Planning and assessment approaches towards disaster resilient hospitals: A systematic literature review

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Abstract

**Background:** Hospitals play a critical role as a frontline agency in disasters, with staff often working within extraordinary circumstances in these facilities to deliver care. This study was inspired by the authors’ interdisciplinary experiences in health and resilience engineering. Observing increasing dialogue about how hospitals could improve their resilience to disasters we sought to understand the construct of ‘hospital resilience during disasters’ and how it could be improved.

**Method:** The study involved a systematic literature review of publications related to hospital resilience during disasters, conducted at the end of January 2020. Of the 553 articles found initially, 49 remained after applying inclusion and exclusion criteria. Quality appraisal tools designed for different types of research were used.

**Results:** The findings are described using language and constructs drawn from the Plan-Prepare-Respond-Recover (PPRR) discourse and Resilience Engineering Theory. The review found broad consensus that staff awareness, education, and training about disaster-related plans need to be improved. The articles documented a wide variety of approaches to evaluating hospital resilience to disasters, wherein the importance of infrastructure and organisational resilience is clear. This included insightful guidance for developing, disseminating, communicating, and implementing disaster plans.

**Conclusion:** Through distilling the literature review findings, we propose a ‘Decision-Support Model for Disaster Resilient Hospitals’ to foster proactive and systemic improvements, from anticipating to managing and monitoring organisational performance during disasters. We also propose a hybrid of two methods towards a more holistic evaluation of hospital disaster resilience. The findings have immediate implications for supporting hospital leadership strategically and operationally.

**Keywords:** Hospital Resilience, Disasters, Planning, Preparedness, Resilience Engineering, Decision-Support
1. Introduction

Hospitals must always be accessible and functioning. They must also be able to meet sudden increases in demand, particularly during disasters, even when the impacts of the disasters are felt by these institutions and their staff. Disasters are abrupt, unexpected events that can cause great destruction, injuries, and death as well as damage to assets and the environment. The planet has been impacted by more than 6,870 recognised natural disasters within the last 20 years, impacting 1.5 billion people and leading to more than 1.35 million deaths (Ghanaatpisheh, Khankeh, & Masoumi, 2019). Natural disasters include, for example, earthquakes, floods, hurricanes, tsunamis, super typhoons, fires, and other extreme weather events such as heatwaves, storm-surge and rain bombs (Landgraf & Officer, 2016; Rivera-Royero, Galindo, & Yie-Pinedo, 2020). Human-made disasters include, for example, biological, chemical, and nuclear accidents, terrorism, and mass causality incidents (El Sayed, Chami, & Hitti, 2018; Grieco, Gleed, Groves, Dyer, & Utley, 2018; Valkanova, Kostadinov, Etova, & Georgieva, 2019). This study aimed to provide hospital managers and leaders with a comprehensive hospital preparedness plan for resilience that will guide them to manage unforeseeable natural and human-made disasters.

People expect hospitals to have a high level of ‘business continuity’ – i.e. to be accessible at all hours, and to provide medical care, water, food, power, and sometimes also information about the disaster itself, accommodation options, and about missing family (Albanese et al., 2008; Carthey, Chandra, & Loosemore, 2008; Geelen-Baass & Johnstone, 2008). There are well-documented examples, however, where hospitals have been overwhelmed in such circumstances, resulting in the partial or complete failure to meet such expectations (Barten, Veltmeijer, & Peters, 2019; Charney, Rehmann, & Flood, 2014; Davis, Zobel, Khansa, & Glick, 2019).

Hospitals are complex systems with many levels of interconnection between their sections, outward-facing services and internal processes (Preparedness & Program, 2000). The aim of evaluating hospitals is to recognize the areas that need improvement and the required significant interventions, to decrease all morbidity, mortality, and socioeconomic consequences of disasters. Over the years, researchers have documented the theoretical foundations, factors that affect hospital resilience, methods adopted in studying and assessing it, and emergent ‘resilience’ strategies in hospitals (Achour, Miyajima, Pascale, & D.F. Price, 2014; Ellis et al., 2019; Rosso & Saurin, 2018). These researchers highlight the need to develop hospital-appropriate (i.e. place-based) strategies for improved resilience. Other researchers have identified the need for metrics to help measure a hospital’s level of resilience and to identify which parts of the hospital are responsible for maintaining a hospital's performance during disasters (Shuang Zhong, Xiang-Yu Hou, et al., 2014).

