having an occurrence of *HB* decreases with the increase of the difference between the number of persons close to the most crowded exit and the least crowded exit. . . what this means is that when this difference is very high, a decision maker prefers the least crowed exit	(62) [50]					•		•			•		Herding tendency is moderated by the crowdedness level
This "follow-the-crowd" [*herding*] behavior was proposed as a possible behavior of simulated humans	(63) [139]			•					•		•		Herding is common evacuation behaviour
Herding happens when ordinary people behave as a group, effectively surrendering their ability to function as individuals. In panic situations where decisions have to be made quickly under duress it is likely for individuals to lose their ability to decide on their own. Instead, these impaired individuals tend to imitate the action of their neighbors. The tendency to rely on others is a product of experience.	(64) [140]	•		•	•				•		•		(i) Herding is a feature of panic behaviour (ii) Herding means imitating/following others/majority
The severe congestion and high pressures that are induced or worsened by *herding* continue to exact a high cost to society in terms of infrastructure damage and loss of life and limb	(65) [140]				•				•		•		Herding is detrimental to evacuation efficiency

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote					The source study						Comments/Interpretations
							Discipline			Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
The role of *herding* in escape panic has been studied using equations of motion in the presence of interaction forces [o.c.]. However, quantitative comparisons between model prediction and experimental result have remained scarce.	(66) [140]	•							•		•		Herding theory is in need of empirical testing
The mice exhibited *herding* behavior while escaping from a pool of water in a two-exit flooded chamber.	(67) [140]				•				•		•		Herding theory in evacuation has been influenced by animal models of behaviour
The phenomenon of *herding* is a very general feature of the collective behavior of many species in panic conditions, including humans. It has been predicted theoretically that panic induced *herding* in individuals confined to a room can produce a non-symmetrical use of two identical exit doors. Here we demonstrate the existence of that phenomenon in experiments, using ants as a model of pedestrians. . . Our experimental results, combined with theoretical models, suggest that some features of the collective behavior of humans and ants can be quite similar when escaping under panic.	(68) [62]	•		•	•				•		•		(i) Herding is a feature of panic behaviour (ii) Herding is common evacuation behaviour (iii) Imbalanced use of exits is evidence for herding (iv) Herding theory in evacuation has been influenced by animal models of behaviour
(i) *Herding* prevented the full utilization of the two exits by the escaping mice. (ii) At the height of panic, allelomimetic tendencies dominate over individual decisions, giving rise to *herding*.	(69) [92]	•		•	•				•		•		(i) Herding means imitating/following others/majority (ii) Imbalanced use of exits is evidence for herding
People in a dark or smoky room are mimicked by "blind" students wearing eye masks. . . Surprisingly, adding more exits does not improve the situation in the expected way, since most people use the exit that is discovered first, which may be viewed as a kind of *herding* effect based on nonlocal, but direct acoustic interactions.	(70) [141]			•	•			•			•		(i) Imbalanced use of exits is evidence for herding

Table 7: Continued.

Quotes	Qu. Ref. No.	Implications of the quote				The source study							Comments/Interpretations
						Discipline				Study type			
		Links to P.	Links to Ir.	Def./ Cha. H.	Supp. H.	Cont. H.	Soc. Sci.	Phys. Sci.	Bio. Sci.	Mod.	Emp. Test.	Conc.	
Herd behaviour is manifested, with underutilisation of other exits. . .The choice model proposed in this work is based on the '*herding* behaviour': in a panic situation, the individual is inclined not to behave autonomously, but to imitate and follow the surrounding persons	(71) [17]	•		•	•			•		•			(i) Imbalanced use of exits is evidence for herding (ii) Herding is a feature of panic behaviour (iii) Herding means imitating/following others/majority
Humans do not tend to imitate direction choices of the majority [*herding*]. To the contrary, they tend to avoid the direction chosen by the majority, and the bigger the majority is, the less likely they are to follow it. The high-urgency treatment (assumed to be associated with higher degrees of stress) did not reverse, nor did it decrease this avoid-the-majority tendency. If anything, it even amplified it in certain choice situations.	(72) [41]					•		•	•		•		Stress does not increase imitation tendency [in direction choices]
The general level of crowding (i.e. the total number of people in the choice-maker's vicinity) is another factor that can moderate the reaction to peers' decision. Higher levels of crowding also amplified the avoid-the-crowd tendency [opposite the *herding*] in certain direction choice scenarios.	(73) [41]					•		•			•		Herding tendency is moderated by the crowdedness level
Imitative *(herd)* behaviour in direction decision-making hinders efficiency of crowd evacuation processes	(74) [49]							•		•			Herding is detrimental to evacuation efficiency

