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Review

How occupants respond to building emergencies: A systematic review of behavioral characteristics and behavioral theories

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ABSTRACT

Understanding human behavior in building emergencies can benefit a wide spectrum of applications, which can ultimately contribute to the improvement of human safety in buildings, and potentially benefit outdoor emergency responses as well. This paper presents a holistic review of prior studies on occupant behavior during building emergencies, with a focus on important behavioral characteristics and explanatory behavioral theories. Based on a search in major databases, the authors identified a total of 164 relevant articles, dating back to the early days of this research area. These articles were reviewed and analyzed in detail to synthesize existing knowledge, particularly regarding the characteristics of various human behaviors in different building emergency contexts, and social and psychological theories that have been referenced to explain these behaviors and associated underlying cognitive and behavioral processes. Based on this review, research gaps, current research trends and directions for future research were also discussed. The review reveals that occupants' wayfinding behavior (i.e. moving towards a safe destination) in building fires has been the focus of prior research, while other types of behavior in response to different types of building emergencies have generally been understudied. Existing research methods in this area have their respective pros and cons, and usages of different methods have been evolving over time. The review also shows that different theories have been referenced ad hoc to explain different behaviors separately, and a holistic framework that incorporates all cognitive and behavioral processes of human involved in the entire building emergency response process could be valuable.

1. Introduction

Buildings play a significant role in our society (e.g., people in the U.S. spend 90% of their time indoors, such as offices, homes, airports, stores, etc. (Klepeis et al., 2001)). Thus, human safety in buildings has become an increasingly critical issue, especially during emergencies. A broad spectrum of emergencies, such as fires, earthquakes, and terrorist attacks, may occur in indoor and outdoor environments. In these circumstances, occupant behavior is one of the most critical determinants of occupant safety (Pan et al., 2006). For instance, fatalities and injuries result from undesired occupant behavior (e.g., pushing and competing) in many cases, rather than the actual hazards of building emergencies. Therefore, understanding occupant behavior in building emergencies is fundamentally important for the mitigation of the negative impacts of building emergencies. It can bring the following potential benefits: (1) advancing the knowledge about occupant behavior to inspire crowd behavior studies, support crowd evacuation simulations, and hence enable informed policy-making; (2) supporting the emergency relief efforts taken by building safety staff and first responders; and (3) facilitating building safety design and public emergency education.

Studies of human behavior in building emergencies date back to the 1950s, which witnessed an increase of natural disasters and a consequent increase of federal funding that supported relevant research (Fritz and Marks, 1954; CRED, 2017; Haddow et al., 2010). Research in this area slowed down since the 1980s because of overall funding reduction in the North America and Europe (Proulx, 2001), until the 2001 World Trade Center (WTC) attack, which boosted the research area again with a particular focus on the protection of humans in buildings against terrorism-related risks (Haddow et al., 2010). Through decades-long efforts, various theories have been developed to explain human behavior in building emergencies. Examples include panic theory (Quarantelli, 1954) and affiliative theory (Mawson, 1978). Research in this area is highly interdisciplinary, involving various domains, such as psychology, sociology, engineering, and computer science. Motivated by the increasing amount of studies in this area, several literature review efforts were made in the past. However, these reviews had limited

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scopes and did not reflect the complex and interdisciplinary nature of this area based on the foundation of theories; they were limited to certain types of buildings (i.e., hotels (Graham and Roberts, 2000) and residential buildings (Thompson et al., 2018)), emergencies (i.e., hurricanes (Huang et al., 2015) and fires (Kobes et al., 2010; SFPE, 2019)), types of human behavior (i.e., pre-evacuation behavior (Mu et al., 2013)), demographics (i.e., children and young people (Mytton et al., 2017)), and research methods (Haghani and Sarvi, 2017; Shipman and Majumdar, 2018). Since different demographics (e.g., elderly) may exhibit highly diverse behaviors that are largely dependent on the specific contexts of buildings and emergencies, prior reviews with their limited and fractured focuses could barely lead to a comprehensive understanding of the state of the art in this area. What further adds to the challenge is the difficulty to conduct drills and experiments that can evoke realistic emergency response behaviors, and to understand the strengths and limitations of different research methods within the context of various scenarios. A holistic review of human behavior in building emergencies would largely improve our knowledge, significantly benefit a range of downstream research areas, such as indoor crowd dynamics simulations and performance-based building design optimizations, and promote various safety measures, such as search and rescue training and public emergency education, that could eventually lead to improved human safety during building emergencies.

Driven by this motivation, this literature review has three objectives. The first objective is to synthesize the latest accomplishments in the area of human behavior in building emergencies, including the characteristics, mechanisms, consequences and explanatory theories of all human behaviors in building emergencies. The second objective is to synthesize findings from different domains, a critical step to advance our knowledge and to facilitate applications in this highly interdisciplinary area. The third objective is to identify gaps in the existing body of literature and provide guidance for future research. More specifically, this literature review is conducted to serve a number of purposes including: (1) to determine which types of human behavior, building, emergency, and research method have been studied in this area; (2) to provide an overview of key findings for each specific human behavior in building emergencies; (3) to provide an overview of key behavioral theories in this area; and (4) to identify the most recent research trends and directions for future research.

By achieving the above objectives, this literature review aims to make the following three contributions to the existing body of knowledge: (1) The review is holistic and not limited to any particular building, emergency or demographic context, and hence provides a comprehensive and comparative overview of existing research in this area, and demonstrate where existing knowledge is still lacking and research is needed; (2) This area has witnessed an increasing volume of literature, as the total number of relevant journal papers almost doubled in the past five years, and cornerstone works such SFPE Guide to Human Behavior in Fire (SFPE, 2019) were updated. This literature review captures the latest advancements in this fast-evolving area, and provide informed analysis of current trends and future directions; (3) To the authors' best knowledge, this is the first literature review that focuses on both characteristics of human behavior in building emergencies and the relevant behavioral theories, with in-depth analysis of their relationships. This can help advance the knowledge on the underlying mechanism of human emergency response behaviors, and evoke further interdisciplinary collaboration.

It needs to be noted that building occupants are the primary victims, whose main goal under such circumstances is to egress from emergency scenes with minimum risks of injuries, fatalities, and economic losses by taking appropriate actions. Apart from building occupants, people with other roles, such as building safety staff and first responders, may also be involved in and affected by building emergencies. However, due to the difference in their missions, responsibilities and professional training they receive routinely, their behavior during building emergencies is not alike occupant behavior. This paper focuses on occupant behavior during building emergencies. Unless otherwise specified, the word *'people'* in this paper mainly refers to building occupants and '*human behavior*' refers to the behavior of individual building occupants.

2. Methodology

To synthesize the latest accomplishments in the area of human behavior in building emergencies, this literature review covers a wide range of materials of various types, including journal articles, books, conference proceedings, reports and technical notes. To include high-impact publications, *Web of Science* and *Scopus* databases were used to search for relevant materials. The objective of the search was to find published works related to human behavior in building emergencies. Combinations of the following keywords were used in the 'topic' field, including 'human behavio*', 'building or indoor or built environment', and 'emergency or disaster or extreme event or extreme environment' and not 'simulat*'. The 'topic' field in *Web of Knowledge* and *Scopus* databases includes articles' keywords, title, and abstract. The reason to exclude simulation-based studies is that while the simulation is a widely used approach in this area, these studies are mostly focused on developing behavioral simulation models based on existing behavioral theories, instead of developing new theories or extending existing ones. To complement the limited amount of search results from the above keywords, titles of publications in the above search results were used in the 'topic' field of *Web of Knowledge* and *Scopus* databases to find related publications. Since some of the major theories in this area dated back to the 1950s, no restriction was set with respect to the year of publication when the above searches were conducted. To further enrich the search results, backward and forward snowballing strategy was also applied, based on references and authors of publications that were returned from the search (Jalali and Wohlin, 2012). In addition, the search results contained a number of irrelevant publications that needed to be filtered. This filtering was manually done by reviewing the title and abstract, as well as the full text when necessary, of each publication in the search results. To be considered relevant, a publication must provide information or evidence to fulfill the aforementioned research objectives using non-simulation-based approaches. Publications that did not meet the above criteria were considered irrelevant and hence excluded from the review.