Such improvement opportunities are often discussed within the broadly understood and recognised context of the disaster management cycle, spanning four phases of prevention, preparedness, response and recovery (PPRR) (Alexander, 2019; Neal, 1997). According to the United Nations International Strategy for Disaster Risk and future Reduction, prevention is defined as the actions taken to evade current risks of disasters. UNISDR defines preparedness as “The knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters” (UNISDR, 2016, p. 21). When actions are taken directly before, during or immediately after a disaster they constitute the disaster response, “using resources and emergency procedures as dictated by emergency plans to preserve life, property, the environment, and the community’s social, economic, and political structure” (Berkoune, Renaud, Rekik, & Ruiz, 2012, p. 23). Recovery is the return of health and wellbeing and reestablishment of whatever formerly occurred preceding the disaster (Quarantelli, 1999), more recently acknowledged to include the construct of ‘Build-Back-Better’, and including rehabilitation and reconstruction. The Sendai Framework for Disaster Risk Reduction (SFDRR) (2015–2030) highlighted that effective disaster response necessitates proper disaster preparedness. Furthermore, the construct of “Build-Back-Better” is significant in recovery, rehabilitation and reconstruction (Dube, 2020; Pearson & Pelling, 2015; Saya et al., 2017).
The field of ‘Resilience Engineering’ (RE) has been explored by several researchers as an avenue for systematically identifying opportunities for improvement in complex operational environments including hospitals (Hollnagel, Woods, & Leveson, 2006; Peñaloza, Formoso, & Saurin, 2017; Rodrigues Santos de Melo & Bastos Costa, 2019). In such environments operations are complex due to augmented stakeholder numbers, the use of innovative technical applications and complex interrelations between units or departments (Komljenovic, Loiselle, & Kumral, 2017). Within the healthcare sector, Shirali and colleagues (2016) were the first to use the RE for their study of hospital resilience. These researchers recommended the RE categories for crisis management, where a prospective view and a preparedness pyramid could be anticipated for any future disasters. Furthermore, the researchers concluded that the key elements of planning, infrastructure, knowledge and capabilities, and training need to be embedded as preventive measures in crisis management (Shirali et al., 2016).

RE addresses the need for people to deal with the complexity and variability of their system during critical situations (Baker & Refsgaard, 2007; Hollnagel et al., 2006; Peñaloza et al., 2017; Rodrigues Santos de Melo & Bastos Costa, 2019), considering both the proactive anticipation of potentially disruptive situations and the reactive creation of unplanned resolutions (Hollnagel et al., 2006). The basic principle of RE is predicting probable, unfavourable outcomes and working proactively to prevent them (Ekstedt & Ödegård, 2014). Four categories of capabilities are used to evaluate readiness of a system to respond in these situations: ‘Potential’ (to anticipate future threats and opportunities); ‘Actual’ (to respond to events); ‘Critical’ (to monitor ongoing developments); and ‘Factual’ (to learn from past failures and successes) (Pariès, Wreathall, Hollnagel, Wreathall, & Hollnagel, 2010).

With this context in mind, the aim of this study was to answer the research question: How do hospital leaders manage the performance of staff and infrastructure during disasters? We sought to understand the construct of ‘disaster resilient hospitals’ in relation to this question, focusing on the commonly understood cyclical PPRR process and what could be learned from RE Theory.

2. Method

A systematic literature review (SLR) of publications related to hospital resilience during disasters was undertaken according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al., 2009; Moher, Liberati, Tetzlaff, Altman, & Group, 2009). The search was conducted at the end of January 2020 by extracting peer-reviewed articles published between 1 January 1990 and 1 January 2020. The Web of Knowledge / Web of Science Core Collection, MEDLINE (Lloyd Wommack, personal communications), and Google Scholar (Google Inc, Mountain View, CA) were searched using the keywords and combinations: "Resili*" AND “Hospital” AND (Disaster* OR Earthquake* OR Flood* OR Storm* OR Hurricane* OR Cyclone* OR Pandemic* OR War* OR MCI* OR Tornado* OR Terrorism* OR Bushfire*). A minimum of 2 reviewers conducted the initial study identification, secondary study screening, and final determination of eligibility and study inclusion. For evaluating the quality of included articles, the checklists designed for quantitative, qualitative and mixed methods studies found in Hong et al. (2018) were used, while a checklist designed specifically for modelling studies was adapted from a comprehensive one presented in Benner & Manuel (2012). [ shown in Tables S1-S4-supplementary material].

