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Review Article

Instructions for planning emergency shelters and open spaces in China: Lessons from global experiences and expertise

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ABSTRACT

Emergency shelters and open spaces play dual roles in providing locations for temporary accommodation and rescue activities during disaster situations. Over time, research has attempted to optimize site selection and design for emergency shelters and open spaces, though they rarely offered lessons to guide actual projects. In this regard, it is paramount to design emergency shelters or open spaces in a forward-looking and dynamic manner, especially when the country faces challenges due to extreme events (e.g. earthquake and floods) and large populations. The aim of this paper is to analyze the issues of this field in China while summarizing instructions for future construction based on the experience and expertise of other countries. Specific suggestions include: (1) combining the designs and plans of emergency shelters/open spaces into the construction of a resilient urban system; (2) embedding routine preparedness into disaster risk reduction approaches; (3) optimizing issues in site-selection using spatiotemporal patterns in refuge demand while designing the shelter system into a hierarchical structure; (4) shifting from a top-down approach to a bottom-up approach, which includes the participation of multiple aspects of shelter construction; and (5) designing and establishing emergency shelters/open spaces to fight against different types of disasters.

1. Introduction

A disaster is defined as a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources, according to the International Federation of Red Cross and Red Crescent Societies (IFRC). Though often caused by nature, disasters can have human origins [1].

According to the International Disaster Database [2], an ongoing trend exists regarding lower death tolls from previous years continuing into 2019. However, the frequency of disaster occurrence demonstrates an almost exponential growth, attributed to the worsening climate change and rapidly growing population and urbanization [3]. As the world's second-largest economy, China is vulnerable to many natural and man-made disasters. In 2018, natural disasters affected approximately 1.3 billion people, killing 589 while having 524.5 million urgently relocated [4]. In addition, as a new form of operation organization, large-scale chemical industry parks have been established in many cities, potentially exposing people to various hazards. Furthermore, human also face the potential threat of public health events, such as the COVID-19 in early 2020. In China, emergency field hospitals and temporary quarantine centers were established immediately based on the stadiums and industrial plants. Hence, emergency shelters/open spaces, as well as quarantine centers, play dual roles in providing places for temporary accommodation and rescue activities. It is paramount to scientifically design shelters and quarantine centers during the early stages, which empowers emergency management and mitigates the damage of passive measures.

Issues pertaining to emergency shelters as well as the use of open spaces have been discussed globally, including the optimization of shelter location [5,6], selection criteria of open spaces [7] and so forth. Despite their proposals, these models and experiences are rarely fully understood in the context of being lessons for actual construction projects. China's current main problems in construction for emergency shelters, for example, include extensive selection of shelter locations,

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mismatch of refuge demand and supply, lack of maintenance during the operation period and defence deficiency of multiple disasters. Further clarity regarding the location and planning of emergency shelters and open spaces are necessary to support response and recovery efforts when disasters occur.

Accordingly, numerous objects are analyzed in this study. First, surveys regarding emergency shelters and open spaces in China were reviewed and compared, which analyzed the current issues in this field thus far. Second, existing literature was consolidated on research pertaining to experiences and strategies in shelters/open space construction projects in Japan, the U.S. and Europe. Finally, guidelines and suggestions for emergency shelters and open spaces were outlined to better incorporate comprehensive factors into site selection and the planning of shelters. Overall, this paper not only highlights the issues surrounding actual implementations of emergency shelters and open spaces in China, but also summarizes instructions for future construction projects based on experiences from other countries.

This study is structured according to the following sections. In Section 2, the research review methods are introduced, while Section 3 reports on the emergent challenges and issues regarding emergency shelters and open spaces in China. In light of these issues, global experiences and strategies for the construction of emergency shelters/open spaces are summarized in Section 4. This section also outlines global progress regarding shelters, explaining details in the design and site selection of shelters and open spaces. In Section 5, suggestions and guidelines for the construction of emergency shelters and open spaces in disaster management are put forward. Finally, Section 6 provides the conclusions reached by this study.

2. Research methods

State of art designs and construction of emergency shelters are usually summarized in conventional literature reviews. However, in this manuscript, challenges pertaining to emergency shelters/open spaces in China are identified and suggestions are provided for the construction of emergency shelters/open spaces according to global experiences. Hence, the relevant literature was comprehensively scoped, and reviewing both qualitative and quantitative studies was necessary in order to obtain extensive and comprehensive results.

Fig. 1 illustrates the study selection and filtering process. Both academic literature and grey literature were included in the systematic review. Grey literature refers to government documents and design standards or guidance, which presents important information concerning potential insights from the government as well as experts. In the document identification step, grey literature was collected by searching the government websites. Furthermore, six databases were considered: Web of Science, Science Direct, Taylor & Francis Online, Google Scholar, VIP (in Chinese) and CNKI (in Chinese). Search keywords include“emergency shelter”AND“risk assessment”OR“site location”OR“data-driven algorithm”OR“natural disaster” OR“urban resilience”OR“daily preparedness”in the title, abstract, and keywords.

The inclusion criteria of the reviewed literature were:

- Possessing design standards and survey reports for emergency shelters in China.
- Containing construction standards for shelter settlement in the UK, Canada, the U.S. and European countries.
- Published guidelines for evacuation and emergency shelters from international humanitarian communities.
- Having construction standards and operating experiences in open spaces in Japan.
- Put forward optimization models for shelter location and site selection.

3. Analysis of current emergency shelters and open spaces in China

3.1. Progress of emergency shelters

Normalized construction of emergency shelters in China started in 2006. The Ministry of Construction issued the *Urban Planning Methodology*, which includes "construction guidelines of disaster prevention system" as part of urban planning [8].

In 2007, disaster prevention and mitigation became a compulsory component of overall planning from the locality to the center. In October of the same year, the "Eleventh Five-Year Plan" for *Comprehensive*

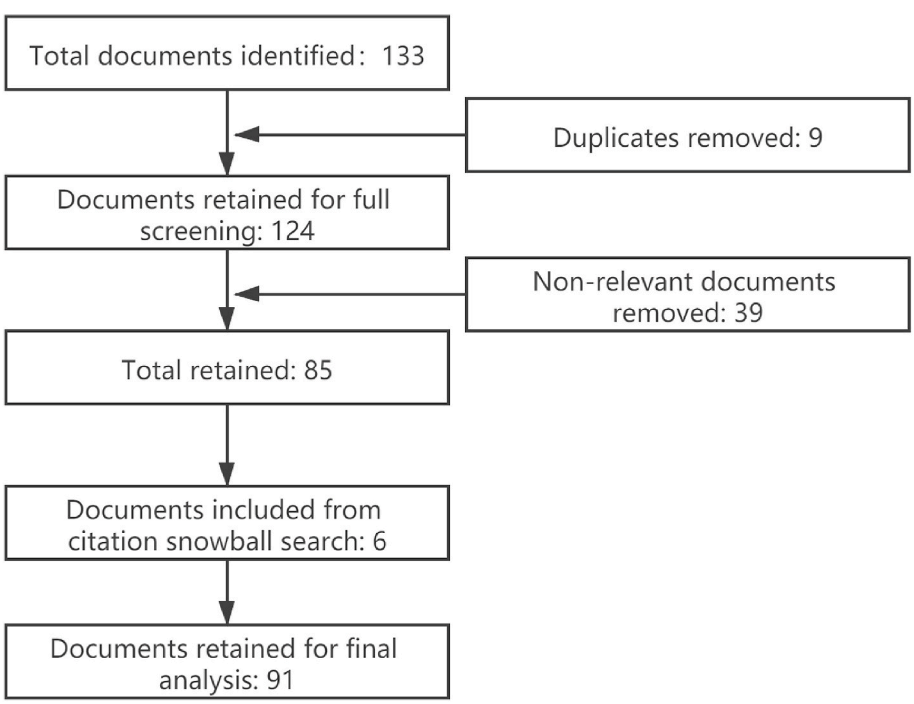

Fig. 1. Study selection for the systematic review.

Disaster Prevention in Urban Construction was issued by the Ministry of Housing and Urban-Rural Development of China, emphasizing that the objective of disaster prevention planning in China is to basically form a comprehensive disaster prevention framework in order to significantly enhance disaster prevention [9]. The principle of "multiple use of shelters, prevention-based mechanism, quick response and effective strategies" are gradually being added into government documents by many cities.

In 2008, the national standard *Site Selection and* Supporting *Facilities for Earthquake Emergency Evacuation* was issued, especially considering earthquake disasters [10]. In January 2017, the *Standards for the Construction of Emergency Shelter in Urban Communities* was proposed, which divided emergency shelters into three levels according to the community's population. Additionally, the construction standards and requirements for each level were provided [11].

In early 2020, the deployment of emergency field hospitals/quarantine centers was regarded as the most effective solution in keeping COVID-19 from spreading. *Technical guidance for construction and operation of emergency hospitals based on industrial buildings* [12] was, in turn, immediately issued by the government. Basic requirements like site selection and ventilation systems were identified in this official document.

Overall, the design of emergency shelters/open spaces is of paramount concern and should be primarily considered within prospective plans. However, in actual implementations, land use and site selection of emergency shelters/open spaces are roughly determined, which fails to fully consider actual demand. Hence, shelter construction and site selection suffer from certain issues, which are discussed in Section 3.2.

3.2. Main limitations

3.2.1. Extensive selection of shelter location

One limitation found in existing guidelines is that most guidelines proposed specific to the single earthquake disaster do not clearly explain site selection for emergency shelters/open spaces. The emergency shelters were usually established based on the existed open spaces. Hence, site selection done in the early stages does not take into account multiple aspects including demographics, community governance unit, various types of disaster, as well as the accessibility of emergency shelters. The technical indexes that stakeholders mostly adhere to are the site's size, per capita area and equipped facilities, rather than the actual performance of the emergency shelter during a disaster. In most cases, the scale and location of the emergency shelter/open space are designed using rough estimations of the population density in city blocks. However, actual demands of the shelter vary greatly in regard to spatial and temporal dimensions according to different disasters.

3.2.2. Lack of publicity and preparedness

Although relevant standards and guidance concerning the construction of emergency shelters/open spaces were proposed in most regions, publicity and evacuation drills were rarely carried out routinely. For example, in Qiqihar city, the number and location of emergency shelters in the electronic map were not consistent with the government's announcement [13]. Furthermore, according to the survey and investigation of the current status of emergency shelters in Wuhai city [14], only 10 out of 180 citizens had some knowledge regarding the disaster prevention park. The aftermath of such inadequate levels of publicity is that many citizens would not know which shelter to go to when a disaster occurs. Hence, "safety culture" would be an unreachable goal if public awareness and performing drills are lacking.