As a result, a total of 164 publications were included in this review. Distributed between 1954 and 2019, these publications included 3 books, 33 conference papers, 120 journal papers, 3 reports and 5 technical notes. Top five sources of these publications were the following journals: *Fire Safety Journal* (18), *Safety Science* (17), *Fire Technology* (16), *Fire and Materials* (6), and *Applied Ergonomics* (6). Conference papers in the search results were distributed in a wide range of conferences with no apparent top conference in this area. According to the subject area classified in the Scopus database, 90 papers were published in venues that were related to engineering, followed by social sciences (40). Top six countries where these publications were originated from were United States (43), United Kingdom (39), China (31), New Zealand (14), Italy (10), and Canada (10).

The most frequently studied types of building emergencies included fires (61), terrorist attacks (7) and earthquakes (6), though a large portion of the publications (88) did not specify any particular type of building emergencies examined in their studies. In addition, in those publications that specified the type of buildings, residential buildings (14) and office buildings (12) were the most widely studied, followed by transportation buildings (e.g., stations) (10). Five widely used research methods in the literature included emergency drills (49), case studies (25), hypothetical surveys (28), VR-based experiments (28), and non-human animal experiments (7).

This literature review is organized as follows. Section 3 reviews the state of the art according to the classifications of human behavior in building emergencies. Section 4 presents a review of prior research that focused on different social, psychological, and behavioral theories that

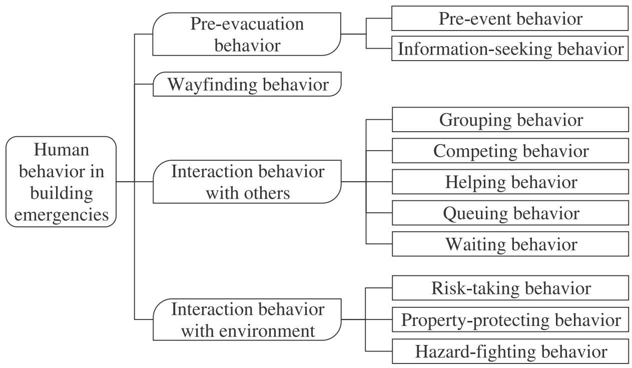

Fig. 1. List of human behaviors observed in building emergencies.

could explain human behavior in building emergencies. Section 5 synthesizes major findings and existing gaps and discusses current research trends and recommendations for future research. Section 6 concludes the paper.

3. Human behavior in building emergencies

Different types of human behavior have been observed in building emergencies and were examined in prior studies. These behaviors can be categorized into four types, as shown in Fig. 1. The behaviors before evacuation decisions made are called pre-evacuation behaviors (Dash and Gladwin, 2007; Kinateder et al., 2015). Wayfinding behavior is defined as moving (walking or running) towards a safe destination. Safe destinations could be building exits in fires and explosions, sheltered spaces from hazards (i.e. attackers and chemicals), top floors in floods, closed spaces in hurricanes, specific positions in earthquakes and collapses. Meanwhile, people may also interact with others and the environment, which are not necessarily aimed at direct evacuation. Interaction behavior with others is defined as an individual's interactions with other people in his/her immediate proximity. Interaction behavior with environment is defined as an individual's interactions with buildings and emergency hazards. What should be noted is that these types of behavior do not necessarily commence in a linear chronological order, and that one behavior may be observed at different stages of a building emergency. For instance, pre-evacuation behavior such as information-seeking could commence when wayfinding behavior is interrupted by hazards. Existing findings on the phenomena, characteristics, and impacts of each of these behaviors, based on a holistic review of prior studies, are summarized and discussed in the rest of this section.

3.1. Pre-evacuation behavior

A common behavioral phenomenon before an evacuation begins is that people may not immediately realize that they need to start evacuation (Liu and Lo, 2011). People may need time to perceive environmental cues related to building emergencies, such as fire alarms and instructions from staff (Rahouti et al., 2018; SFPE, 2019), to determine the severity of the emergency (Meng and Zhang, 2014). There are two types of pre-evacuation behavior, including pre-event behavior and information-seeking behavior. A prior study found that 65% of the people who had experienced building emergencies continued their pre-event behavior before starting to evacuate (Kuligowski and Hoskins, 2010). Information seeking behavior is *"the purposive seeking for information as a sequence of a need to satisfy some goal"* (Wilson, 2000), which could be triggered and impacted by the risk level, task complexity, and time pressure (Gu and Mendonça, 2008). Kuligowski (2011) studied the 2001 WTC attack and developed Lindell and Perry's (2004) Protective Action Decision Model (PADM) for explaining why specific actions were performed before evacuation. Based on Kuligowski's work (2011), Gwynne (2012) further developed a process to make qualitative predictions, who called for further validation of the process and model in other incidents.

Empirical evidence has indicated that pre-evacuation behavior may significantly delay people's emergency responses, and increase total evacuation time by up to hours (Kuligowski and Hoskins, 2010). Most prior research that aims to assess and decrease the negative impact of pre-evacuation behavior has focused on examining people's risk perception under building emergencies (Kinateder et al., 2014), as risk perception largely determines whether people would require extra time to seek information and how long it delays evacuation (Lerup et al., 1980). Risk perception in the context of building emergencies is defined as people's psychological processes of subjective assessment of the probability to be affected by building emergencies, one's own perceived vulnerability, and available coping resources (Kinateder et al., 2015). Several theoretical frameworks of risk perception have been used in building fire evacuation studies to understand the process of risk perception, including heuristic-systematic models (Kahneman and Tversky, 1979), appraisal models (Lazarus and Folkman, 1984), protective action models (Houts et al., 1984), reasoned action models (Sheppard et al., 1988), hazard to action chain model (Wachinger et al., 2013), security motivation system (Szechtman and Woody, 2006), and mediator hypothesis (Martin et al., 2010). Factors potentially modulating risk perception have been identified, including situational factors, individual factors, social factors and organizational factors. How specific cues of different types of factors impacted risk perception and pre-evacuation behavior was based on a process of sensing, paying attention, comprehending, processing, decision-making and taking actions (SFPE, 2019).

3.2. Wayfinding behavior

How to arrive at targeted destinations safely in the shortest possible time is occupants' primary goal in building emergencies. Wayfinding includes cognitive processes of goal setting, perception of environments, acquisition of spatial knowledge, assessment of distance and direction to the destination, decision making, and movement (Darken and Peterson, 2001). In building emergencies, people need to make a series of wayfinding decisions, such as how to choose a route at each intersection and whether to update their targeted destinations and route choices given dynamically changing environments. Targeted destinations vary across different emergencies. For instance, occupants in terrorist attacks tend to find a way to spaces sheltering them from attackers but occupants in flooding buildings will go upstairs to floors with roof and no flooding. How people make wayfinding decisions and take subsequent actions is of crucial importance to the efficiency of their evacuation. Therefore, wayfinding behavior has been studied extensively in prior research.