The SLR search was restricted to peer-reviewed, journal research articles, written in English. Each included article had to have the following key words in either their title or abstract, ‘resilience’, ‘hospital’, and ‘disasters’ or their synonyms. Literature reviews were excluded from the search. In addition, articles were excluded if they only addressed related but not relevant topic areas of community resilience, psychological and psychiatric resilience, or the resilience of people, patients, families, and citizens. Articles were also excluded if they focused on resilience of medical students/interns/health professionals (if addressed alone without investigating hospital resilience), the resilience of transportation, or field-deployment of hospital personnel.
Data analysis of included studies was performed according to the following areas: Study details, Study author(s), Journal, Year of publication, Country of study, Methods, Type of disaster, Type of resilience, Themes (what questions or concepts recur across the literature), Outcome measures (what does it uncover), and Research limitations/implications. The findings were reviewed within the evolving construct of ‘disaster resilient hospitals’ to identify critical components of hospital actions and strategies for enhancing their capability for business continuity. We considered hospitals’ organisational capabilities regarding ‘responding to’ (Actual), ‘monitoring’ (Critical) and ‘anticipating’ (Potential) disasters. Given the substantial literature available (in the order of an additional 70 papers) on the fourth RE category – hospitals learning from past failures and successes (Factual) – we chose to address this aspect of the research question in a separate systematic literature review, which will build on and connect with the investigation presented in this paper. Once the SLR results had been analysed, an additional extant literature review of additional publications informed discussion of the findings. This was important to contextualise the findings within the established appreciation of the PPRR Model, organisational resilience, infrastructure and utility resilience, and ongoing monitoring and management.

3. Results

Figure 1 summarises the literature sorting process, and the key decision-points in distilling the literature. The search returned an initial set of 553 results which were subsequently screened to exclude literature reviews, books, conference proceedings, and those written in non-English languages. This resulted in 339 peer-reviewed research journal articles and when duplicate documents (143) were removed, 196 journal articles remained. These 196 publications were then read in full to ensure that those that lacked any of the key inclusion criteria (listed below) and those that addressed a different context were excluded. A total of 49 articles were included in the final analysis.

![Figure 1. Literature Review Selection Process and Results](attachment://figure1.jpg)
3.1 Descriptive analysis of literature

Regarding the chronological summary of publications included in this study, there has been a gradual and significant increase in relevant publications since 2004 with a peak between 2016-2019 when nearly 31 (63 per cent) of the articles were published. The highest number of publications 13 (26.5 per cent) was in 2019. Figure 2 shows the number of articles addressing hospitals and disaster resilience by their geographical distribution. This was based on either the location of the study (if mentioned explicitly) or the affiliation of the authors, if not described in the article. While disasters are globally distributed, it is evident that studies addressing hospital disaster resilience were lacking in Africa, South America, Middle America, and North Asia.

![Figure 2. Number of publications concerning the geographical distribution](image)

The growing number of publications addressing the effect of natural disasters on hospitals, highest between 2016-2019, could in part be explained by the concurrent global rise in climate change impacts, including extreme weather conditions.

Of the 49 included studies, 34 (69 per cent) discussed specific disasters in relation to hospital resilience. The remaining articles (15) addressed disasters, or group of commonly occurring disasters, without being specific to one type. Table 1 provides a summary of papers addressing specific disasters. Fourteen papers addressed hospital resilience in the context of earthquakes and were published consistently between 2008 and 2019. Eight of these 14 studies were relevant to Japan and the USA. Climate change was addressed explicitly only in Australia (3 articles). However, it was identified as an underlying cause or concurrent risk factor influencing other disaster types, for example, the floods in Sri Lanka and Siberia (Farley, Suraweera, Perera, Hess, & Ebi, 2017; Nenkovic-Riznic, Brankov, Petrovic, & Pucar, 2018).
### Table 1. A Summary of disaster literature relating to hospitals, organised by disaster type (sources as noted)