3.2.3. Unbalanced development within regions

In principle, the distributions of emergency shelters should be arranged according to the dispersion of the disaster as well as population density. According to the survey, most emergency shelters are located within developed cities in eastern China, while the disaster prevention system in rural areas are often disregarded, especially in western China [15]. According to W. Li et al. [15], as shown in Fig. 2, the top 20% of developed cities provide 16780 emergency shelters/open spaces, which account for the 88.6% of the total. In contrast, the proportion of emergency shelters/open spaces of the remaining 270 less developed cities is only 11.4%.

Furthermore, compared to new communities, emergency shelters/open spaces are scarcer in old towns and undeveloped area [16]. In fact, the damage due to building collapse or fire would be more serious in poorer regions or old towns, which lack safety designs including wide laneway, emergency equipment and aseismatic structure of building. Hence, economics accounts for the unbalanced safety rates among different regions.

3.2.4. Mismatch of demand and supply

Numerous mismatches exist among the construction of emergency shelters with the actual demands of the evacuees. China suffers from various natural and man-made disasters every year; requirements for post-disaster resettlement and evacuation are different depending on the disaster type and spatiotemporal distribution of population. However, risk assessment ascertaining threats from hazards prior to a disaster is rarely carried out in the shelter designing phase [17].

Moreover, emergency shelters/open spaces are usually regarded as welfare rather than being rooted in developmental issues. For example, governments in most cities prefer to establish high-level emergency shelters, which provide short-term and long-term relocation. The construction of medium and small shelters is rarely integrated into disaster prevention planning [18]. However, the function of small shelters cannot be neglected-in regions that have difficulties in accessing high-level shelters, any small and medium emergency shelters/open spaces may be necessary as the transfer sites in case of a disaster.

3.2.5. Vague responsibility of stakeholders

Another issue with emergency shelters is the vague responsibility held by multiple units. For example, government departments, social groups, enterprises and institutions are separated during the planning, construction, maintaining and emergency stages. These stakeholders lack close communication and cooperation since they do not treat emergency shelters/open spaces as an integral component within urban resilience. In addition, few regulations and legislation clarify issues concerning the maintenance and management of emergency shelters/open spaces. *Management Guidance for Earthquake Emergency Shelter,* proposed in 2017 [19], is the first regulation concerning the operation. Another challenge is the lack of financial support provided by the government and developers. Multiple financing channels including loans, fundraising and bonds should be activated to facilitate the construction of disaster prevention systems.

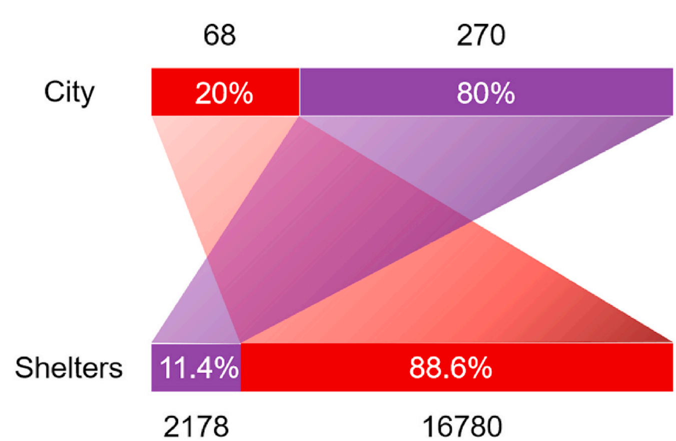

Fig. 2. Quantitative proportions of emergency shelters/open spaces of different cities [15].

4. Global experience in shelter construction

4.1. Progress with shelters

4.1.1. Japan

Japan has paid attention to disaster prevention systems from early on as they continue to face great challenges pertaining to natural disasters and high-density population for several decades [20]. The Great Kanto Earthquake in 1923 changed the spatial distribution of building/dwellings [21]. Green spaces, parks, squares and basements in the cities have been regarded as the most important parts of emergency shelters and evacuation sites. After World War II, the government enacted a series of standards and laws to integrate the public space into the disaster prevention system. For example, the *Law of Urban Park* [22] and the *Preservation Law of Urban Green Space* [23] combined the protection of green areas within the disaster prevention system. In 1999, the *Guidelines for planning and design of disaster prevention parks* [24] was proposed to demonstrate the design of the disaster prevention park.

4.1.2. United States

Since 1977, The National Earthquake Hazard Reduction Program (NEHRP) supported research, practices and policies that identified earthquake hazards and mitigated earthquake risks by improving the performance of emergency shelters [25]. After the catastrophic events of Hurricane Katrina [26] in 2005, the government actively promoted "disaster prevention communities", which took on responsibilities in disaster prevention, disaster response and post-disaster recovery. At present, the United States has established a disaster prevention and mitigation system comprised of federal, state and local entities. In addition, various standards concerning emergency shelters have been proposed for different types of disasters such as hurricanes, biochemicals, earthquakes, fires, explosions and so forth [27–29].

4.1.3. Europe

In Europe, construction of emergency shelters could be retraced to the Renaissance [30]. For example, the 1963 January earthquake struck the southern parts of Italy and caused extensive amounts of damage [31]. In the recovery phase, narrow and curved roads were replaced by wide and straight avenues, ensuring quick and safe evacuation for its citizens. In the UK, according to the *Evacuation and shelter guidance* [32] proposed by the UK government, large stadiums, schools and other public buildings were appointed as emergency shelters. The responsibility of the government, voluntary organizations, enterprises and citizens have been identified in several standards and laws [33] (see Table 1).

Table 1
Progress with emergency shelters/open spaces.

Year	Progress
1982	*Shelter after Disaster – Guidelines for Assistance* First set of United Nations Shelter Guidelines
1987	*Housing and Culture after Earthquakes, A Guide for Policy Making on Housing in Seismic Areas. (UK)* First guidance on cultural aspects of shelter and housing reconstruction
1999	*Guidelines for planning and design of disaster prevention parks* ■ Japan–Ministry of Land and Transport
2002	*Hurricane Evacuation Shelter Selection Standards* ■ American Red Cross (ARC)
2004	*The Sphere Project, The Humanitarian Charter and Minimum Standards in Disaster Response* Guidelines on Humanitarian Assistance included shelter performance standards
2011	*Shelter after Disaster: Strategies for Transitional Settlement and Reconstruction* ■ United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA)
2011	First specific master's courses on shelter are initiated
2013	*Evacuation and shelter guidance-refresh* ■ HM Government (UK)
2015	Third UN World Conference: Building the Resilience of Nations and Communities to Disasters ■ United Nations International Strategy for Disaster Reduction (UNISDR)
2017	*Humanitarian Shelter and Settlements Guidelines* ■ European Civil Protection and Humanitarian Aid Operations (ECHO) and European Commission

4.2. Global experience and strategies

4.2.1. Optimizing shelter location and evacuation schemes

As previously mentioned, enormous damages are usually caused by various disasters in Japan. An open space called the disaster-prevention park has been divided into seven types according to their functions and scales, as shown in Table 2.

Moreover, a hierarchical network was formed by roads connecting these seven types of parks. For example, a community park of 500 m^2 was set up to provide facilities like a rest area and lavatory to its citizens. The distribution of these open spaces should cover all communities within the urban city. Acting as temporary shelters, neighboring parks were equipped with a water supply system and warehouse, providing shelter with a service radius of 500 m. In addition, the minimum width of the road connecting temporary shelters and emergency shelters was 10 m. Notably, the service radius of the emergency shelter and disaster-prevention stronghold at the district level was 2 km. The disaster-prevention stronghold for large areas should be located near to the expressway, which takes on responsibilities in logistics transport and effective communication.

Aside from the construction of open spaces, an evacuation route was designed and optimized combined for the disaster-prevention park. For example, in the *Planning handbook for countermeasure of the earthquake*, developed by the Japan Fire Administration, the density of the apartment, storage of the hazardous chemicals and distance of the evacuation route were adequately outlined. Since 1980, flame retardant projects

Table 2
Seven types of disaster prevention parks in Japan.

Types	Main function	Scale
Disaster-prevention stronghold for large areas	Hold rescue activities and provide recovery assistance	Large-scale parks Larger than 50 ha
Disaster-prevention stronghold for districts	Hold rescue activities and relief distribution	Central parks Larger than 10 ha
Emergency shelter	Relocate nearby residents from disasters	Central parks Larger than 10 ha
Temporary shelter	Provide temporary shelters and transit residents to larger shelters	Neighboring parks Larger than 1 ha
Green avenue	Act as an evacuating road	Green avenue with the width at least 10 m
Green buffer belt	Protecting neighboring cities from radiation/fire	
Service station	Help residents to return home safely when the bus is stopped	Community parks Larger than 500 m^2

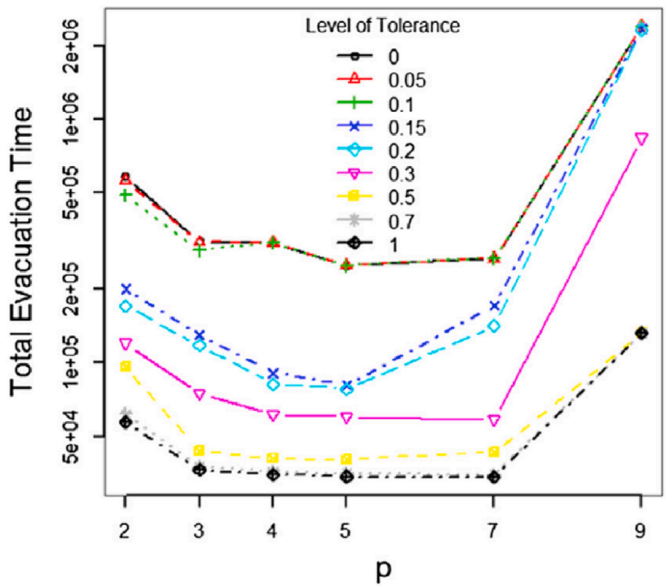

Fig. 3. The effect of the number of shelters (p value) and the level of tolerance on total evacuation time [37].

have been carried out in urban systems, where both green plants and building materials were optimized to be fireproof. Due to this project, the safety level surrounding the disaster-prevention park as well as the evacuation route was improved [34].