"Qu./Ref. No." means *Quote/Reference number.*
"Links to P." means *(The quote) links Herding (H.) to Panic (P.).*
"Links to Ir." means *(The quote) links Herding (H.) to Irrationality (Ir.).*
"Def. Cha. H." means *(The quote) defines/characterises Herding.*
"Supp. H." means *(The quote) supports (the theory of) Herding.*
"Cont. H." means *(The quote) contradicts (the theory of) Herding.*
"Soc. Sci." means *(The source of the quote) is a study in Social Sciences.*
"Phys. Sci." means *(The source of the quote) is a study in Physical Sciences.*
"Bio. Sci." means *(The source of the quote) is a study in Biological Sciences.*
"Mod." means *(The source of the quote) is a study with a main focus on Modelling.*
"Emp. Test." means *(The source of the quote) is a study with a main focus on Empirical Testing.*
"Conc." means *(The source of the quote) is a study with a main focus on Conceptualisation.*
Note that individual studies can belong to multiple categories (e.g., multiple disciplines).

Table 8: Review summary of the empirical studies on herding.

Ref.	Aspect of behaviour		Experiment method				Evidence of herding		Further details
	Exit (direction) choice	Exit (direction) choice changing	Reaction time	Human crowds	Virtual reality	Ants	Mice	Observed	Not observed	
[62]	•					•		•		Herding observed in the form of asymmetric use of exits by 'panicked' ants
[59]	•					•		•		The degree of asymmetry increased linearly with the temperature
[60]	•					•		•		The degree of asymmetry increased then decreased by ants' density
[61]	•					•		•		Ants under stress demonstrated the phenomenon of "symmetry breaking".
[42]	•			•		•			•	Symmetry breaking was associated with the difference in the width of exit in proportional ways
[140]	•						•	•		The mice exhibited herding behaviour while escaping from a pool of water in a two-exit flooded chamber
[92]	•						•	•		The mouse experiments yielded lower throughputs caused by herding. Herding prevented the full utilization of the two exits.
[91]	•						•	•		The occurrence of blind copying is suggested by the uneven (biased) utilization of the available pool space and exits by untrained members especially in the larger 30-mouse groups
[52]	•				•				•	Experiments in interactive virtual-reality setting ruled out the herding effect
[54]	•				•			•		[In a non-crowded virtual tunnel evacuation], participants under social influence treatment were more likely to follow the virtual agent
[55]	•		•		•			•		(i) [In a non-crowded virtual tunnel evacuation], Participants were less likely to move to the emergency exit in the conflict conditions compared to the no-conflict condition. (ii) The presence of passive virtual agent made subjects delay their movement reaction

Table 8: Continued.

Ref.	Aspect of behaviour		Experiment method					Evidence of herding		Further details
	Exit (direction) choice	Exit (direction) choice changing	Reaction time	Human crowds	Virtual reality	Ants	Mice	Observed	Not observed	
[56]	•				•			•		(i) [In a non-crowded virtual tunnel evacuation], exit choice is jointly influenced by both exit familiarity and by the egress behaviour of neighbours. (ii) Social influence increases with the number of neighbours
[50]	•				•			•		Occurrences of herding behaviour are affected by both environmental and personal factors.
[47]	•				•				•	People prefer searching for an exit and avoiding smoke rather than following the crowd
[40]	•				•			•		The observed herding patterns do not result from a change in the herding tendency but instead from the crowdedness
[58]			•		•			•		(i) The more people someone sees leaving, the more inclined this person is to leave. (ii) Seeing people leave has more impact than seeing people stay.
[64]			•	•				•		(i) Social influence is an important factor in reaction time especially when fire cue is unclear (ii) Social influence (on reaction time) increases with decreasing distance between visitors.
[48]	•			•					•	Social influence (on exit choice) is moderated by the level of decision ambiguity

Table 8: Continued.

Ref.	Aspect of behaviour		Experiment method					Evidence of herding		Further details
	Exit (direction) choice	Exit (direction) choice changing	Reaction time	Human crowds	Virtual reality	Ants	Mice	Observed	Not observed	
[45]	•			•					•	(i) Social influence (on exit choice) does not necessarily increases with decreasing distance between individuals. (ii) [In a crowded evacuation], exit choice is jointly influenced by both social interactions and physical factors (iii) Social influence increases with the number of neighbours
[53]	•			•					•	(i) Social influence is moderated by the effect of individual differences (ii) Social influence (on exit choice) does not necessarily act to the direction of herding
[41]	•			•					•	(i) Social influence acts to the opposite of herding (ii) Stress does not increase imitation tendency (iii) The number of neighbours moderate the social influence
[49]	•			•					•	Mis-specifying herding tendency can substantially bias modelling outcomes
[65]	•	•		•				•	•	(i) Individuals show clear imitative tendency in changing their exit choice decisions (ii) Individuals do not show herding tendency in their exit choices (iii) Herding tendency of individuals (in exit choice) does not increase by stress
[66]	•	•		•				•	•	(i) Social groups show clear imitative tendency in changing their exit choice decisions (ii) Social groups do not show herding tendency in their exit choices (iii) Herding tendency of groups (in exit choice) does not increase by stress

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