<table>
<thead>
<tr>
<th>Disaster type (N = Total papers)</th>
<th>Countries involved</th>
<th>Number of papers</th>
<th>Year</th>
<th>Key literature (References as shown)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Iran</td>
<td>2</td>
<td>2019</td>
<td>(Aghapour, Yazdani, Jolai, &amp; Mojtahedi, 2019; Ghanaatpisheh et al., 2019)</td>
</tr>
<tr>
<td></td>
<td>New Zealand</td>
<td>1</td>
<td>2014</td>
<td>(Jacques et al., 2014)</td>
</tr>
<tr>
<td></td>
<td>Nepal</td>
<td>1</td>
<td>2019</td>
<td>(Moitinho de Almeida et al., 2019)</td>
</tr>
<tr>
<td></td>
<td>Italy and Monte Carlo</td>
<td>1</td>
<td>2017</td>
<td>(G. P. Cimellaro, Malavisi, &amp; Mahin, 2016)</td>
</tr>
<tr>
<td></td>
<td>Canada</td>
<td>1</td>
<td>2008</td>
<td>(McDaniels, Chang, Cole, Mikawoz, &amp; Longstaff, 2008)</td>
</tr>
<tr>
<td>Mass Casualty Incidents and Crowdedness N (4)</td>
<td>Middle East</td>
<td>2</td>
<td>2004, 2018</td>
<td>(El Sayed et al., 2018; Schreiber et al., 2004)</td>
</tr>
<tr>
<td></td>
<td>USA</td>
<td>2</td>
<td>2019, 2020</td>
<td>(Davis et al., 2019; Tariverdi, Fotouhi, Moryadee, &amp; Miller-Hooks, 2019)</td>
</tr>
<tr>
<td>Storms N (4)</td>
<td>Philippines (Super typhoon)</td>
<td>1</td>
<td>2017</td>
<td>(Labarda, Labarda, &amp; Lamberte, 2017)</td>
</tr>
<tr>
<td></td>
<td>USA (Hurricane)</td>
<td>2</td>
<td>2017, 2019</td>
<td>(Toner et al., 2017; Ybarra, 2019)</td>
</tr>
<tr>
<td></td>
<td>USA (Snowstorm)</td>
<td>1</td>
<td>2015</td>
<td>(I. Park, Sharman, &amp; Rao, 2015)</td>
</tr>
<tr>
<td>Climate Change N (3)</td>
<td>Australia</td>
<td>3</td>
<td>2015, 2016</td>
<td>(Chand &amp; Loosemore, 2016a, 2016b, 2016c)</td>
</tr>
<tr>
<td>Floods &amp; Tsunami N (3)</td>
<td>Sri Lanka</td>
<td>1</td>
<td>2017</td>
<td>(Farley et al., 2017)</td>
</tr>
<tr>
<td></td>
<td>Serbia</td>
<td>1</td>
<td>2018</td>
<td>(Nenkovic-Riznic et al., 2018)</td>
</tr>
<tr>
<td></td>
<td>Sri Lanka</td>
<td>1</td>
<td>2019</td>
<td>(Munasinghe &amp; Matsui, 2019)</td>
</tr>
<tr>
<td>Chemical, Biological, Radiological and Nuclear Incidents N (2)</td>
<td>Australia</td>
<td>1</td>
<td>2018</td>
<td>(Currie &amp; Heslop, 2018)</td>
</tr>
<tr>
<td></td>
<td>England</td>
<td>1</td>
<td>2018</td>
<td>(Grieco et al., 2018)</td>
</tr>
<tr>
<td>Others (disasters that could not be categorized into any of the disaster categories)</td>
<td>USA</td>
<td>1</td>
<td>2015</td>
<td>(Y. S. Park, Behrouz-Ghayebi, &amp; Sury, 2015)</td>
</tr>
<tr>
<td></td>
<td>Belgium</td>
<td>1</td>
<td>2019</td>
<td>(Al-Shamsi, Moitinho de Almeida, Nyanchoka, Guha-Sapir, &amp; Jennes, 2019)</td>
</tr>
<tr>
<td></td>
<td>The Netherlands</td>
<td>1</td>
<td>2019</td>
<td>(Barten et al., 2019)</td>
</tr>
<tr>
<td></td>
<td>England and Australia</td>
<td>1</td>
<td>2015</td>
<td>(Morgan et al., 2015)</td>
</tr>
</tbody>
</table>

**Total Articles** 34
3.2 Defining disaster resilient hospitals

The SLR uncovered an emerging appreciation of disaster resilient hospitals through discourse that spans the last decade. In the following subsection, this is discussed in relation to the emergence of common language (Section 3.2.1). We then present the literature findings relating to hospitals’ organisational and resilience capabilities. Drawing on the established appreciation of the ‘plan-prepare-respond-recover’ (PPRR) model, and resilience engineering regarding ‘anticipating’ (Potential) disasters, ‘responding to’ (Actual), and ‘monitoring’ (Critical), the SLR is then presented using the over-arching themes shown in Table 2.