According to A. Esposito [35], prior to 2011, emergency shelter/-open space designs and car-based evacuations were considered to be separated issues in most countries. In 2012, a scenario-based bi-level model was proposed by A.C.Y. Li et al. [36] to optimize the site selection of shelters by explicitly considering car-based evacuations for various hurricane events. In their model, the evacuee's route choice, traffic dynamics and stochastic nature were included, resulting in the reduction in average travel times up to 20%. However, not all of the minimal total evacuation time is attainable using the shortest routine due to uncertainty and traffic congestion. According to Turkey's experience [37], Constrained System Optimal approaches assumed that evacuees were willing to accept slightly longer travel routes. As shown in Fig. 3, maximum latency decreased if more people were convinced of higher levels of tolerance. Furthermore, increasing the number of shelters to nine had an adverse effect on evacuation time. In 2017 [38], an extended model was developed to consider uncertainties regarding evacuation demand, road network structure and possible disruption in shelters.

Other than car-based evacuation (self-evacuation), bus-based evacuation (supported evacuation) combined with shelter location was first addressed by M. Goerigk et al. [39]. Since the Comprehensive Evacuation Problem was a multi-objective and complicated issue, a genetic algorithm was established as an optimization method. Both the evacuation time as well as the risk for evacuees were taken into account in the macroscopic model. Additionally, in 2016 [40], a multi-objective integer programming model was proposed for decision-making in regard to shelter location and evacuation routine in different conditions of bushfires. In the corresponding model, sensitivity analysis of evacuation plans according to the number of functioning shelters, disruption of shelter availability and major roads were taken into account. A summary of the aforementioned studies is given in Table 3.

4.2.2. *Embedding shelter design into the emergency management cycle*

The emergency management cycle is an open-ended process. The four phases (preparedness, response, mitigation and recovery) indicate the ongoing attempt to prevent the effects of a disaster [41]. In this section, the role of the emergency shelter in different stages of the emergency management cycle is identified. As shown in Table 4, the emergency shelter/open space mainly plays an important role in mitigation and recovery.

In view of densely populated communities or old towns, strengthening urban system resilience may improve the mitigation of risks in various disasters. According to six case studies performed in Italy [43], the main critical issues of strategic urban structures include: (1) lack of public space in the old town; (2) lack of a differentiated network of public spaces and functions (lack of redundancy); and (3) concentration of urban functions inside the old town. Pizzo et al. discussed the function of public spaces in risk mitigation along with the imperatives of urban resilience and environmental safety.

Many researchers have also investigated the function of the emergency shelter/open space during a city's recovery. As put forward by Brand and Nicholson [44], public spaces and urban structures of Christchurch, New Zealand following the 2010 and 2011 earthquakes were evaluated and compared. As shown in Fig. 4, the employee density in the commercial districts was dispersed along with the urban structure.

Table 3
Combinations of shelter location with evacuation route.

Ref.	Country	Case study	Model
[36]	USA	Car-based evacuation in hurricanes	Dynamic Traffic Assignment (DTA) and Dynamic User Equilibrium (DUE)
[37]	Turkey	Car-based evacuation in earthquakes	Constrained System Optimal
[39]	Germany	Car-based and bus-based evacuation in earthquakes/bomb threats	Comprehensive Evacuation Problem (CEP) and genetic algorithm
[40]	Australia	Bus-based evacuation in bushfires	Ɛ-constraint technique

Table 4
The role of shelters/open spaces in the emergency management cycle.

Ref.	Region	Case study	Emergency management cycle			
			PR	RS	MT	RC
[42]	Istanbul, Turkey	Earthquake			✓	
[43]	Umbria Region, Italy	Earthquake			✓	
[44]	Christchurch, New Zealand	Tsunami				✓
[45]	Mehuin & Dichato, Chile	Tsunami				✓
[46]	Tokyo & Kobe, Japan	All hazards	✓		✓	
[47]	Concepción, Chile	Earthquake and Tsunami		✓		✓
[48]	New York City, U.S.	Hurricane			✓	✓
[49]	San Francisco, U.S.	Earthquake	✓	✓	✓	✓

PR= Preparedness, RS = Response, MT = Mitigation, RC = Recovery.

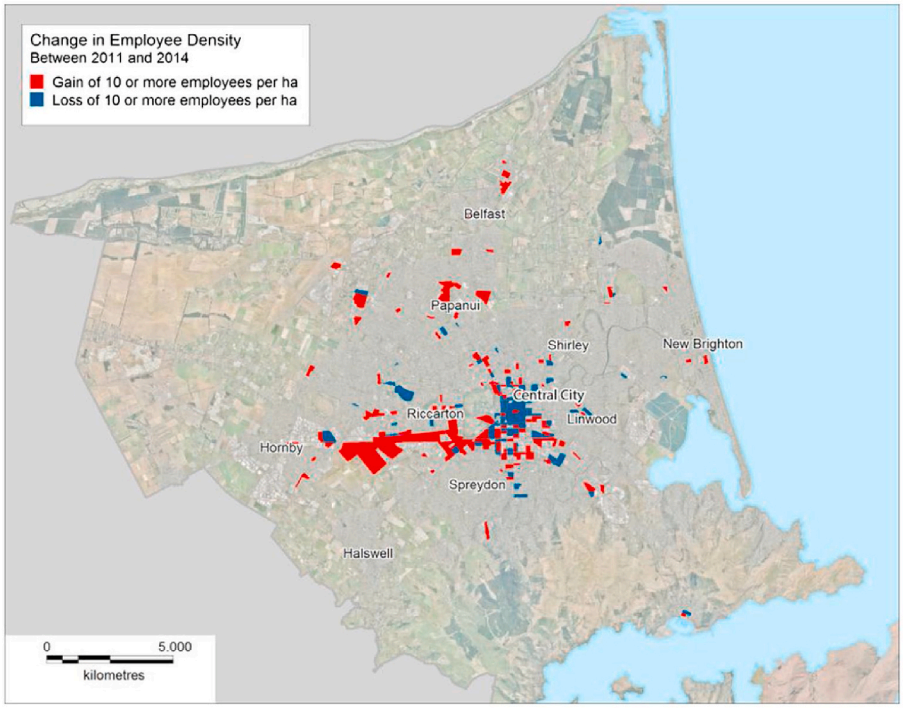

Fig. 4. Change of business location in Christchurch measured by the change in employee density between 2011 and 2014 [44].

According to the Council's Draft Central City Plan (Draft CCP), which was developed by the government after the earthquake, several projects were proposed to animate shelter construction to balance the political, individual and organizational lives of those within the territory for participatory planning. Several key lessons regarding resilience were summarized: (1) laneway construction encouraging public access and supporting retail use; (2) decentralized water supply system in order for parts of the system to continue to function independently; (3) minimized use of restrictions for public access; (4) retreating or protecting flood prone areas; (5) developing low rise cities that are greener and more people-friendly; and (6) outlined the *Transitional City Project,* which provided opportunities for individuals and small groups of citizens to occupy the spaces left on grounds/walls.

The role of community gardens in relation to post-disaster recovery has been previously discussed by J. Chan et al. [48]. Here, the authors conducted an exploratory multi-case study of several hurricane-impacted community gardens in order to understand its role in New York City. The results demonstrated that community gardens have long served as verdant refuges and community hubs in NYC neighborhoods [50]. The evacuees preferred to gather during the chaotic days that immediately followed hurricanes. Unlike other shelters and open spaces, such as parking lots and commercial buildings, community gardens were regarded as restorative places, supporting the resilience of an urban social-ecological system and inspiring their community members.

In Chile, two different reconstruction programs were supported by the government; one was focused on providing houses for affected people, while the other included comprehensive plans for urban design and managing investments, which was phrased as the 'cross-sectoral reconstruction approach' [47]. According to the comparative results, a more significant improvement in resilience may be observed in the cross-sectoral reconstruction approach. Specifically, its projects

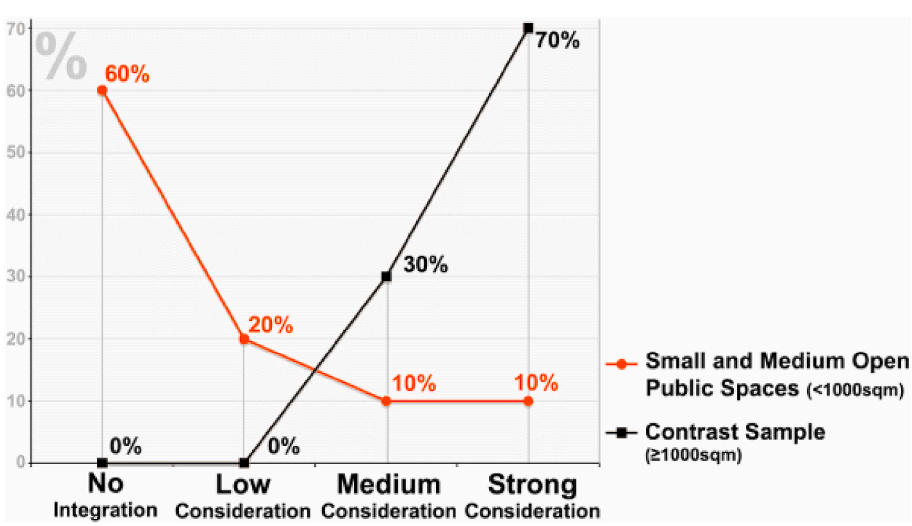

Fig. 5. Integration of open public spaces in disaster prevention planning in Japan [46].

Table 5
Commercial shelter categories [58].

Shelter Considerations	In-Ground	Single-Use	Multi-Use	Community
Expected capacity	1–100	1–10	1–100	100–1000
Level of Protection	Blast (medium)	Blast (low)	All	All
Location	Basement or sub-basement area without windows and semi-hardened walls and ceiling.	Interior space without windows and semi-hardened walls and ceiling.	Conference room, data center, bathroom, stairwell and elevator core.	School, church, mall and government building.
Special Considerations	Difficult to site; build in high water table and rocky areas.	Annual or semi-annual inspection and rotation of supplies.	Multiple areas in large buildings; plan to prevent overcrowding.	Plan for multi-lingual, elderly and special needs populations.

included anti-tsunami measures, improvement in accessibility and connectivity, more comprehensive plans in design, and multi-functionality of open space systems.

To the best of our knowledge, few cases combined emergency shelters/open spaces with the preparedness phase in the emergency management cycle. The Golden Gate Park polo field in San Francisco is a multifunctional open space [51,52] that acts as a leading component in emergency management. After the 1906 earthquake, these parks played a critical role in the entire emergency management process. The Hyphae Design Laboratory and CMG landscape architecture settled a displaced population of 12,000 individuals in case of disaster. In addition, daily infrastructural "lifelines" like food, water, energy, shelter and waste management were promised for three days [49].