There is a variety of factors that could impact wayfinding behavior. The foremost important factors are building attributes. Signage systems are critical to egressing behavior and transferring behavior. However, statistics in the 1990s involving 400 cases showed that 92% of people who experienced building fires did not follow signage systems to evacuate (Ouellette, 1993). Although people usually know that complying with signage systems increases their safety level during emergencies (Vilar et al., 2014), when they are under the influence of stress, they may not notice and follow signage systems during wayfinding (Ouellette, 1993; Proulx, 1993). Thus, recent research has looked into how to improve the effectiveness of signage systems in guiding occupants to pass through safe routes (McClintock et al., 2001). This has led to the development of a few novel designs of signage systems, such as a smart exit sign system (Ferraro and Settino, 2019; Vilar et al., 2018), reflective and continuous signage systems with photoluminescent materials (D'Orazio et al., 2016; Occhialini et al., 2016), flash lights at emergency exit portals in road tunnels (Ronchi et al., 2016), and an exit signage that dissuades people from taking certain routes (Olander et al., 2017). Another building attribute that impacts people's wayfinding behavior is vertical transportation, such as going up to avoid flooded floors and going down to egress buildings in earthquakes. Since most modern buildings have multiple floors, people usually need to move between floors, during which they face the choice of whether to use stairs or elevators. This choice is especially critical in high-rise buildings because of the longer travel distance and time compared with mid- and low-rise buildings. People have been educated that using elevators in building emergencies is unsafe, thus stairs are more widely used in building emergencies (Gerges et al., 2017). Nevertheless, the efficiency of evacuation via stairs is limited by the occupancy density. When people try to enter the stairway with the presence of crowds already on the stairs, the speed of crowd movement will decrease due to the merging of the flows (Chen et al., 2018). In addition, people tend to use main stairs while ignoring other available stairs, which may overload the main stairs and reduce the evacuation efficiency (Averill et al., 2005; Gerges et al., 2017). Recent research has addressed the need for emergency-safe elevators, which can effectively facilitate evacuation, especially for those with disabilities and for search and rescue operations (Bukowski, 2012). What is more commonly seen is that people's preference for using elevators is largely decreased in building emergencies compared with normal conditions (Kinsey et al., 2012). This indicates that when emergency-safe elevators are used, additional training of building occupants may be necessary.

Wayfinding behavior is also affected by personal factors, such as vision impairment (Zhang et al., 2019), familiarity with space layout (Cao et al., 2019; Lin et al., 2019), and care for personal belongings (Kuligowski et al., 2013). Vision impairment would slow down wayfinding, especially when there are obstacles on the way (Zhang et al., 2018). Observations of past emergency incidents showed that people usually follow familiar routes or choose familiar exits (Graham and Roberts, 2000; Sime, 1985; Yoon and Sugahara, 1989). One possible reason is that people tend to perceive familiar routes as shorter than unfamiliar ones (Moeser, 1988). Some studies have pointed out that blindly following familiar routes or exits not only may lead to longer travel distance and travel time, but also may increase risks of injuries and fatalities as the routes may be blocked by fire and smoke (Ramachandran, 1990; Sime, 1985; Tang et al., 2009). Thus, the efficiency of following familiar routes and exits is decided by the available routes, i.e. the certainty and accuracy of information, the length, occupancy density and obstacles (Gwynne, 2012; Sime, 1983). Social influence (e.g., choosing the same routes as others) may strengthen the tendency of evacuating via familiar routes (Kinateder et al., 2018). Social influence may also interact with other factors to affect occupants' route choices in building emergencies. For instance, Bode and Codling (2013) reported the interaction effect between signs and social influence on exit choices. Benthorn and Frantzich (1999) also reported that there was an interaction effect between the visibility of outdoor environments and social influence.

Social factors, by themselves, also have a critical impact on wayfinding behavior. One example of wayfinding behavior affected by social factors is herding phenomenon (Lovreglio et al., 2016), which suggests that people tend to imitate others wayfinding behavior (e.g., crowd of relatives, friends and even strangers) during building emergencies. When it comes to the exit choice, herding may help people evacuate safely, as people who are not familiar with the building can follow others to exits (Lovreglio et al., 2014). However, herding could also lead to unbalanced use of exits, causing inefficiencies in evacuation (Altshuler et al., 2005). Moreover, people may follow the wayfinding behavior of certain individuals, such as 'leaders' (Aguirre, 2005) and 'neighbors' (Kinateder et al., 2018). In building emergencies, leaders may emerge temporally during the response process, who instruct people to move to the safe destinations, help others or exhibit other behaviors to help the crowd respond to emergencies. Leaders could be either individuals of the social groups or strangers. People may follow leaders to judge whether a building emergency has occurred and when they should start evacuation (Haghani and Sarvi, 2017; Pan, 2006). The role of leaders suggests that the knowledge and skills of leaders may largely affect the evacuation outcomes of an entire group (Aguirre, 2005).

3.3. Interaction behavior with others

People may interact with others during building emergencies, exhibiting various social behaviors such as grouping, queueing, helping, competing and waiting. These behaviors are not directly aimed at wayfinding but might have significant impacts on the response process and outcomes. It has been frequently observed that people may form a group with their social members before wayfinding begins (Galea and Burroughs, 2015), and such grouping is usually maintained during the following processes. Empirical evidence has also shown that people may queue by the stairs, exits and elevators in crowded situations (Gerges et al., 2017; Nicolas et al., 2017; Saloma et al., 2003). While queueing, other situations may occur, such as elders falling down or someone cutting line causing chaos. Under such circumstances, people may be inclined to offer help to others, especially to those with disabilities or physical injuries (Aguirre, 1994; Johnson, 1987), or compete with others for personal space (Johnson, 1987). Shiwakoti et al. (2017) conducted a survey in a train station, and reported that people were generally more likely to help others than to compete. However, researchers should analyze the extent to which these survey responses reflect true human reactions during real emergencies. Other researchers found that higher severity of emergency situations could increase the possibility of competing behavior, while helping behavior might not be affected as much (Drury et al., 2009b; Quarantelli, 1957). The same studies also reported that helping behavior would be more likely to occur when people share the same social identity (Drury et al., 2009b; Quarantelli, 1957). In addition, when people are trapped in buildings, due to limited access to safe destinations or impaired mobility, they may choose to wait at a safe place to be rescued (Proulx, 1995). People waiting to be rescued would call for help, such as sending messages to friends (Aguirre, 1994), seek protection from toxic smoke and flames (Kuligowski, 2011), or just passively wait for instructions and help (Proulx, 1995). Effective communication (Proulx, 1995) and efficient search and rescue in the initial hours (Form and Nosow, 1958; Wenger, 1990) are the key to the survival of these trapped occupants.

The consequences of interaction behavior with others during building emergencies are complicated. Competing behavior usually affects the overall evacuation process negatively and may lead to extra risks of physical injuries (Johnson, 1987). Grouping behavior is also linked with negative impacts in many cases, because it might delay the following processes (Proulx and Fahy, 1997). However, when people are grouped with those with injuries or disabilities, helping behavior is likely to occur, providing them with crucial assistance and relief (Aguirre et al., 2011). For queuing behavior, Proulx (2007) suggested that it may block routes and cause congestion. As a result, people's movements would be negatively affected by limited space in stairs, exits and elevators. Under such circumstances, individuals with low speed would slow down the movement of the crowd and cause significant negative consequences. However, several other studies argued otherwise, suggesting that under certain occupancy density, queueing behavior would actually foster people to follow the fastest evacuee in the group (Zhang et al., 2018) and hence improve their wayfinding performance (Pan, 2006).

3.4. Interaction behavior with environments

Risk-taking behavior is observed when people overlook potential threats caused by the external environment. A typical risk-taking behavior is taking shortcuts in hazard zones (Proulx, 2003), such as chemical smoke and falling items, which exposes people to the risks of direct injuries or deaths by hazards nearby (Hofinger et al., 2014).

Jumping out of windows is another typical risk-taking behavior that is occasionally seen in building emergencies (Bukowski, 2012). In addition, it has been observed at times that people may protect their property, such as preventing property nearby damaged by hazard (Lindell et al., 2016) and retrieving their property in hazard-intensive areas(Kuligowski et al., 2013). Property-protecting behavior may cause fatalities and injuries due to stays in hazard-intensive areas and even delays of the wayfinding process (Galea and Burroughs, 2015). Another interaction behavior between people and the environment is hazard-fighting behavior, where people take actions to fight with hazards in the environment, trying to contain emergency situations (Thompson and Wales, 2015). Hazard-fighting behavior is more often seen in residential building emergencies, likely due to the fact that people intend to protect their valuable belongings at home (Thompson and Wales, 2015). Yet, such behavior may cause injuries in that people usually have limited knowledge of hazards and incorrect assessment of emergency situations, and lack professional skills to fight the hazards (Thompson and Wales, 2015).