Table 2. The PPRR Model and RE overarching themes and their sub-thematic analysis

<table>
<thead>
<tr>
<th>RE overarching themes (Adapted from Pariès et al., 2010)</th>
<th>PPRR Model overarching themes (Adapted from Neal, 1997; Weichselgartner &amp; Pigeon, 2015)</th>
<th>PPRR Model Sub-thematic Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage of ‘Anticipating’ (Section 3.2.2)</td>
<td>Planning and preparedness (PP)</td>
<td>Planning for organisational resilience</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Planning for infrastructure and utilities resilience</td>
</tr>
<tr>
<td>Coverage of ‘Responding to’ – organisational capacity (Section 3.2.3)</td>
<td>Response (R)</td>
<td>Response to disasters</td>
</tr>
<tr>
<td>Coverage of ‘Monitoring’ Evaluating disaster resilient hospitals (Section 3.2.4)</td>
<td>Recovery (R)</td>
<td>Recovery following disasters (Monitoring &amp;Managing-Resilience assessment)</td>
</tr>
</tbody>
</table>

3.2.1 Emergence of associated vocabulary

Ten reviewed papers discussed in detail disaster management and varying types of resilience, which is captured here to demonstrate the emergence of the vocabulary. Disaster resilience is considered as a systemic quality, that reflects, “not only inherent vulnerabilities and capacities, but also decisions and actions” (Labarda et al., 2017; McDaniels et al., 2008, p. 311). When a disaster occurs, it can overwhelm emergency services, potentially including human and infrastructure resources. As patient survival is correlated with the quality of medical decisions, decisions about the deployment of hospital capabilities are critically important (Jacques et al., 2014; Tseng, Shih, Shen, Ho, & Wu, 2018).

In the past, the success of hospitals during disasters has largely been discussed using language such as ‘crisis management’. In contrast, the emergent language of ‘resilience’ during disasters has been discussed as a holistic approach to improving the effectiveness of managing any crisis using prevention, preparedness, response, and recovery phases (Shirali et al., 2016). Determining the extent to which a hospital is ‘resilient’ has recently been examined from the organizational perspective by Shahverdi and colleagues (2019) where the resilience of any system is the post-disruption capability of this system to uphold sustained operations. For example, health care systems are considered resilient when, during disasters, they can provide their patients with services nearly similar to those provided in normal situations (Shahverdi et al., 2019). These resilient systems or organizations have the capabilities of being robust, flexible, and mannerly in terms of: 1) responding to threats; 2) monitoring the current situation, including its performance; 3) predicting risks and opportunities; 4) notification of the outcome of events; and 5) learning from experience (Shirali et al., 2016).
The term ‘hospital resilience’ is more recently discussed in the literature with regard to the potential capacity of the organisation to respond to disasters and its actual performance in responding to disasters including enduring the effects of a disaster, and decreasing death and morbidity. It is the ‘hospital’s ability to resist, absorb, and respond to the shock of disasters while maintaining its critical health care functions, and then recover to its original state or adapt to a new one’ (Barten et al., 2019; Zhong, Clark, Hou, Zang, & FitzGerald, 2015, p. 74). According to (Vugrin et al., 2015), ‘improving resilience’ refers to improving the capacity of a hospital to respond, and the effectiveness of its response efforts during a disaster. It comprises the three related capacity terms of absorptive (the system can withstand disruption), adaptive (using alternate reserves or processes while providing that services), and restorative (recovery from a disruptive event can be achieved rapidly and at sensible cost). Resilience also spans consideration of the availability of disaster resources, disaster medical care, equipment capabilities, cooperation and training management, hospital safety, and disaster management mechanisms (G. Cimellaro, Malavisi, & Mahin, 2018; S. Zhong, M. Clark, X.-Y. Hou, Y. Zang, & G. FitzGerald, 2014).

### 3.2.2 Coverage of ‘Anticipating’ – strategies and actions for planning and preparedness (PP)

Of the reviewed papers, substantial research (25 papers) has been conducted around the world on hospital planning and preparedness to face disasters, including, but not limited to, Japan, Sri Lanka, Middle East, Iran, USA, Australia, Serbia, and Belgium highlighted the value and importance of disaster preparedness plans in hospitals. For instance, Gao et al. (2018) surveyed medical staff in 65 secondary and tertiary hospitals in Heilongjiang province to investigate their perceptions of disaster management capacity. They found that all tertiary hospitals and nearly all secondary hospitals (93%) had known disaster management plans which can help in effectively coping with disaster and accordingly being more resilient (Gao et al., 2018; Moitinho de Almeida et al., 2019).