Tokyo is another international metropolis suffering from various natural disasters and over-utilization problems. In 2015, the *Disaster Prevention in Tokyo* handbook [53] was edited by the government with comprehensive consideration of local features, urban construction, lifestyle of its citizens and so forth. The handbook mentions drills to be enacted for disasters during the preparedness phase, which tells people how to take adequate action during evacuations and in emergency shelters. In addition, a trend exists in the integration of small and medium open public spaces for disaster prevention planning, such as evacuation planning of densely populated communities. According to the survey (Fig. 5), however, only 40% of small and medium open spaces were integrated into disaster prevention planning. These spaces were considered to function in evacuation assistance, which were often associated with firefighting by permitting water access; its function also stemmed from its morphology by interrupting densely built fabric [46].

4.2.3. *Deployment of diverse space typologies*

Typically, public open spaces and emergency shelters cannot accommodate large numbers of people, hence, integration of the role of privately owned spaces with the disaster prevention system is proposed in this study. In Japan, the standards *Deployment of Emergency Shelters* [54] was proposed in 2017, which put forward that companies and personal places could be adopted as emergency shelters whenever they were deemed necessary. Enterprises located in disaster-prone regions usually have strong backgrounds in disaster prevention. Accordingly, temporary shelters could be successfully assigned as the local government may share a long-term cooperative relationship with such enterprises.

A similar measure was adopted by other counties. In the UK, *Evacuation and Shelter Guidance* [32] addressed that suitable buildings, such as schools, leisure centers or community halls, may be used as rest centers. Undoubtably, an agreement should be reached with the building operators or owners, and basic utilities (gas, electricity or water) should be identified as well. Notably, the additional disruption was probably caused by activation of the shelter; planners should consider minimizing the impact of the assignment while bolstering protection for the confidential department. The guidance also recommended that it may be more cost-effective to use hotels rather than opening commercial buildings as emergency shelters. Hence, planners should keep a list of local hotels that can accommodate residents and sign a contract with the corresponding accommodation providers.

Underground spaces like parking lots, train stations and underground air raid shelters have been deployed as emergency shelters in many counties, such as Korea and Germany [55]. Subsurface and underground spaces play specific roles in that they promote urban resilience and disaster prevention [56]. In order to protect people from disasters, additional utilities like water supply systems and ventilation have been installed [57].

The decision on whether to leave or stay in buildings/bunkers is also important. Several American cities acquired lessons in hurricane prevention, where indoor shelters were mostly utilized compared to public open spaces. In terms of official standards and guidance, shelters that provide safety during storms/hurricanes are termed "safe rooms" by FEMA and "storm shelters" by ICC 500. A safe room is an interior room, a space within a building, or an entirely separate building, which is designed and constructed to provide near absolute life-safety protection for its occupants from tornadoes or hurricanes [58]. Table 5 depicts shelter categories classified by different purposes, capacities, locations and levels of protection. Furthermore, the American Red Cross proposed ARC 4496 [59], which identified the minimum requirements for shelters in terms of location selection. The hazards associated with hurricanes were also considered, including surge inundation, rainfall flooding, high winds and hazardous materials.

Other than private enterprises and personal places, neighborhood cities or regions may be used to relocate citizens. In the case of Dichato, Chile, the interconnection among neighborhoods facing the sea has been clearly encouraged. If one collapses, other towns could take on responsibilities in evacuation and accessibility to emergency shelters and open spaces. Hence, the resiliency of the city was improved to a certain degree [47].

5. Instructions for shelter construction

The following summary of instructions for the future construction of emergency shelters/open space stems from the experiences and strategies utilized by numerous countries. The planning and site selection of emergency shelters/open spaces should be conducted with the extensive participation of multiple stakeholders.

5.1. *Construction of urban system resilience*

One particular goal of the United Nations' 2030 Agenda for Sustainable Development is to "*make cities and human settlements inclusive, safe, resilient and sustainable*" [60]. According to the UN International Strategy for Disaster Reduction [61], resilience is defined as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, which encompass the preservation and restoration of its essential basic structures and functions [62]. As previously discussed,

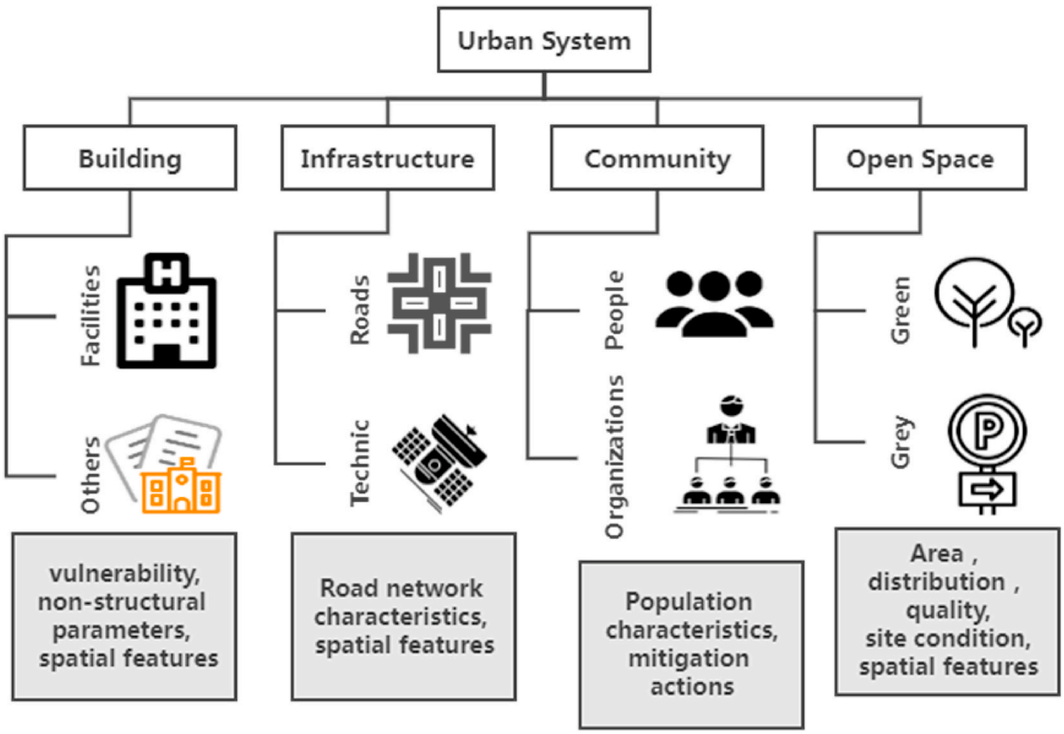

Fig. 6. Urban systems' four components.

combining the design and planning of emergency shelters and public open spaces into the construction of urban resilience may improve disaster management.

Therefore, it is necessary to infuse the construction of shelters/open spaces into the design of urban systems. Existing divisions of urban systems are comprised of four basic components: buildings, constructions, communities and open spaces [63,64], as shown in Fig. 6. Factors attributed to a proposed building could be evaluated according to its vulnerability, non-structural parameters and spatial features. Namely, neighborhood density and design are essential to emergency response services during disasters [65,66]. Moreover, urban infrastructures consist of many components, where the road transportation network serves as the most important characteristic related to emergency shelters. Furthermore, the community is made up of people and organizations, which is important for urban resilience in protecting against extreme events or disasters [67]. In addition, the total area, distribution, quality and site conditions of an open space influence urban resilience to a disaster.

In order to acquire a more detailed and reliable analysis of urban systems, the Building Information Modelling (BIM) and Geographic Information System (GIS) approaches may provide complete data and documents in regard to site selection and modelling for emergency shelters and public open spaces [68,69]. Furthermore, it is one of the key tasks to establish databases based on BIM and GIS to provide guidance for shelter construction. For example, user feedback could be integrated into the database of post-occupancy evaluation, which is significant to optimize the site location and facility of emergency shelter and open space with the consideration of residents' need. In addition, layout-planning database gathering spatial function and area ratio of national emergency shelters is beneficial for designers and planners to carry out risk assessment and construction optimization in the early stage. Not only the living comfort and site selection problem could be optimized based on the databases, applicable construction standards and technology can be improved in the long term.

Although decentralization is at the macro level in urban resilience systems, emergency shelters/open spaces should operate as a self-contained model, providing protection for the vulnerable in a centralized system [70]. Hence, four requirements exist concerning the selection of the location as well as the surrounding amenities including alternative connections of road networks [71,72], avoiding congestion in densely-populated areas, hierarchical scales of shelter (such as region, metro, city, section and site [73]) and diversity in a spatial distribution [74]. Especially, risk assessment should be conducted in the multi-risk coupling area, such as city-industry integration zone. Beside open space, diversiform facilities are recommended to be integrated into the emergency shelter system, including the safe room, movable rescue capsule and refuge chamber [75,76].

5.2. *Facilitating the role of daily preparedness*

As previously mentioned, preparedness in the emergency management cycle is only emphasized by a few developed countries like Japan and the U.S. However, preparedness in disaster management not only reduces the time it takes to reach emergency shelters/open spaces in the wake of an incident, but also facilitates the optimization of the site's location as well as the operating schedule of emergency shelters/open spaces.

Hence, it is recommended to embed daily preparedness and practice to existing community-based disaster risk reduction systems. Evacuation drills and other related activities should be carried out within communities, schools, and companies. To operate the emergency shelter in the school area, surrounding residents, parents and teachers are suggested to be trained on communication skill [77]. Essentially, everyday preparedness should not be a burden for citizens. Organization leaders, government officials, academic researchers and emergency nurses must begin by understanding the lifestyles, interests and actual needs of the households in cities and rural regions [78]. Accordingly, the element of preparedness in disaster management should be added into its initial activities. For example, cherry-blossom viewing is a popular cultural event, though its anecdotal purpose is to foster preparedness. The soil could be maintained by public gatherings, mitigating the risk of bank collisions [79] and flooding.

Lack of prepared awareness is the deficiency in many countries. Questionnaire [80], return on investment (ROI) analysis [81] and risk assessment [82] are usually adopted to analyze the capability of disaster preparedness. In view of the experiences acquired by Australia, most people prefer to stay indoors rather than evacuate to the emergency shelters/open spaces during bushfires [83] and flooding [84]. The reason why they decide to stay and protect their property and pets is primarily due to lack of awareness. In China, however, most evacuations are generally compulsory and are ordered by the local governments [85]. Other than passive and compulsory evacuations to shelters/open spaces, residents are educated to plan and prepare for active sheltering as it is more significant for effective evacuation.