4. Explanatory theories for human behavior in building emergencies

In the 1950s, when human behavior in building emergencies first became a notable research topic, it was interpreted as a consequence of panic and irrationality under stress, with the panic theory (Quarantelli, 1954) and heightened emotionality theory (Janis, 1954) being the dominant theories at the time. Social interactions or affiliations were not considered until the 1970s when the social attachment theory (Mawson, 1978) and social identity theory (Tajfel and Turner, 1979) were proposed and attracted considerable attention. Later on, by accounting for the influence of social environment, prior theories were extended (Mawson, 2005, 1980; Sime, 1985), and new theories, such as the role rule theory (Canter, 1980), were established. These social or psychological theories were all drawn upon in one way or another for explaining the complex behaviors of building occupants when they are exposed to building emergency situations. A mapping between the theories and behaviors they are referenced to explain is illustrated in Fig. 2. However, since these theories were not originally motivated by or developed specifically for human behavior in building emergencies, they were mostly referenced ad hoc, which has inevitably resulted in various incongruities in their presumptions, cognitive models, and behavioral predictions, causing notable impediment to a deep understanding of the mechanism of human emergency response behaviors. Nevertheless, the above theories are reviewed and discussed in further details in a chronological order in the remainder of this section with the hope that future research would be provoked to develop a holistic framework that can incorporate all cognitive and behavioral processes of human involved in the entire building emergency response process. Such knowledge would enable (1) researchers to learn the shifting of the focus in this field in different stages and elaborate findings from a systematic and theoretical way by explaining results by different theories; (2) engineers to understand the knowledge that get consensus in research field and hence to guide building design safety tools; and (3) professionals to develop guidelines and apply tools to educate the public and emergency management team with precautions of theories suggested by these theories or the following research.

4.1. Panic theory

The panic theory was proposed by Quarantelli (1954) based on the analysis of a set of emergency cases. According to the panic theory, panic is *"the very antithesis of organized group activity as an acute fear reaction marked by loss of self-control, which is followed by non-social and non-rational flight"*. Panic behavior is usually caused by possible entrapment, collective powerlessness, and individual isolation. Social interactions were argued to have the ability to transfer the powerless feeling of an individual to other people which can ultimately result in panic (Quarantelli, 1954). All behaviors that are considered as losing self-control can be explained by the panic theory (Aguirre et al., 2011). For example, when people perceive that their personal space is too small to evacuate, they might lose self-control and hence compete with others (i.e., competing behavior). If there is no safe way to move, people may choose to jump out of the building or walk through smoke as they are driven by panic (i.e., risk-taking behavior). The panic theory was often cited in the early days of research on human behavior in building emergency. However, a number of studies after the 1970s debunked the panic theory, by arguing that despite the impact of stress people make rational decisions in building emergencies instead of losing self-control (Fahy and Proulx, 2009; Johnson, 1987; Mawson, 1978), and that real panic behavior is rarely seen in building emergencies (Fahy and Proulx, 2009).

4.2. Heightened emotionality theory (conflict-theory model)

Another theory formed in the early days of this research area is the heightened emotionality theory, first proposed by Janis (1954) based on a classification of the most frequently investigated evacuation behaviors in prior studies and further developed by Janis and Mann

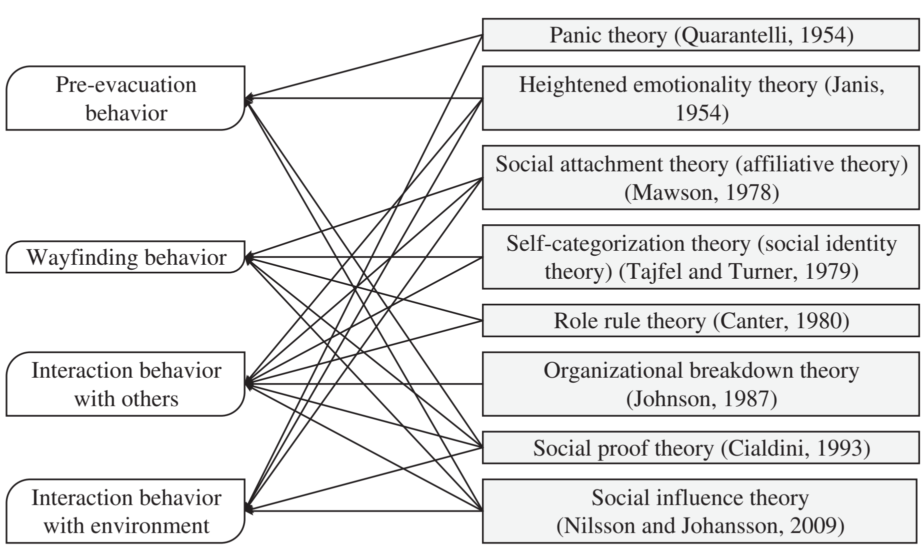

Fig. 2. Theories that have been referenced to explain human behavior in building emergencies.

(1977) to explain the decision making under stress. The classic heightened emotionality theory in 1954 considers all types of human behavior under emergencies as emotional responses to danger. According to the heightened emotionality theory, five typical behaviors are defined, including apprehensive avoidance, stunned immobility, apathy and depression, docile dependency, and aggressive irritability. These five behaviors may lead to loss of mental efficiency to some extent, which would then interfere with people's perception and decision-making and as a consequence reduce the efficiency of emergency evacuation and relief. The heightened emotionality theory also identifies two categories of factors that may affect those five emotional behaviors, including situational determinants and pre-dispositional determinants. Situational determinants include physical and social environments in building emergencies, whereas pre-dispositional determinants include existent inherent factors, such as emergency training, social roles and identities. The causal relationships between the above determinants and evacuation behaviors, however, are not clearly specified by the heightened emotionality theory, hence this theory is seldom cited in the literature due to its proposition for explaining human behavior in building emergencies.

4.3. Social attachment theory (affiliative theory)

The social attachment theory, also known as the affiliative theory, was proposed by Mawson (1978) and Sime (1983) based on extensive case studies, and was continuously developed in the following years (Mawson, 2005, 1980; Sime, 1985). The social attachment theory argues that people, when facing building emergencies, would behave differently when in crowds compared with being alone due to social interactions (Hofinger et al., 2014). Social attachment is one of the dominant motives of human behavior in emergencies. It has been used in a number of studies to explain human behavior in building emergencies from the view of social factors (Bode et al., 2013; Prati et al., 2013). For instance, Mawson (2005) pointed out that when the social attachment is present, human behavior would highly depend on social attachment and crowd behavior. Specifically, when the perceived degree of physical danger is low, people would tend to exhibit grouping behavior first and then evacuate along familiar routes; when the perceived degree of physical danger is high, people would be affected by social interactions to follow others' competing behavior and risk-taking behavior.

4.4. Self-categorization theory (social identity theory)

The self-categorization theory, also referred to as the social identity theory, was proposed by Tajfel and Turner (1979) and elaborated later by Turner (1982). Drury et al. (2009a) further developed the self-categorization theory based on case studies of mass emergency events. According to the self-categorization theory, individuals would establish social bonds with others to form social groups in building emergencies. People consider themselves as members of social groups who are all threatened by building emergency situations, and hence behave on the basis of their social identity and act collectively (Drury et al., 2009a). The self-categorization theory, which has been widely applied in crowd simulations, is one of the mainstream theories used to explain helping behavior, queuing behavior, and leader-following behavior (Drury et al., 2009a; Drury and Reicher, 2000; von Sivers et al., 2016). Specifically, an individual caught in a building emergency who shares the same fate with others is considered as one possible psychological candidate for shared self-categorization. People would help social group members based on the same social categorization and queue in lines consisting of members in social groups. People would follow the evacuation instructions of familiar people if they have the same social identity.