Other research that reported on the effects of extreme weather conditions (EWC) on hospitals in Australia. For example, Chand and Loosemore (2015) found that the disaster planning process was not comprehensive and based on a top to down approach. Additionally, they uncovered that most of the plans were based only on human-made disasters and were ignoring the value of resilient-built facilities (Chand & Loosemore, 2015). El Sayed et al. (2018) reported on hospitals during a mass casualty incident (MCI) involving a car bomb in Beirut, Lebanon recognizing that though the hospital disaster plan was activated, there was a large influx of patients before this activation (El Sayed et al., 2018). A major drawback in disaster plan implementation was found to be responsible for lowering the resilience of hospitals in one study, where a personal approach was adopted by managers rather than a team approach during such critical situations (Ghanaatpisheh et al., 2019). Challenges faced when taking action to help many disaster victims were revealed in another study, describing a level of confusion that occurs when there is enthusiasm without coordination (Labarda et al., 2017; Munasinghe & Matsui, 2019).

#### 3.2.2.1 Planning for organisational resilience

Half of the included studies (51%) addressed hospital planning and preparedness from the organizational perspective. The review found discussion regarding a wide variety of ways to anticipate what could be required, in the form of disaster preparedness plans, their development, dissemination, communication, and implementation during disasters. Key factors to consider are summarised here:

- Each hospital disaster plan should be developed specifically for each hospital, based on its location, capacity, and services provided (Ghanaatpisheh et al., 2019).
• It must also be developed for both natural and human-made disasters, to ensure its value as a resilient-built facility (Chand & Loosemore, 2016c).

• General hospital disaster management plans developed by a disaster committee and implemented in diverse hospitals may be helpful in several situations (Currie & Heslop, 2018).

• The plan must be patient-focused, systematic, and multidisciplinary approach to disaster planning process using bottom-up strategies that are recommended (Currie & Heslop, 2018).

• The coordination of managers, directors, and stakeholders is essential to identify the possibilities and challenges of any disaster, and planning for these disasters if a comprehensive, well-resourced and integrated disaster preparedness plan is to be established in any hospital (Acosta et al., 2015; Al-Shamsi et al., 2019; El Sayed et al., 2018; Schreiber et al., 2004).

• These plans should be dynamic, regularly reviewed, and flexible according to the assessment of emerging needs, allowing managers to modify their plans according to the type and impact of the disaster to increase efficiency (Ghanaatpisheh et al., 2019; Schreiber et al., 2004).

• Financial support of the disaster plan, associated activities and training programs was recommended to ensure adequate staff rehearsal (Al-Shamsi et al., 2019).

Shirali and colleagues (2016) used RE for their two-phase study of hospital resilience. In this study, a seven dimensions-questionnaire was established, covering preparedness, awareness, flexibility, opacity, just culture, top management commitment, and learning culture. This was followed by an assessment of its reliability and validity. In their study, they used the PPRR crisis management as themes (Shirali et al., 2016, p. 438).

Staff training and development about disaster preparedness was commonly identified as an ongoing need (Al-Shamsi et al., 2019). Farely and colleagues (2017) evaluated the flood preparedness in government healthcare facilities in Sri Lanka, identifying the need to improve disaster-related training, continuing clinical education, and workforce investment to reinforce flood and other disaster resilience (Farley et al., 2017). Similarly, Al-Shamsi et al. (2019) in their study mentioned above revealed that training and communication need further improvement (Al-Shamsi et al., 2019). When Currie and colleagues (2018) assessed a large-scale multiagency decontamination exercise, they identified problems relevant to communication, safety, and clinical handling. Munasinghe and colleagues (2019) examined disaster preparedness at Matara District General Hospital in Sri Lanka, exploring the perception of nurses and doctors about the preparedness of this hospital, revealing a lack of awareness of most respondents regarding the disaster response plan (Currie & Heslop, 2018; Munasinghe & Matsui, 2019).

Many papers called for capacity building to be a priority in the form of relevant and consistent operational response plans, proper supervision and evaluation of staff awareness, communication, education, intensive and scenario training, and safeguarding adequacy of protective equipment and supplies (Chand & Loosemore, 2015; Currie & Heslop, 2018; Gao et al., 2018). These actions should also be based on a systematic collaborative approach accompanied by technologies and training that enhance the resilience of health care facilities (Chand & Loosemore, 2015).