In addition, thanks to opportunities in evacuation drills and other activities, it is possible to optimize shelter locations as well as their designs. Specifically, the planner could check whether congestion would occur during the evacuation period and design a route from an apartment to a corresponding emergency shelter/open space. In order to maintain communal engagement and sustainability in regard to preparedness, activities should adhere to the principles outlined in daily life, through participation and collaboration, repeatedly, multiple purposes and locality [85].

5.3. Spatiotemporal pattern and hierarchical design

Many Chinese cities have recently tackled high risks in disasters due to rapid urbanization, economic development, centralized population and wealth, especially in Beijing and Shanghai.

In most regions, the scale and location of emergency shelters/open spaces are designed using rough and static estimations of population density in the area of city blocks. However, the actual demands of the shelter and population distribution vary greatly in both the spatial and temporal dimensions. As shown in Fig. 7 (a) and (b), the total daytime and nighttime populations in Haidian District of Beijing was 3.24 million and 3.3 million, respectively. Although the ratio is nearly 1, there are obvious differences in the spatial population density [86]. According to GIS, high-density employment centers and business districts would be considered serious blocks as they have high deaths and injuries during the daytime. In parallel with daytime, most of the population would be mainly concentrated in residential areas during nighttime. In addition, long-distance commuting and dispersed distribution are the lifestyles adopted by most people in developed cities. Hence, developing dynamic modelling in regard to the spatiotemporal distribution of the population based on the GIS platform can offer guidance for a shelter's capacity and location [87]. Furthermore, it can also provide prospective and adequate strategies to be used in disaster prevention, emergency response and relief distribution.

Furthermore, the demand for emergency shelters would vary following a disaster. For example, Huiyong et al. [88] extracted the population sizes of residential communities from the Economic and Social Development Statistics Yearbook [89] of Shanghai and identified the population density from hundreds of communities. When an earthquake occurred, nearly 100% of the residents had to seek temporary shelter/open space immediately, while 40% and 20% of residents had demands for higher-level shelters one day following the disaster and ten days following the disaster, respectively. Hence, it is necessary to establish hierarchical emergency shelters/open spaces combined with a dynamic program for evacuation. Specifically, temporal variation in regard to necessities should be taken into consideration when planning and designing an emergency shelter system.

In addition, people's demand and refuge requirements should be considered as the important factor for site selection and shelter design. Sometimes, the "in place" shelter can accelerate recovery and reinforce communal bonding [90,91]. However, larger emergency shelters that require long-distance traveling is also necessary when the urban area is too dense [92]. The hierarchical shelter system provides different levels of service after the disaster, such as long-term shelter, short-time shelter and immediate shelter. A number of multi-criteria location models have been proposed to meet various requirements in complex applications, including p-median model, location set-covering problem (LSCP) and maximal covering location problem (MCLP). Total number of emergency shelters is fixed in p-mediam model [93]. The objective of LSCP model is to find the minimum number of shelters and cover all demand points in specified regions [94]. MCLP model aims to determine the number of shelters and optimal locations to cover more demand points [95,96]. In these models, data-driven approaches have been adopted to solve the optimal location problem, such as ant colony optimization (ACO) [97], genetic algorithm (GA) [98], greedy algorithms and Tabu search algorithms [99]. In other words, the construction cost of the shelter/open space could be reduced by optimizing resident allocation through a dynamic refuge demand estimation.

5.4. Bottom-up approach

Underdeveloped areas also face problems in mismatch between

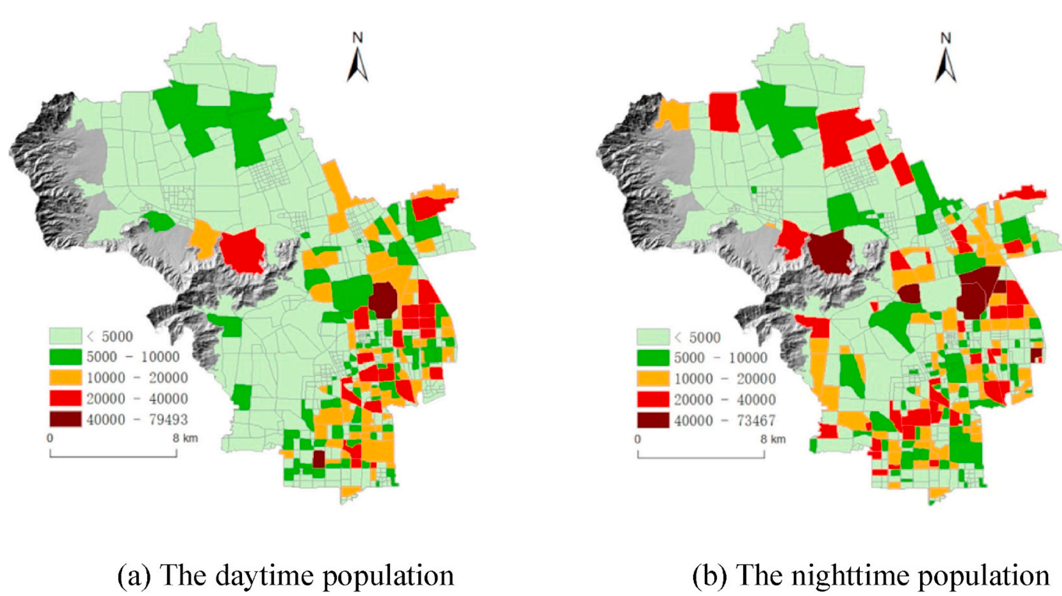

Fig. 7. The population block distribution [86].

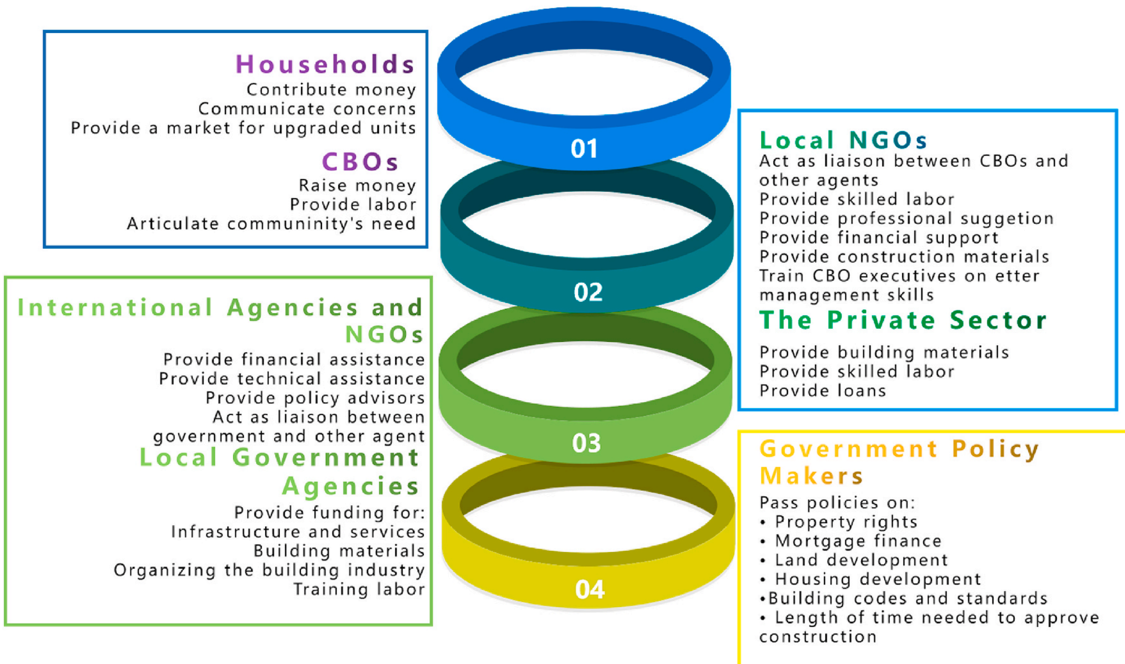

Fig. 8. The responsibility of each participant in a bottom-up approach [102].

refuge demand and shelter accommodation. The distribution of residential houses is dispersed in the countryside, especially in mountainous areas. After the 2008 earthquake in Sichuan province, a top-down approach was applied for post-disaster recovery and reconstruction in Wenchuan Town. Guangzhou, a developed city, was assigned by the government as the corresponding city to support this project [100]. Both the long-term and short-term developments were promoted along with public spaces including a memorial system, a tourism system and a network of open spaces [101].

However, many new problems were introduced due to rapid recovery and reconstruction. For example, the new emergency shelter and open space occupied almost all available land, preventing sustainability of the town. In addition, the residents and developers have few chances to join the recovery program in such a top-down approach, and utilizing such a large number of public open spaces was inefficient.

Hence, experts and researchers have called for a shift from a top-down approach to a bottom-up approach, which encompasses the participation of households, community-based organizations (CBOs), Non-Governmental Organizations (NGOs), private enterprises, international agencies, local government agencies and the national government, as shown in Fig. 8. Responsibilities in construction and fundraising as well as program planning are delegated to multiple participants. For example, questionnaire survey could be conducted to identify the best measurement to generate income and facilitate normal time uses of the shelters [103]. Importantly, the community administrator should know more about the need, lifestyle and age distribution of residents and strengthen the coordination among various CBOs. The generalized CBOs not only means the households, but also includes the schools, restaurants and commercial complex nearby. Furthermore, cross-regional and cross-sector cooperation should be strengthened to comprehensively improve professionalism when constructing emergency shelters. Volunteered geographic information, such like Twitter, can capture people's preferences for planning flood evacuation shelters in a much faster and more comprehensive method than questionnaires and surveys [104].

5.5. Response to multiple disasters

The spatial distribution of a disaster varies across China, especially in the southeast, which possesses multi-disaster characteristics. Different types of emergency shelters are required depending on the disaster. Several coastal cities, such as Shanghai, Dalian and Qingdao, have recently established shelters in seaside parks. These open spaces are effective during earthquakes and fires, though it is difficult for seaside shelters to resist other forms of natural disasters such as tsunamis and typhoons. Therefore, establishing emergency shelters by considering the prevention of damage remains a challenge in China.

In order to reduce the damage of multiple disaster, dynamic designation of emergency shelter combined with varying shelter need is necessary. For example, in flood-prone areas, the desirable location of the emergency shelter/open space should be optimized by considering the probability of stochastic damage caused by floods.