4.5. Role rule theory

The role rule theory, first proposed by Canter (1980), posits that people are influenced by pre-event actions and social roles, which altogether are termed as role rules (Tong and Canter, 1985). The role rule theory emphasizes that role rules in daily life largely determine human behavior in building emergencies (Canter, 1980). This theory has been used to explain helping behavior and leader-following behavior, and is considered in many evacuation simulation studies (Chu and Law, 2018; Owen et al., 1997). According to the role rule theory, people's decision to help others in building emergencies may be based on their roles in daily life (Canter, 1980). For instance, Tong and Canter (1985) found that males in building emergencies are likely to help females due to males' masculine role in daily life in certain cultures. The role rule theory also suggests that the reason for some people to emerge as authoritative leaders during a crisis is because of their roles in daily life (Canter, 1980). For instance, restaurant waitresses in building emergencies would lead patrons during evacuations, because they are expected to serve patrons as waitresses prior to the emergency (Tong and Canter, 1985). That being said, it is noteworthy that leaders in building emergencies do not always have to be leaders prior to the events. As Aguirre (2005) argued, people may emerge and act as situational or temporary leaders during emergencies. Yet, some studies pointed out that the role rule theory may not always apply, and not all people would behave based on their social roles. Rahouti et al. (2018) reported, for instance, that during a fire drill, although patients started to evacuate by following instructions of hospital staff, the majority of the patients made their own exit choices regardless of the suggested routes provided to them.

4.6. Organizational breakdown theory

Another explanatory theory is the organizational breakdown theory. First proposed by Johnson (1987), the organizational breakdown theory largely rejects the panic theory, and argues that selfish and aggressive behaviors that are often observed during the crisis are the results of broken social orders. Organizational breakdown theory suggests that functioning social order would constrain individual behavior because of the norms of civil behaviors and role expectations, and hence prevent competition among individuals. However, organizational breakdown theory is rarely used in current studies due to the difficulty of identifying social orders. Organizational breakdown theory explains why people sometimes may compete with others when caught in building emergencies, but in some other times may choose to help others as they would normally do in daily life. Specifically, when the emergency situation is not severe, the social order would remain functional and people would help each other to meet their role expectations in their daily life. However, severe building emergencies can weaken the social orders, and as a result people may become less constrained by social orders and more likely to compete with each other (Cocking et al., 2009).

4.7. Social proof theory

The social proof theory was proposed by Cialdini (1993) to explain the influence of persuasion. Social proof is defined as "*the tendency to act in certain ways simply because others do*". Pan et al. (2007) referred to the concept of social proof to explain human behavior in building emergencies with the presence of crowds. Lovreglio et al. (2014) combined social proof theory and social influence theory to explain herding phenomenon in the wayfinding process. Based on the social proof theory, the initial reactor in a group who first behaves differently, such as the first individual to take an evacuation route or to begin to help others, is critical (Pan et al., 2007). If no one breaks the ice to react to the building emergency, according to the social proof theory, all people would wait at their initial positions or continue their pre-event activities. Once the crowds begin to evacuate, every individual would follow the crowds' behavior, such as wayfinding, in order to seek social proof. Similarly, if the crowds compete for personal space, individuals would choose not to evacuate orderly but compete with others as a way to seek social proof. In summary, the behavior exhibited by the crowds in building emergencies would lead all individuals to take the same behaviors.

4.8. Social influence theory

One recent theory that has been used to explain human behavior in building emergencies is the social influence theory. This theory was first proposed by Nilsson and Johansson (2009), based on the analysis of data collected in unannounced evacuation experiments that were designed to understand the initial phase of a fire evacuation. More recently, this theory has also been referenced to understand other types of occupant behaviors during evacuation (Lovreglio et al., 2016, Lovreglio et al., 2014). The social influence theory argues that there are two types of social influence, namely informational social influence and normative social influence. Informational social influence affects peoples' behavioral responses in building emergencies through their observations of surrounding people, whereas normative social influence affects people's behavioral responses by persuading them to act as others do. According to the social influence theory, people observe others' behavior and are impacted by them, especially when the environmental cues of building emergencies are ambiguous, the social bonds are strong, and the distance from others is short (Nilsson and Johansson, 2009). The social influence theory has been used to explain pre-evacuation behavior, competing behavior, helping behavior and wayfinding behavior. Specifically, people may show helping behavior or competing behavior because the informational social influence indicates the need of providing help to others or the need for personal space. If no one begins to evacuate, individuals may be affected by normative social influence and hence delay their own evacuation.

It is noteworthy that the social attachment theory, social identity theory, social proof theory and social influence theory share some common grounds with respect to the explanation of various types of human behavior in building emergencies, such as herding and leader-following from a social perspective. These theories differ, however, in their views of the social context. On the one hand, social attachment theory focuses on the effect of the relationship between individuals and the social environment in building emergencies. Social identity theory shares this view but emphasizes that the relationship has a precondition, namely the presence of social groups. Social identity theory further explores the formation of social groups during building emergencies. Social proof theory, on the other hand, suggests that humans tend to act in certain ways simply because others do, namely their primary motivation is to seek social proof, regardless of the existence of social attachment or social bonds. The role of social proof is further described by social influence theory based on two motivations, namely active motivation (normative social influence) and passive motivation (informational social influence), which explain the impact of interpersonal interactions on evacuation behavior. For instance, if an injured person sits on the floor and calls for help, an individual would perceive this expectation from others to offer help as active motivation; if surrounding people are seeking information for identifying whether they should evacuate, an individual would observe others' behavior as a passive motivation to act like others.

5. Discussions

5.1. Building types and occupant demographics studied in prior research

Building types may affect human behavior during building emergencies in several ways. Proulx and Pineau (1996) found that human behavior during emergencies differed notably between office buildings and residential buildings. Human behavioral responses would also vary from office floors and residential floors in multi-purpose buildings when emergencies happen (Horiuchi et al., 1986). For example, people tend to fight with a dwelling fire and re-enter residential buildings (Thompson and Wales, 2015), whereas these behaviors are rarely seen in other types of buildings (Thompson et al., 2018). This is probably due to the stronger attachments people have to physical belongings as well as stronger social bonds in residential buildings, which would motivate them to protect their belongings, relatives and friends, by taking fire-fighting behavior and returning behavior (Mawson, 2005). Additionally, people's pre-event behavior also depends on the type of building. For example, people are likely to be sleeping in residential and healthcare buildings when an emergency occurs, thus people's responses to emergencies are often delayed in these buildings, compared to other types of environments, such as office buildings (SFPE, 2019).

Moreover, human emergency response behavior also differs between types of indoor spaces they are likely more familiar with, such as homes and offices, and those they are less familiar with, such as hotels and concert halls; and between types of indoor spaces that have complex layouts, such as museums and transport hubs, and relatively simple ones, such as houses and apartment buildings. It is noteworthy that, even though people may be familiar with a building in normal conditions, they may still find certain escape routes and emergency exits unfamiliar during emergencies (Sime, 1983). In addition, the warning and emergency management systems differ between types of buildings, which will affect pre-evacuation behavior (SFPE, 2019). For instance, it is common to have broadcasting systems in transportation buildings but not office buildings.

The majority of prior studies (114 out of 164) did not specify the types of buildings they used or aimed to study. Two types of buildings were relatively well studied, including residential buildings (14) and office buildings (12). The mechanism of how building types affect human behavior in building emergencies deserves further investigation (Horiuchi et al., 1986; Proulx and Pineau, 1996; Thompson et al., 2018; Thompson and Wales, 2015). Answers to this critical question would enable the assessment of generalizability of findings on human emergency response behavior derived from a particular indoor environment to other building contexts and guide the development of effective building-specific measures for intervening evacuation processes and mitigating building emergency hazards. Moreover, these answers may also benefit the understanding of human behavior in outdoor emergencies, as it is possible to extrapolate many of the principles discussed in an indoor context to outdoor emergency situations.