3.2.2.2 Planning for infrastructure and utilities resilience

Nine articles (18%) addressed the resilience from a health infrastructure and utilities perspective. McDaniels and colleagues (2008) developed a conceptual framework to identify the factors that affect resilience to earthquakes as having “two dimensions: robustness (the extent of system function that is maintained) and rapidity (the time
required to return to full system operations and productivity)” (McDaniels et al., 2008, p. 310). They used flow diagrams to illustrate a framework of decisions that influenced the resilience of an infrastructure system. This framework was applied in planning system resilience within hospitals. The scholars in this study recognized the significance of factors including the: knowledge and experiences gained from previous disasters; and the readiness of the facility’s staff during a disaster and the staff communication to guarantee the best utilization of the available hospital capacity and tackle the breakdown of specific systems (McDaniels et al., 2008).

Likewise, in 2010, Cimellaro and colleagues, investigated a standard hospital building in California using a basic recovery model to assess both human losses and physical system damages and then analysed the hospital network to illustrate the resilience framework (G. P. Cimellaro et al., 2010a). Later, Achour et al. (2014) identified that healthcare utilities tackle three main challenges: the less effective performance of the alternative sources; vulnerability of infrastructure to natural dangers; and, non-contemplated healthcare utility supplies (in codes and legislation of resilience) (Achour et al., 2014). In 2016, Chand and Loosemore developed a theoretical framework that could integrate hospital infrastructure resilience into disaster planning and preparedness and have published several studies addressing hospital facilities resilience while facing and preparing for extreme weather events (EWEs) especially in Australia. In one of these studies, the authors explored how hospital facilities managers could enhance the resilience of hospitals and identified that these facilities managers were unable to enhance the resilience of their hospital facilities due to the presence of organizational impediments (Chand & Loosemore, 2015, 2016a).

Moreover, Chand and Loosemore examined EWC and hospital facilities, identifying that the role of hospital built facilities was perceived variably (Chand & Loosemore, 2016a). Toner and colleagues (2017), in their study about the experience of Hurricane Sandy, described how chronically ill people were endangered due to road closure and the lack of car fuel, electricity, automation, and the transport system. The capability of healthcare facilities to properly react was critically influenced, given that emergency vehicles were a priority for fuel, for health professionals and first responders, and non-emergency patients were unable to reach hospitals via their vehicles. These fuel shortages also affected hospital emergency generators, impacted patients, and the facilities (Toner et al., 2017). Gao and colleagues (2018) recommended reviewing the availability of emergency equipment and that it functions, to safeguard demand when there is a failure of the electrical supply grid. Moreover, they also advised that adequate consumables such as personal protective equipment (stockpiling) and strengthened supply chain management of medical consumables should be available (Gao et al., 2018). Xu and Colleagues recommended proposed a resiliency-based methodology for using Microgrids as emergency sources due to the possible unavailability utility power after a major disaster (Xu, Liu, Schneider, Tuffner, & Ton, 2018).

3.2.3 Coverage of ‘Responding to’ – organisational capacity

In the face of disasters, lack of capacity is discussed at length in the reviewed papers (14 papers). This includes discussion about the persistence of vulnerabilities in the case of Heilongjiang Province (Gao et al., 2018). With Hurricane Sandy in New York and New Jersey, Toner and colleagues (2017) described an insufficient capacity of special needs and medical shelters, with a scarce consideration to the mission, enrolments, and concepts of the operation in terms of such shelters before the storm. This lack of preparedness in shelters was manifested as a lack of coordination, staffing, food quality and medication, unclear operational responsibilities, spread of infectious diseases, improper communication with other elements of the health sector, and the inability to access
drug treatment programs (Toner et al., 2017). Several studies uncovered inadequate communication, response to victims, safety, security transport, vital supplies, and morgue capacity during disasters (Al-Shamsi et al., 2019; Currie & Heslop, 2018; Munasinghe & Matsui, 2019). A case study paper regarding the performance of hospital facilities in response to extreme weather conditions emphasized that proper processes and structures should be developed and captured in building capacity for response (Chand & Loosemore, 2016b).

Specific expertise, knowledge, command, and control, regular training, and rehearsal are required for a proper hospital response to the decontamination of casualties (Currie & Heslop, 2018). Measures to reinforce constant intra and interhospital communications and defined roles and accountabilities must be contemplated and arranged (Acosta et al., 2015). For instance, formal communication channels and collaboration between different types of hospitals and medical centres should be established with communication networks created via reciprocal arrangements to boost their rush capacity during disasters (Al-Shamsi et al., 2019; El Sayed et al., 2018; Farley et al., 2017; Schreiber et al., 2004; Shahverdi et al., 2019). Implementing any disaster plan and preparedness program must incorporate structures of hospital facilities and processes on a daily bases, along with a strong team-based approach for managing any disaster (Ghanaatpisheh et al., 2019; Labarda et al., 2017; Shahverdi et al., 2019; Shirali et al., 2016).