Hence, a flood risk analysis should be conducted to decide the location and capacity of emergency shelters in a dynamic manner. The evacuees' demand for shelter would change in the event of new flooding damage [105]. The population, traffic network, dam site and reservoir are the significant information for developing numerical experiment to select shelter location in the inundation area. Most evacuation models

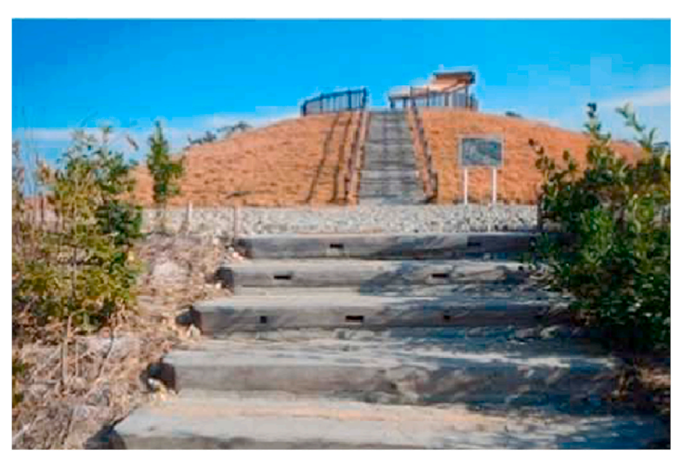

Fig. 9. Elevated ground in the disaster prevention park (also referred to as a vertical emergency shelter) [114].

that consider the optimal selection of shelter based on user equilibrium (UE) [106,107], system optimal (SO) [108,109] and the Constrained System Optimal (CSO) [110–37], Decision Making Trial and Evaluation Laboratory (DEMATEL) [111] models. Specifically, UE model is designed to minimize individual travel time while the main goal of SO model is to minimize the total evacuation time. CSO brings together the two conflicting SO and UE ideas in the bi-level model. The shelter location was specified using SO method and the evacuation route is designed in a UE manner [112]. Cities with high earthquake/hurricane hazard and inundation areas, such like Istanbul, Logan, north Carolina, are adopted as the instances. Since the flood and storm would approach in uncertain paths, shelters located in at-risk regions are assumed as not suitable for use. Hence, planners are suggested to adopt an algorithm as well as GIS to develop a deterministic model for site selection for emergency shelters/open spaces and logistics during shelter operations.

Japan has valuable experiences in resisting the destruction of various disasters, including earthquake, tsunamis and typhoons. In addition to structural countermeasures such as sea dikes and offshore breakwaters, non-structural approaches were adopted to mitigate the effects of tsunamis. Green embankments, coastal forests and disaster prevention parks were established to minimize damages caused by disasters, as shown in Fig. 9. For example, in the "Morino Project" [113] proposed in 2011, a special layout of man-made hills and connecting elevated pathways was promoted, which acted to reduce tsunami impact and served as an evacuation function. Six park units connected with a long network and high land could resettle hundreds of evacuees. In addition, green embankments and coastal forests are able to absorb the tsunami energy while saving human lives during the tsunami [114].

Furthermore, an individual's decision-making behavior and companionship should also be integrated into the design and site selection of emergency shelters for different disasters. An agent-based model could be conducted in conjunction with GIS, where the topography of the site, population distribution, evacuating speed, and inundation features are all considered [115]. According to Fig. 10, a certain number of people prefer to evacuate vertically when the shelter is located in the center of the population, decreasing the mortality rate. However, risk and threat that residents facing would be different in a tsunami-triggered oil spill from industrial parks. Emergency shelters and evacuating routes should be planned with the consideration of different individual behaviors [116].

In China, the number of public open spaces outnumbers that of indoor shelters. School buildings, leisure malls, hotels and enterprise facilities could be assigned as alternatives for indoor emergency shelters. In addition, the cooperation between governments and enterprises should be strengthened. For example, training exercises and drills should be carried out by enterprises to enhance the ability of disaster prevention and emergency management. The pilot projects designating enterprises as emergency shelters should also ensure that all departments actively coordinate with each other and work together. Fortunately, when the COVID-19 broke out, the government and experts have carried out effective measures to establish the emergency field hospitals and temporary quarantine centers immediately. Parts of the functional sites were remodeled based on the school, hotels, convention center, stadiums and industrial plants. Therefore, significant experience should be adopted to guide the assignment of the indoor emergency shelters in the future.

6. Conclusion

Designing emergency shelters and open spaces takes into account optimized issues that both governments and researchers have profoundly discussed. In this study, we critically analyzed the current limitations of emergency shelters and open spaces in China. According to design standards and surveys, the following issues were ascertained: (1) guidelines/standards concerning site selection is vague, and the scale and location of emergency shelters/open spaces are determined by a rough estimation of population density in city blocks; (2) publicity and evacuation drills are rarely carried out in daily life, where problems like congestion and disorder affect evacuation in the wake of an incident; (3) most emergency shelters are located in developed cities and new communities rather than in disaster-prone regions or old towns; (4) mismatch of accommodation and demand is present, which varies depending on the disaster, attributed to population density and temporal variation; and (5) responsibilities of government departments, social groups, enterprises and institutions during the planning, construction, maintaining and emergency stages were not identified.

In order to better incorporate comprehensive factors into planning and site selection for emergency shelters/open spaces, global experiences and strategies pertaining to shelter construction were analyzed. From the reviewed literature concerning shelter construction, the present authors summarized past experiences regarding the planning and location of emergency shelters and open spaces as: (1) tackling shelter location and evacuation routing problems in an integrated manner, such as disaster prevention parks, car-based evacuation and bus-based evacuation; (2) embedding shelters/open spaces into the emergency management cycle, comprised of preparedness, response, mitigation and recovery, as well as multifunctionality of public shelters and open spaces, which would contribute to improving urban resilience; and (3) integrating privately owned spaces and public facilities into the disaster prevention system in order to safeguard people when open spaces are deemed inadequate to accommodate evacuees.

The results from the corresponding documents and articles provided

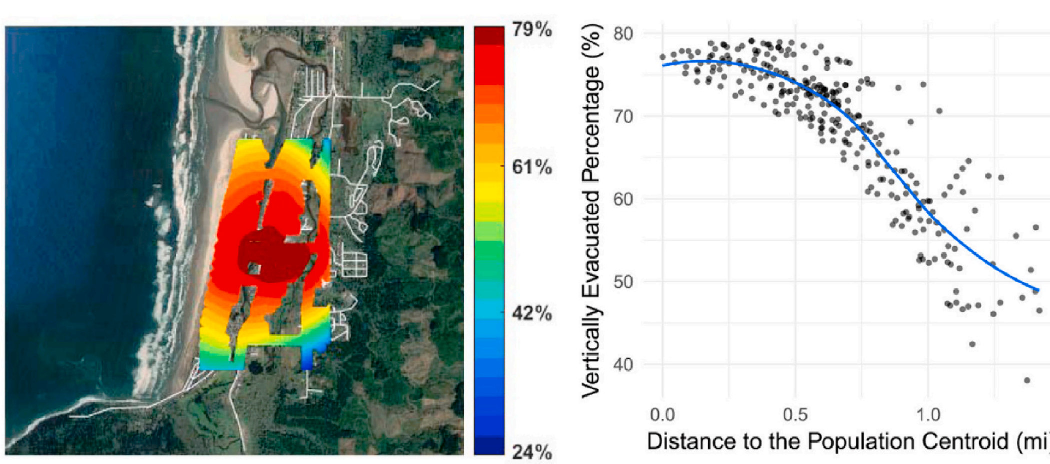

Fig. 10. The proportion of people who consider vertical evacuation in coastal cities [115].

further clarity for prospective planning and site selection for emergency shelters/open spaces, which can significantly impact the safety of people as well as the city. Additionally, instructions for future construction including five potential directions are proposed. In order to solve current issues within shelter construction, the following suggestions are offered:

- Combine the design and planning of emergency shelters and public open spaces into the construction of urban systems;
- Embed everyday-life preparedness and practice to existing community-based disaster risk reduction systems;
- Estimate the refuge demands, and select adequate locations for shelters via spatiotemporal patterns and hierarchical planning;
- Shift from a top-down approach to a bottom-up approach by including private enterprises, non-governmental organizations and community institutions;
- Establish emergency shelters/open spaces by considering different disasters, while incorporating diverse spaces as alternatives.