Building types could largely determine the types of occupants and their demographics, such as their age and occupation. However, only several types of occupants have been specifically studied, including students (5), vulnerable people (5), children (3), patients (3), and people with learning difficulty (1) or visual impairment (2), while the majority of prior studies did not specify any particular occupant type. Future research is needed to examine how characteristics of different types of occupants may potentially affect human responses and how occupants with different characteristics interact in building emergencies. For instance, it is widely projected that aging population is one of the most significant social transformations in the coming decades, and the number of people with other special needs is increasing (UN DESA, 2019; WHO, 2018a, 2018b, 2015). Compared with other occupants, elderly people or those with special needs are different in their physical characteristics (e.g. movement speed) and they are usually in need of help during building emergencies, which necessitates more considerations of their behavior, their interaction with other people, and the formulation of evacuation management measures tailored to their needs.

5.2. Different types of emergencies studied in prior research

Different types of emergencies could happen in buildings, such as

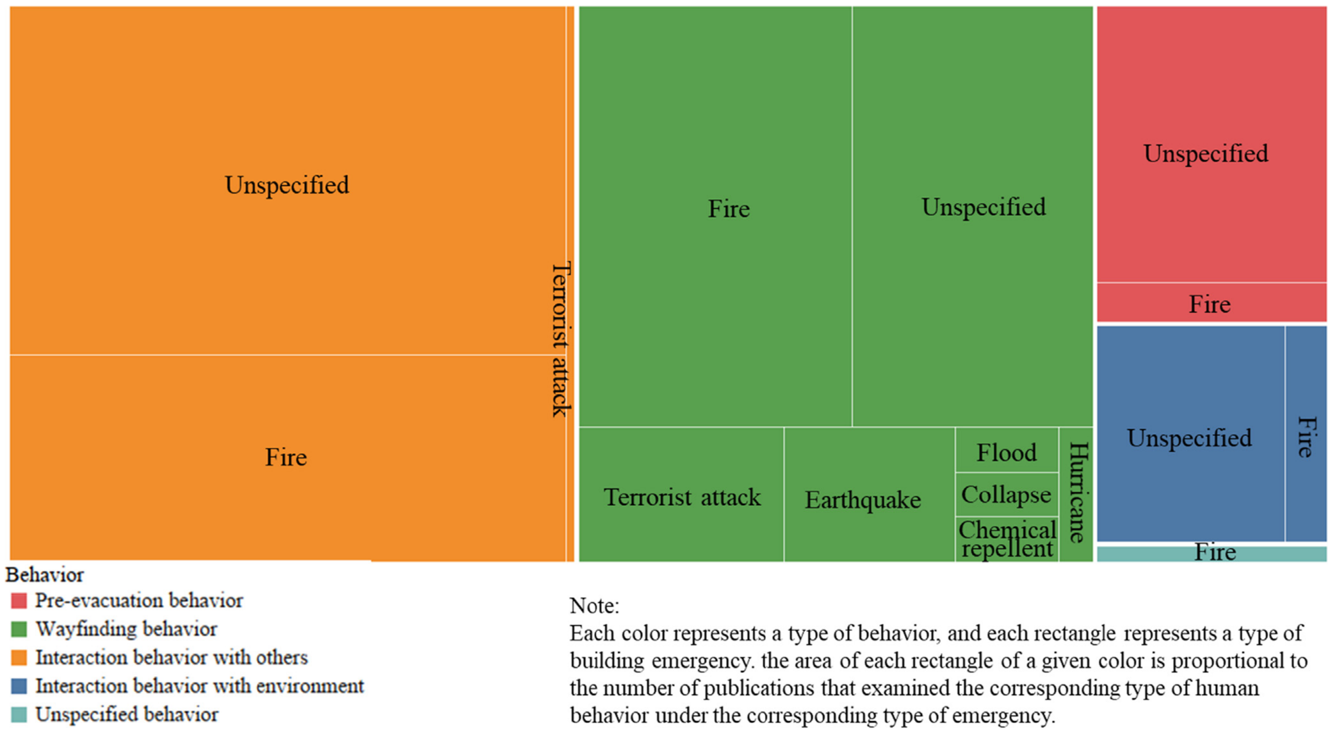

Fig. 3. Classification of prior studies by behavior type and building emergency type.

fires, earthquakes, flooding and terrorist attacks. An important question that needs to be answered is: what are the similarities and differences of human behavioral responses in different types of emergencies? To help answer the above question, a classification of all prior studies included in the search results described in Section 2 is presented in Fig. 3, using the types of the building emergency examined in the studies as a criterion. As can be seen in the figure, the majority of these studies did not focus on any specific types of emergency. It is hypothesized that the underlying assumption by these studies might be that stress is a primary determinant of human emergency response behaviors, and the nature and impact of stress are similar regardless of the type of emergencies. However, the effect of stress is highly dependent on the nature of the task and scenario (Raaijmakers, 1990), hence people may have different behaviors in different types of building emergencies.

Among different types of emergencies, fires, earthquakes and terrorist attacks are relatively well studied in prior research. For each of these emergencies, all types of human behavior in Fig. 2 have been observed and reported (Averill et al., 2005; Bernardini et al., 2019; Feng et al., 2018; Grimm et al., 2014; Knuth et al., 2014; Liu and Lo, 2011; Yang et al., 2012). These three emergencies are inherently different in terms of types of hazard and associated consequences (Knuth et al., 2014), and would, therefore, influence human behavior differently. First of all, different environmental cues can lead to significantly different initial behavioral responses (Gerges et al., 2017). For instance, people may be hiding under tables or by walls to protect themselves from the shaking of buildings caused by an earthquake (Feng et al., 2019). However, people usually tend to evacuate from current positions when fires break out. Second, the location of safe zones varies between different emergency contexts, which sets different wayfinding goals and requires different wayfinding strategies. For instance, people would flee from burning and shaking buildings to outdoor spaces, whereas the safe zone in terrorist attacks may depend on the positions of attackers and bombs. The above comparison suggests that human behavior under one type of building emergency may not necessarily be explainable and predictable by knowledge derived from other emergency contexts. Given that prior studies have largely focused on a limited types of emergencies, future research is needed to investigate other types of emergencies to reveal the similarities and differences of human behavioral responses in different emergency contexts, and to develop emergency-specific behavioral models or behavioral intervention strategies. Researchers could use the knowledge of this paper as a foundation to summarize the specific emergency contexts and human behavior from a theoretical perspective and then explore the validity of the numerous findings in prior studies with or without specific type of emergencies.

5.3. *Different types of human behavior studied in prior research*

The classification of prior studies as illustrated in Fig. 3 involves another criterion, i.e. the type of human behavior. There are several observations from this classification. First, wayfinding behavior is the most extensively studied, with a particular focus on and rich findings of route choice decision making and wayfinding performance. Interaction behavior with others has also drawn considerable attention of researchers, probably owing to the significance of social factors in the formation of human behavior, as all theories in Section 4 clearly point out the effects of social contexts. Interpersonal interactions in a crisis context are of particular interest to psychologists and social scientists whose research looks into the related cognitive and behavioral processes, as well as to engineers who need this knowledge to build crowd-level simulation models. Second, fire is the predominate type of emergency examined for each type of behavior. It is noteworthy that most other types of emergency, when they were examined in prior studies, were not associated with any particular type of behavior, and the investigation was focused on the impact of stress in general. Third, pre-evacuation behavior and interaction behavior with environment were relatively understudied, accounting for only 7.49% of all prior studies reviewed in this paper. While recent efforts have been made to examine pre-evacuation behavior (SFPE, 2019) (Gwynne, 2012; Kinsey et al., 2019; Kuligowski, 2011), future research should be carried out to also examine interaction behavior with environment, and its impact on the overall emergency response process and outcomes.