There is growing urgency to develop novel designs for the fortification of shelter construction and open spaces as rapid population growth and climate change would introduce numerous natural and man-made disasters in the future. The corresponding literature review serves as the authors' initial step toward the development of a framework for the holistic assessment and optimization of emergency shelters and open spaces. Notably, the archival documents and academic articles cited in this study possess certain limitations. Only the full text in English, Japanese and Chinese was included. In order to gain a wider and deeper knowledge of existing literature, future research should include other languages to ensure impartiality of the study's results. In addition, man-made disasters should be included in future analyses.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] IFRC, Definition of disaster. https://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/what-is-a-disaster/. (Accessed 2 March 2020).
[2] EM-DAT, Death toll trend. https://www.emdat.be/. (Accessed 2 March 2020).
[3] Giulia Cerè*, Y. Rezgui, W. Zhao, Critical review of existing built environment resilience frameworks: directions for future research, International Journal of Disaster Risk Reduction 25 (2017).
[4] Ministry of emergency management of the people's Republic of China, basic situation of natural disasters. https://www.mem.gov.cn/xw/zhsgxx/201901/t20190108_242580.shtml. (Accessed 2 March 2020).
[5] Tetsuya Akamatsu, Kayoko Yamamoto, Suitability analysis for the emergency shelters allocation after an earthquake in Japan, Geosciences 9 (8) (2019) 336.
[6] Fırat Kılcı, Bahar Yetiş Kara, Burçin Bozkaya, Locating temporary shelter areas after an earthquake: a case for Turkey, Eur. J. Oper. Res. 243 (1) (2015) 323–332.
[7] M. Montejano-Castillo, M. Moreno-Villanueva, The adaptability of public space in Mexico City after an earthquake: a preliminary classification, International Journal of Safety and Security Engineering 6 (2) (2016) 104–113.
[8] The Central People's Government of the People's Republic of China,Urban planning compilation method. http://www.gov.cn/ziliao/flfg/2006-02/15/content_191969.htm. (Accessed 2 March 2020).
[9] The Central People's Government of the People's Republic of China, Law of the people's Republic of China on urban and rural planning. http://www.gov.cn/ziliao/flfg/2007-10/28/content_788494.htm. (Accessed 2 March 2020).
[10] National Earthquake Response Support Service, Emergency shelter for earthquake disasters—site and its facilities. http://zgyjjy.nerss.cn/newsview_1122_401.html#. (Accessed 2 March 2020).
[11] Huangpi district people's government of wuhan city, construction standards of emergency shelters in urban communities. http://www.huangpi.gov.cn/fbjd_33/xxgkml/aqsc/yjgl_123/202005/t20200522_1326329.html. (Accessed 2 March 2020).
[12] Technical guidance for construction and operation of emergency hospitals based on industrial buildings. http://www.cstcmoc.org.cn/uploads/soft/200225/47-200225130J4.pdf. (Accessed 2 March 2020).
[13] Anaer, K. Li, N. Zheng, L. Hao, H. Jin, Investigation and analysis of emergency shelters in Wuhai City, Inner Mongolia Science Technology & Economy 24 (2018) 19–22 (in Chinese).
[14] Anar, et al., Investigation and analysis of the current situation of emergency refuges in Wuhai city, Inner Mongolia Science Technology and Economy 418 (24) (2018) 21–24.
[15] W. Li, et al., Current situation of emergency refuges in China in the context of urban security concepts, Sci. Technol. Rev. 37 (16) (2019) 38–47.
[16] Selection of Emergency Shelter Sites for Seismic Disasters in Mountainousregions: Lessons from the 2008 Wenchuan Ms 8.0 Earthquake, (China).
[17] H. Wu, P. Ren, Z. Xu, Addressing Site Selection for Earthquake Shelters with Hesitant Multiplicative Linguistic Preference Relation, Information ences, 2019, p. 516.
[18] X. Zhang, Study on the system planning of the urban three-dimensional shelter, Urban. Archit. 17 (2020) 21–24+37 (in Chinese).
[19] CHINA EARTHQUAKE ADMINISTRATION, Guide for operation and management of earthquake emergency shelters. https://www.cea.gov.cn/cea/zwgk/zcjd/5256231/index.html. (Accessed 2 March 2020).
[20] Cabinet Office, Government of Japan, White Paper on Disaster Management, 2013 (in Japanese), http://www.bousai.go.jp/kaigirep/hakusho/. (Accessed 4 August 2020).
[21] Okazaki, et al., Impact of natural disasters on industrial agglomeration: the case of the Great Kanto Earthquake in 1923. Explorations in Economic History, 2016.
[22] Bureau of Construction,disaster prevention system construction. https://www.kensetsu.metro.tokyo.lg.jp/jigyo/park/kouen0020.html. (Accessed 2 March 2020).
[23] Ministry of Land, Infrastructure, Transport and tourism, preservation law of urban green space. http://www.mlit.go.jp/crd/townscape/pdf/ryokuchi-shishin01.pdf. (Accessed 3 March 2020).
[24] Technical note of NILIM,No.857. http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn0857pdf/ks085702.pdf. (Accessed 3 March 2020).
[25] FEMA, The national earthquake hazards reduction program (NEHRP) fact sheet. https://www.fema.gov/media-library/assets/documents/5772. (Accessed 3 March 2020).
[26] Brian Carriere, et al., Fostering Community Resilience: Homeland Security and Hurricane Katrina, Ashgate Publishing, Ltd., 2013.
[27] FEMA, Safe rooms for tornadoes and hurricanes: guidance for community and residential safe rooms. https://www.fema.gov/media-library-data/1467990808182-0272256cba8a35a4e8c35eeff53dd547/fema_p361_July2016_508.pdf. (Accessed 3 March 2020).
[28] FEMA, Taking shelter from the storm: building a safe room for your home or small business. https://www.fema.gov/media-library-data/1418837471752-920f09bb8187ee15436712a3e82ce709/FEMA_P-320_2014_508.pdf. (Accessed 3 March 2020).
[29] FEMA, ICC/NSSA standard for the design and construction of storm shelters. https://www.fema.gov/media-library-data/1444388800229-0902a12ce6670c6f96d8419c7464ca67/Highlights_of_ICC_500.pdf. (Accessed 3 March 2020).
[30] L. Ye, Research on the Planning and Design of Urban Disaster Preventation Park-Take the Planning and Construction of Disaster-Prevention Park in Bejing for Example, Master Thesis, Beijing Forestry University, 2009 (in Chinese).
[31] S. Grasso, M. Maugeri, The seismic microzonation of the city of Catania (Italy) for the maximum expected scenario earthquake of January 11, 1693, Soil Dynam. Earthq. Eng. 29 (6) (2009) 953–962.
[32] H.M. Goverment, Evacuation and shelter guidance, 2015. Retrieved February 26 (2006).
[33] HM Government, Evacuation and shelter guidance. https://www.gov.uk/government/publications. (Accessed 3 March 2019).
[34] Urban Development Division, Urban Development Division, Town planning bureau, hokkaido construction department. http://www.pref.hokkaido.lg.jp/kn/tkn/grp/03/sekkei1.pdf. (Accessed 3 March 2020).
[35] A. Esposito Amideo, M.P. Scaparra, K. Kotiadis, Optimising shelter location and evacuation routing operations: the critical issues, Eur. J. Oper. Res. 279 (2) (2019) 279–295.
[36] Anna CY. Li, et al., Shelter location and transportation planning under hurricane conditions, Transport. Res. E Logist. Transport. Rev. 48 (4) (2012) 715–729.
[37] Vedat Bayram, Barbaros Ç. Tansel, Hande Yaman, Compromising system and user interests in shelter location and evacuation planning, Transp. Res. Part B Methodol. 72 (2015) 146–163.
[38] Vedat Bayram, Hande Yaman, Shelter location and evacuation route assignment under uncertainty: a benders decomposition approach, Transport. Sci. 52 (2) (2018) 416–436.
[39] Marc Goerigk, Kaouthar Deghdak, Philipp Heßler, A comprehensive evacuation planning model and genetic solution algorithm, Transport. Res. E Logist. Transport. Rev. 71 (2014) 82–97.
[40] Shahrooz Shahparvari, et al., Enhancing emergency evacuation response of late evacuees: revisiting the case of Australian Black Saturday bushfire, Transport. Res. E Logist. Transport. Rev. 93 (2016) 148–176.
[41] Four phases of emergency management. http://www.thepreparednesspodcast.com/the-four-phases-of-emergency-management/. (Accessed 3 March 2020). ≤.

[42] Fatma Aycim Turer Baskaya, Disaster sensitive landscape planning for the coastal megacity of Istanbul, J. Coast Conserv. 19 (5) (2015) 729–742.
[43] Pizzo, Barbara, et al. "Earthquakes, public spaces and (the social construction of) environmental disasters.".
[44] Diane Brand, Hugh Nicholson, Public space and recovery: learning from post-earthquake Christchurch, J. Urban Des. 21 (2) (2016) 159–176.
[45] Irina Tumini, Paula Villagra-Islas, Geraldine Herrmann-Lunecke, Evaluating reconstruction effects on urban resilience: a comparison between two Chilean tsunami-prone cities, Nat. Hazards 85 (3) (2017) 1363–1392.
[46] M.R. Dionísio, The Importance of Public Space for Sustainable Urban Rehabilitation, 2010.
[47] Paula Villagra-Islas, Dobbie Meredith, Design aspects of urban wetlands in an earthquake-prone environment, J. Urban Des. 19 (5) (2014) 660–681.
[48] Joana Chan, Bryce DuBois, Keith G. Tidball, Refuges of local resilience: community gardens in post-Sandy New York City, Urban For. Urban Green. 14 (3) (2015) 625–635.
[49] San Francisco, The U.S. emergency management cycle. https://www.cmgsite.com/project/resilient-sf/. (Accessed 3 March 2020).
[50] Lindsay Campbell, Anne Wiesen, Restorative commons: creating health and well-being through urban landscapes, in: Gen. Tech. Rep. NRS-P-39, vol. 278, US Department of Agriculture, Forest Service, Newtown Square, PA, 2009, p. 39. Northern Research Station.
[51] Penny Allan, Martin Bryant, Resilience as a framework for urbanism and recovery, Journal of Landscape Architecture 6 (2) (2011) 34–45.
[52] Penny Allan, et al., The influence of urban morphology on the resilience of cities following an earthquake, J. Urban Des. 18 (2) (2013) 242–262.
[53] Disaster prevention manual "Tokyo disaster prevention. http://www.metro.tokyo.jp/chinese/guide/bosai/index.html. (Accessed 3 March 2020).
[54] Cabinet office, government of Japan,guide to designation of designated emergency evacuation sites. http://www.bousai.go.jp/oukyu/hinankankoku/pdf/shiteitebiki.pdf. (Accessed 3 March 2020).
[55] Dong Wan Yoo, Taegoo Lee, The case and planning elements of an underground shelter for emergency disasters, Journal of the Korean Society of Hazard Mitigation 19 (2) (2019) 137–142.
[56] Han Admiraal, Antonia Cornaro, Future Cities, Resilient Cities–The Role of Underground Space in Achieving Urban Resilience, Underground Space, 2019.
[57] Taegoo Lee, Younghae Han, Measures to ensure effective disaster shelter facilities using underground parking lots in existing apartment houses, Journal of the Korean Society of Hazard Mitigation 19 (2) (2019) 129–136.
[58] Federal Emergency Management Agency, and Washington. "Design and Construction Guidance for Community Shelters. FEMA vol. 361. ".
[59] Hurricane evacuation shelter selection standards. https://nationalmasscarestrategy.org/wp-content/uploads/2019/02/HurricaneEvacuationShelterSelectionStandards.pdf. (Accessed 3 March 2020). ≤.
[60] The United Nations, The 2030 Agenda for sustainable development. https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf. (Accessed 3 March 2020).
[61] UNDRR, UN international strategy for disaster reduction. http://www.unisdr.org/. (Accessed 3 March 2019).
[62] UNDRR, UN international strategy for disaster reduction terminology. http://www.unisdr.org/we/inform/terminology. (Accessed 3 March 2020).
[63] David Koren, Vojko Kilar, Katarina Rus, A Conceptual Framework for the Seismic Resilience Assessment of Complex Urban Systems, 2018. https://www.researchgate.net/publication/326479539_A_CONCEPTUAL_FRAMEWORK_FOR_THE_SEISMIC_RESILIENCE_ASSESSMENT_OF_COMPLEX_URBAN_SYSTEMS. (Accessed 3 March 2020).
[64] David Koren, Vojko Kilar, Katarina Rus, Proposal for holistic assessment of urban system resilience to natural disasters, in: IOP Conference Series: Materials Science and Engineering, vol. 245, IOP Publishing, 2017. No. 6.
[65] Gonzalo Álvarez, et al., Identification and classification of urban micro-vulnerabilities in tsunami evacuation routes for the city of Iquique, Chile, Nat. Hazards Earth Syst. Sci. 18 (7) (2018) 2027–2039.
[66] Michael Mehaffy, et al., Urban nuclei and the geometry of streets: the 'emergent neighborhoods' model, Urban Des. Int. 15 (1) (2010) 22–46.
[67] People resilience framework. http://peoplesresilience.org/what-is-resilience. (Accessed 3 March 2020). ≤.
[68] Jinghai Xu, et al., Multi-criteria location model of earthquake evacuation shelters to aid in urban planning, International Journal of Disaster Risk Reduction 20 (2016) 51–62.
[69] Xue Jiang, et al., A practical approach to constructing hierarchical networks for urban hazard mitigation planning using GIS: the case of Futian, Shenzhen, International journal of disaster risk reduction 28 (2018) 629–639.
[70] Penny Allan, et al., The influence of urban morphology on the resilience of cities following an earthquake, J. Urban Des. 18 (2) (2013) 242–262.
[71] Xudong Zhao, et al., Assessing urban lifeline systems immediately after seismic disaster based on emergency resilience, Structure and Infrastructure engineering 12 (12) (2016) 1634–1649.
[72] UNDRR, Making cities resilient campaign. https://www.unisdr.org/campaign/resilientcities/. (Accessed 3 March 2020).
[73] David E. Alexander, Resilience and disaster risk reduction: an etymological journey, Natural Hazards and Earth System Sciences Discussions 1 (2) (2013) 1257–1284.
[74] 100 Resilient Cities,Helping cities around the world become more resilient to physical, social, and economic shocks and stresses. https://www.rockefellerfoundation.org/our-work/initiatives/100-resilient-cities/. (Accessed 3 March 2020).
[75] H. Zhou, K. Dhiradhamvit, T.L. Attard, Tornado-borne debris impact performance of an innovative storm safe room system protected by a carbon fiber reinforced hybrid polymeric-matrix composite, Eng. Struct. 59 (feb) (2014) 308–319.
[76] H. Zhao, X. Qian, Simulation analysis on structure safety of two typical refuge chamber shell forms under explosion load, Procedia Engineering 45 (none) (2012) 910–915.
[77] H. Kawasaki, S. Yamasaki, M.M. Rahman, Y. Murata, M. Iwasa, C. Teramoto, Teachers-parents cooperation in disaster preparation when schools become as evacuation centers, International Journal of Disaster Risk Reduction 44 (2020) 101445.
[78] C.A.B. A, A.H. A, K.S.H. B, S.K.G. C, A feasibility study on disaster preparedness in regional and rural emergency departments in new south wales: nurses self-assessment of knowledge, skills and preparation for disaster management, Australasian Emergency Care 23 (1) (2020) 29–36.
[79] K. Yamori, Promoting 'Everyday-Life Preparedness' ['seikatsu Bosai'no Susume], 2011.
[80] R.P.K. Lam, L.P. Leung, S. Balsari, K.H. Hsiao, E. Newnham, K. Patrick, et al., Urban disaster preparedness of Hong Kong residents: a territory-wide survey, International Journal of Disaster Risk Reduction 23 (2017) 62–69.
[81] C. Kousky, L. Ritchie, K. Tierney, B. Lingle, Return on investment analysis and its applicability to community disaster preparedness activities: calculating costs and returns, International Journal of Disaster Risk Reduction 41 (2019) 101296.
[82] M. Battarra, B. Balcik, H. Xu, Disaster Preparedness Using Risk-Assessment Methods from Earthquake Engineering, European Journal of Operational Research, 2018. S0377221718301292.
[83] Raphaele Blanchi, et al., Surviving bushfire: the role of shelters and sheltering practices during the Black Saturday bushfires, Environ. Sci. Pol. 81 (2018) 86–94.
[84] Katharine Haynes, et al., Motivations and experiences of sheltering in place during floods: implications for policy and practice, International journal of disaster risk reduction 31 (2018) 781–788.
[85] Jiabing Wu, et al., Planned sheltering as an adaptation strategy to climate change: lessons learned from the severe flooding in Anhui Province of China in 2016, Sci. Total Environ. 694 (2019) 133586.
[86] Haihong Yuan, Xiaolu Gao, Wei Qi, Modeling the fine-scale spatiotemporal pattern of earthquake casualties in cities: application to Haidian District, Beijing, International journal of disaster risk reduction 34 (2019) 412–422.
[87] Chen Chen, Lin Cheng, Evaluation of seismic evacuation behavior in complex urban environments based on GIS: a case study of Xi'an, China, International Journal of Disaster Risk Reduction 43 (2020) 101366.
[88] Huiyong Li, et al., Hierarchical earthquake shelter planning in urban areas: a case for Shanghai in China, International journal of disaster risk reduction 22 (2017) 431–446.
[89] Economic and social development Statistics Yearbook. http://tjj.sh.gov.cn/html/sjfb/201701/1000196.html. (Accessed 4 March 2020). ≤.
[90] Paul Stangl, Prospects for Urban Morphology in Resilience Assessment." Resilience-Oriented Urban Planning, Springer, Cham, 2018, pp. 181–193.
[91] Resilience-Oriented Urban Planning: Theoretical and Empirical Insights, in: Yoshiki Yamagata, Ayyoob Sharifi (Eds.) vol. 65, Springer, 2018.
[92] Ayyoob Sharifi, Urban form resilience: a meso-scale analysis, Cities 93 (2019) 238–252.
[93] J.M. Marcelin, M.W. Horner, E.E. Ozguven, How does accessibility to post disaster relief compare between the aging and the general population? A spatial network optimization analysis of hurricane relief facility locations, Int. J. Disaster Risk.
[94]] C. Toregas, R. Swain, C. ReVelle, L. Bergman, The location of emergency service facilities, Oper. Res. 19 (6) (1971) 1363–1373.
[95] V. Azhmyakov, J.P. Fernández-Gutiérrez, S.K. Gadi, S. Pickl, A novel numerical approach to the MCLP based resilent supply chain optimization, IFAC-PapersOnLine. 49 (31) (2016) 137–142.
[96] S. Davari, M.H.F. Zarandi, A. Hemmati, Maximal covering location problem (mclp) with fuzzy travel times, Expert Syst. Appl. 38 (12) (2011) 14535–14541.
[97] Z. Fang, X. Zong, Q. Li, Q. Li, S. Xiong, Hierarchical multi-objective evacuation routing in stadium using ant colony optimization approach, J. Transport Geogr. 19 (3) (2011) 443–451. Reduct. 15 (2016) 61–72.
[98] Evaluation and comparison of Genetic Algorithm and Bees Algorithm for location–allocation of earthquake relief centers, Int. J. Disaster Risk Reduct. 15 (2016) 94–107.
[99] X.P. Li, Z.X. Zhao, X.Y. Zhu, T. Wyatt, Covering models and optimization techniques for emergency response facility location and planning: a review, Math. Methods Oper. Res. 74 (2011) 281–310.
[100] Recovery and reconstruction plan of Weizhou town. http://www.gzpi.com.cn/social.html. (Accessed 4 March 2020).
[101] Lixiong Liu, Yanliu Lin, Shifu Wang, Urban design for post-earthquake reconstruction: a case study of Wenchuan County, China, Habitat Int. 41 (2014) 290–299.
[102] Petronella WK. Muraya, Failed top-down policies in housing: the cases of Nairobi and Santo Domingo, Cities 23 (2) (2006) 121–128.
[103] M.Z. Haider, M.F. Ahmed, Multipurpose uses of cyclone shelters: quest for shelter sustainability and community development %, J International Journal of Disaster Risk Reduction 9 (2014).
[104] A.N.L. Kusumo, D. Reckien, J. Verplanke, Utilising volunteered geographic information to assess resident's flood evacuation shelters. case study: jakarta, Appl. Geogr. 88 (2017) 174–185.
[105] Mustafa Anil Yazici, Kaan Ozbay, Impact of probabilistic road capacity constraints on the spatial distribution of hurricane evacuation shelter capacities, Transport. Res. Rec. 1 (2007) (2021) 55–62.

[106] A. Kulshrestha, D. Wu, Y. Lou, Y. Yin, Robust shelter locations for evacuation planning with demand uncertainty, J. Transport. Saf. Secur. 3 (4) (2011) 272–288.
[107] Z.J.M. Shen, J. Pannala, R. Rai, T.S. Tsoi, Modeling Transportation Networks during Disruptions and Emergency Evacuations, 2008.
[108] V. Bayram, H. Yaman, Shelter Location and Evacuation Route Assignment under Uncertainty: a Benders Decomposition Approach, 2015.
[109] S. Kongsomsaksakul, C. Yang, A. Chen, Shelter location–allocation model for flood evacuation planning, J. East Asia Soc. Transp. Stud. 6 (1) (2005) 4237–4252.
[110] C.Y. Li, L. Nozick, N. Xu, R. Davidson, Shelter location and transportation planning under hurricane conditions, Transp. Res. Part E: Logist. Transp. Rev. 48 (4) (2012) 715–729.
[111] T. Ashish, A multi-criteria decision approach based on dematel to assess determinants of shelter site selection in disaster response, in: International Journal of Disaster Risk Reduction, 2018. S2212420918304424;
[111a] V. Bayram, H. Yaman, Shelter Location and Evacuation Route Assignment under Uncertainty: a Benders Decomposition Approach, 2015.
[112] V. Bayram, Optimization models for large scale network evacuation planning and management: a literature review, Surveys in Operations Research and Management Science 21 (2) (2016) 63–84.
[113] Morino Project. http://morinoproject.com/english. (Accessed 4 March 2020).
[114] Agnieszka Strusińska-Correia, Tsunami mitigation in Japan after the 2011 tōhoku tsunami, International journal of disaster risk reduction 22 (2017) 397–411.
[115] Alireza Mostafizi, et al., An agent-based vertical evacuation model for a near-field tsunami: choice behavior, logical shelter locations, and life safety, International journal of disaster risk reduction 34 (2019) 467–479.
[116] Wai Phyo Kyaw, et al., Numerical analysis of tsunami-triggered oil spill from industrial parks in Osaka Bay, J. Loss Prev. Process. Ind. (2017). S0950423017303996.