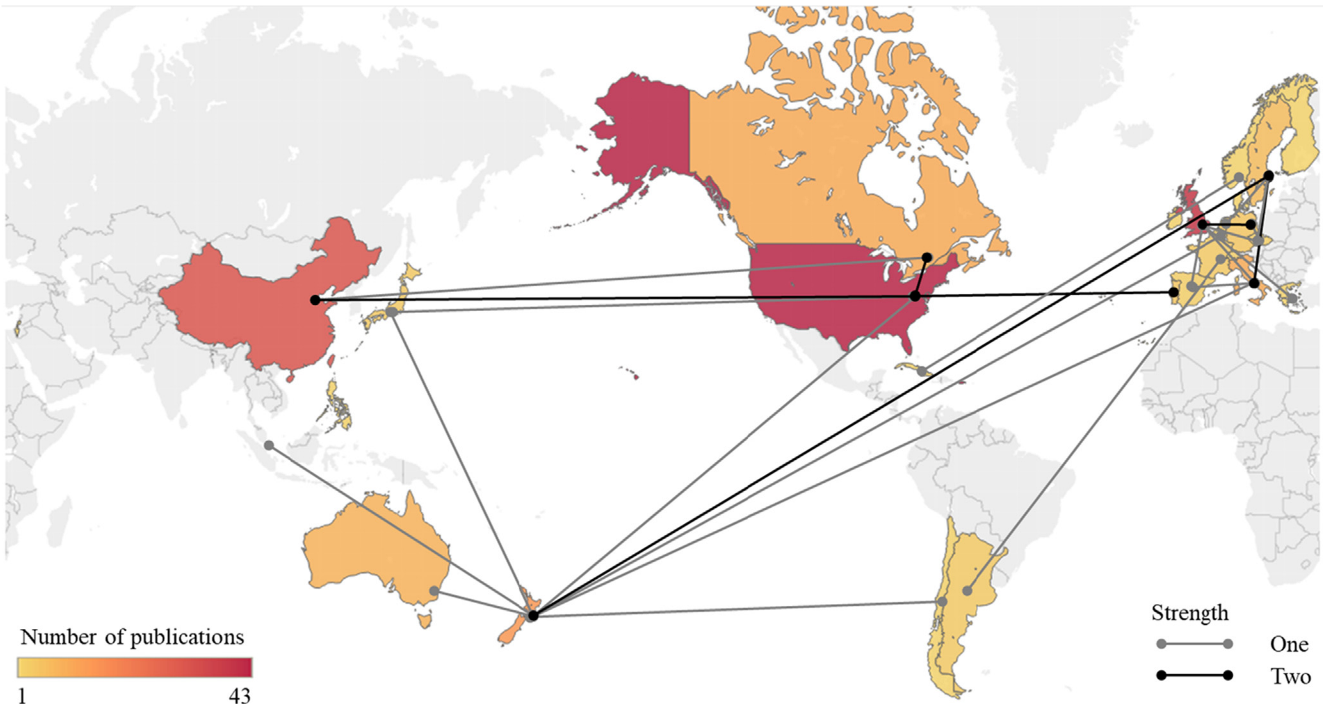

Fig. 4. Geographical distribution of prior studies and the strength of international collaboration.

5.4. Research efforts in different countries and international collaboration

The strength of international collaboration in this research area is analyzed, based on the country information of the authors' affiliation. The results are visualized in Fig. 4. The darkness of the color of each country in the figure is proportional to the number of publications from that country. The co-authorship relationships are represented by lines in the figure. Bibliographic data showed that a total of 25 publications were co-authored by researchers from different countries, accounting for 15.24% of all publications. Researchers from New Zealand, Sweden, the U.S. and the U.K. are the most actively involved in these international collaborations. The current strength of international collaboration is relatively low, partly due to the fact that different countries are faced with different challenges in buildings and occupant safety, and their concerns and priorities are therefore different. Such difference may be reflected in distinct interests of funding agencies and research focus of scholars, and hence to some extent hinder the cross-border collaboration. However, there is positive sign that international collaboration has strengthened in recent years, with an increasing number of joint publications, involvement of researchers from multiple countries, and emergence of several active research teams that are fostering such collaboration.

That being said, the international collaboration in this research area should be further strengthened, as it could have several important implications. First of all, many emerging threats to buildings and their occupants, such as terrorist attacks and climate change-induced extreme weather events, are global issues with global impacts. These challenges cannot be solved regionally and would require collaborative endeavors across borders. Second, international collaboration can encourage more cross-cultural comparative studies. Cultural background plays a potentially significant role in people's cognition, decision making and behavioral formation during a mental crisis, and may affect behavioral responses to building emergencies, such as their risk-taking tendency, and the likelihood of helping or competing with crowds. Behavior, Security, Culture (BeSeCu) was a project aiming at investigating human behavior in emergencies in European countries (BeSeCu-group, 2012). The project compared risk perception and behavioral responses in building emergencies in Czech Republic (Galea et al., 2010), Turkey (Galea et al., 2011), Poland (Galea et al., 2012) and U.K. (Galea et al., 2014). The findings indicated how people perceive and respond to emergencies might be potentially affected by the frequency of emergencies, emergency education, safety culture habits and building standards of their respective countries (BeSeCu-group, 2012; Knuth et al., 2014). Lindell et al. (2016) compared people's immediate behavioral responses to earthquakes in New Zealand and Japan. Notable similarities of human behavior in emotional reactions and risk perceptions were found, while some differences between the two countries were identified. For instance, people in New Zealand usually chose to drop to the ground, whereas people in Japan were more likely to evacuate from the buildings immediately, which was due to the difference in severity of frequent earthquakes. Further fostering such international collaboration would provide additional opportunity for researchers to collect multi-cultural datasets and carry out cross-cultural studies, enriching our knowledge about the impact of culture in this area.

5.5. Research methods used in prior research

To collect sufficient and reliable behavioral data for studying human behavior in building emergencies, researchers use various research methods to evoke and analyze behavioral and emotional human responses. These methods allow researchers to investigate human behavior in building emergencies, without having to expose human to real emergency situations and hence to avoid possible injuries and associated moral and legal risks (Paulsen, 1984). Five methods have been commonly used in prior studies, the usages of which have been evolving over time, as shown in Fig. 5. Drawing upon Kinateder et al.'s study (2014b), the pros and cons of these methods are analyzed in the present paper, and the results are summarized in Table 1. In addition to the criteria used in the work of Kinateder et al. (2014b), granularity of behavior, data collection instrument, whether involving crowds and social interaction, and result generalizability are the additional assessment criteria used in the present study, due to their importance to the collection and interpretation of human building evacuation data and the application of research findings.

Case studies and emergency drills are the most widely used methods

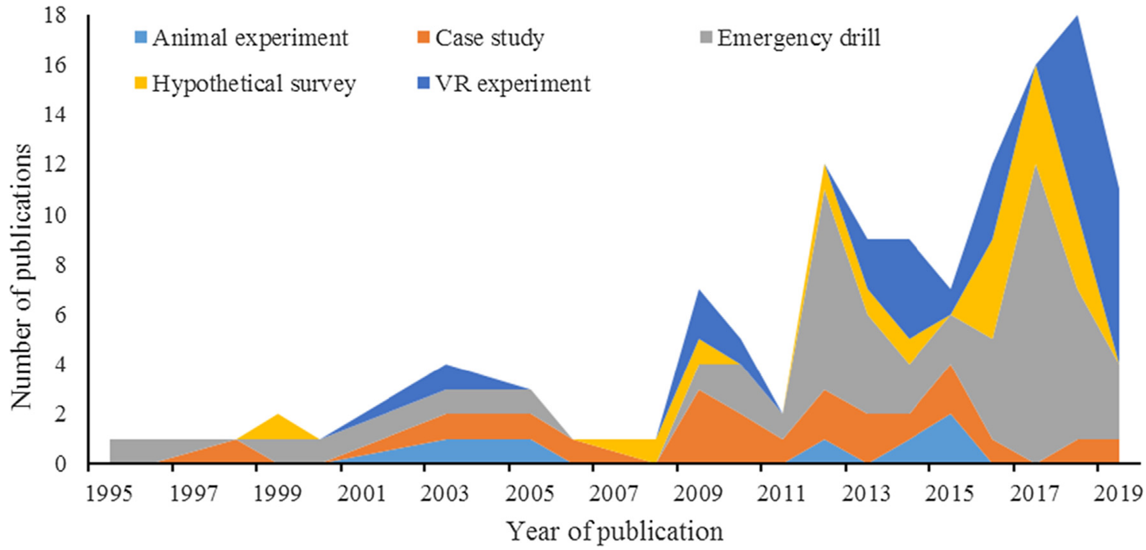

Fig. 5. Evolvement of usages of research methods.

in the literature. This is mainly due to the maturity of their methodological design and relative ease of implementation. With the fast advancement of virtual reality (VR) technology, VR-based experiments have quickly become another mainstream research method in this area (Zou et al., 2017), being the second mostly used method in publications in the last five years. Among other research methods, non-human animal experiments are occasionally reported, although the validity of the experiment results in explaining human behavior is controversial (Parisi et al., 2015). As for hypothetical studies, Huang et al. (2015) reported certain consistency in the results of actual and hypothetical hurricane evacuations. Nevertheless, hurricane evacuation and indoor evacuation differ in their time span: there are forewarnings days before the evacuation whereas building emergencies usually occur more instantaneously. Therefore, there are still doubts about the level of ecological validity of hypothetical surveys when it comes to responses to building emergencies without preparation for incoming emergencies (Haghani and Sarvi, 2017). That being said, hypothetical studies allow experimenters to collect various types of data for hypothetical scenarios, generated with controllable and manipulatable environmental setting, some of which could be hard to replicate with other research methods. Such advantage may have led to the increasing usage of hypothetical studies in recent studies. In sum, comparative analysis of existing research methods could enable researchers to optimize their future research design, inform improvements upon current methods, and inspire the introduction of novel methods that would provide new opportunities for collecting and analyzing fine-grained human behavioral responses data.

5.6. Recent research trends and directions for future research

A synthetic review of recent publications indicates that the following are amongst the most studied subjects in this area: (1) design of effective signage systems for guiding people during building emergencies; (2) people's decision-making and behavioral formation during building emergencies, especially when given conflicting information and faced with competing impact factors; (3) the mechanism of specific behaviors in response to building emergencies, such as competing behavior and helping behavior; (4) measures for efficient evacuation in high-rise buildings through safe vertical transportation; and (5) emergency response behavior of specific groups, such as children and elders.

Directions for future research are suggested based on analysis of current trends of research and existing gaps in the body of knowledge. As aforementioned, existing knowledge on human behavior during building emergencies is primarily related to limited types of buildings and building emergencies. Important questions that should be answered in future research include: (1) To what extent do people behave differently when exposed to different types of emergencies in different types of indoor spaces, and more ambitiously, even in outdoor spaces? (2) What are the particular attributes of buildings, emergencies and occupants that can impact human behavior, and how is human behavior impacted? (3) Whether and how can knowledge of human behavior derived from a specific building emergency context be generalized to other contexts? To address these challenges, it is suggested that evidence collected in case studies and hypothetical studies can be used to establish hypotheses regarding causal relationships between building

Table 1
Comparison of methods for studying human behavior in building emergency.

	Case study	Emergency drill	Hypothetical survey	VR experiment	Animal experiment
Granularity	Crowd and individual	Crowd and individual	Individual	Individual	Crowd
Setting	Field	Field	Field or laboratory	Laboratory	Laboratory
Allow variable control	No	Partial	Partial	Yes	Yes
Type of data	Subjective, objective	Subjective, objective	Subjective	Subjective, objective	Objective
Data collection instrument	Interview, questionnaire	Interview, questionnaire, videotape	Interview, questionnaire	Interview, questionnaire, videotape, software	Videotape
Equipment for invoking behavior	No	Yes	No	Yes	Yes
Data collection difficulty	High	Medium to low	Low	Low	Low
Involve crowds and social interaction	Yes	Yes	No	Yes	Yes
Fidelity to real emergency condition	High	Medium to low	Low	High to medium	High
Ecological validity	High	Depends	Low	Medium	Low
Result generalizability	High to medium	Medium	Medium to low	Medium to low	Low

and emergency contexts and human behaviors. These hypotheses can then be tested through experimental studies, in which the causal relationships can be investigated statistically while possible confounding factors can be controlled to ensure the validity of the results. Potential mediating variables between building types and human behaviors that have been reported in prior studies (Thompson et al., 2018) could serve as a starting point for this line of inquiry.

Given the fact that different types of behaviors in building emergencies are usually investigated individually, and that different theories have been cited in an ad hoc manner to explain these behaviors separately, there is a substantial need for building a holistic framework that can incorporate all cognitive and behavioral processes of human beings involved in the entire building emergency response process, one that is built upon a set of reconciled social and psychological theories that otherwise may be incongruous with each other. Moreover, this framework should have a quantitative nature, so that it would allow for structured and quantitative modeling and prediction of human behavior during building emergencies, providing the very much needed support to downstream research areas such as human behavior simulations (Busogi et al., 2017) and crowd behavior studies (Mitsopoulou et al., 2019). In addition, researchers can also further look into people's attention and memory as the critical parts of their cognitive process in response to building emergencies (Kinsey et al., 2019). In sum, to achieve the goal of a holistic framework, future research needs to be conducted to answer a few important research questions: (1) How to understand human attention and memory in relation to their behavioral responses to building emergency? (2) How to develop a holistic framework for understanding human behavior in building emergencies, considering all potential influencing factors and drawing upon various existing theories? (3) How to assess the efficacy of existing research methods and use them to examine the validity of current behavioral theories? and (4) How to utilize advanced technologies to develop new methods for collecting sufficient amounts of behavior data, in order to support quantitative behavioral modeling with high fidelity and validity? The last question in particular requires collaboration across different domains, such as social sciences and engineering, which is not yet common at the present time and needs to be strengthened in the future.

Other questions that are also worthy of investigation in future research include questions related to cultural impacts, such as (1) How does cultural background impact people's behavioral responses in building emergencies? (2) To what extent can knowledge on human behavior in building emergencies derived in one cultural context be transferred to other cultural contexts, and how can such knowledge transfer be done? In addition, practical application related questions also warrant future research endeavors, such as (1) How to optimize building design, drawing upon knowledge on human behavior, to enable efficient evacuation during emergencies? (2) How to develop simulation tools to computerize and visualize behavioral models to support tasks such as building performance assessment and emergency planning? (3) How to develop behavior intervention measures for managing the evacuation process during emergencies, and how to test the efficacy of these measures in advance? and (4) How to utilize knowledge on human behavior to train building safety staff and optimize building emergency response procedures?

6. Conclusions

Since the 1950s, numerous research efforts have been made in order to understand how humans behave during building emergencies. This paper presents a systematic review of the state of the art on human behavior in building emergencies, tracking back to the early days of this research area, with a focus on the characteristics of behaviors and relevant behavioral theories. The review demonstrates that occupants' wayfinding behavior has been the focus of prior research, while other types of behavior in response to different types of building emergencies have generally been understudied. The professionals and researchers should work together to assess the generalizability of findings on human emergency response behavior derived from a particular indoor environment under a particular type of emergency to other building and emergency contexts. There is limited knowledge on interaction behavior with environment, however, it is worthy of further investigation, which would help reduce exposures to hazards and risks of fatalities and injuries during building emergencies. The review also summarizes existing research methods in this area, compares their respective pros and cons, and points out based on bibliographic data that the usages of different methods have been evolving over time. In addition, it is pointed out that different theories have been referenced ad hoc to explain different behaviors separately. Researchers from the engineering, psychology, sociology and computer science domains should work collaboratively to develop a holistic framework that can incorporate all cognitive and behavioral processes of human beings involved in the entire building emergency response procedure, built upon a set of reconciled social and psychological theories that are otherwise inconsistent with each other in various aspects. Lastly, future research directions are discussed, which are expected to advance this line of research, deepen the understanding of human behavior in building emergencies, and improve the safety of building occupants in practice.

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