3.2.4 Coverage of ‘Monitoring’ Evaluating disaster resilient hospitals

As concluded by many, it is imperative to evaluate the safety and functionality levels of hospitals across a range of disaster situations, to enhance hospital resilience to disasters (Ghanaatpisheh et al., 2019; Nenkovic-Riznic et al., 2018). Sixteen of the reviewed papers discussed hospitals undertaking evaluation (i.e. monitoring and assessment) of their resilience post-disaster, as summarised in Table 3.

Table 3 A summary of approaches used in post-disaster evaluations

<table>
<thead>
<tr>
<th>Hospital evaluation approach</th>
<th>Authors</th>
</tr>
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<tbody>
<tr>
<td>[Number of articles(N) - 16 in total]</td>
<td></td>
</tr>
<tr>
<td><strong>Hospital Functionality</strong></td>
<td></td>
</tr>
<tr>
<td>N(7)</td>
<td></td>
</tr>
<tr>
<td>Fault tree analysis N(2)</td>
<td>(Hassan &amp; Mahmoud, 2019; Jacques et al., 2014)</td>
</tr>
<tr>
<td>Time-based N(4)</td>
<td>(G. P. Cimellaro et al., 2016; G. P. Cimellaro et al., 2011; Moitinho de Almeida et al., 2019; Shahverdi et al., 2019)</td>
</tr>
<tr>
<td>Crowdedness-based N(1)</td>
<td>(Davis et al., 2019)</td>
</tr>
<tr>
<td><strong>Hospital Safety</strong></td>
<td></td>
</tr>
<tr>
<td>N(4)</td>
<td></td>
</tr>
<tr>
<td>(Mulyasari et al., 2013; Murshid, Riaz, Islam, &amp; Haque, 2019; Sunindijo, Lestari, &amp; Wijaya, 2019; Takim, Samsuddin, &amp; Nawawi, 2016)</td>
<td></td>
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<tr>
<td><strong>Resilience Measuring</strong></td>
<td></td>
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<tr>
<td>N(2)</td>
<td></td>
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<tr>
<td><strong>Disaster Planning Assessment</strong></td>
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<tr>
<td>N(2)</td>
<td></td>
</tr>
<tr>
<td>(Dobalian et al., 2016; Vugrin et al., 2015)</td>
<td></td>
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<tr>
<td><strong>Adaptive Capacity Tools</strong></td>
<td></td>
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<tr>
<td>N(1)</td>
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<tr>
<td>(Geelen-Baass &amp; Johnstone, 2008)</td>
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</tbody>
</table>
3.2.4.1 Hospital functionality

Where articles focused on evaluation of hospital resilience through exploring functionality, three sub-topic areas were evident, as detailed below.

**Fault tree analysis evaluation**

Jacques and colleagues (2014) addressed the influence of the Christchurch earthquake on the local hospital system in terms of its performance and resilience. They analysed the data using fault-tree analysis of the three key factors of structure, staff, and stuff. Their findings established the significant effect of utility networks and non-structural components on hospital functionality. Also, these redundancies resulted in a 12 per cent increase in the resilience of this hospital (Jacques et al., 2014). Similarly, Hassan and Mahmood (2019), used a fault tree analysis in resilience appraisal of a scenario seismic event in Memphis introducing a framework to quantify functionality and estimate recovery of a hospital. They identified the hospital functionality was reliant on the building’s damage. Both the quantity and quality of the hospitalization service were considered parts of functionality assessment. The direction of the earthquake had an obvious impact on hospital functionality, recovery, and resilience (Hassan & Mahmoud, 2019).

The approach of fault-tree analysis can be a tool to estimate the loss of function of hospitals. It correlates the functionality of the complex system to the state of the underlying sub-systems. As an example of the fault trees created for partial and complete loss of function of hospital service areas; there was association of the top, basic and intermediate events with their comparable levels in the tree (Jacques et al., 2014). Two fault tree analysis studies were included in this study. In both, a significant finding emerged from the analysis; the link between physical or building damage, various supplies accessibility, and the infrastructure processes and backup systems support, staff reactions and availability, and the impacts of all these on the hospital's functionality. Nevertheless, there were recommendations for further research to focus on these key areas for predictive purposes in catastrophic events in other parts of the world (Jacques et al., 2014). Also, a comprehensive set of data and more investigations were recommended for an appropriate complete evaluation of hospital functionality (Hassan & Mahmoud, 2019). These findings further support that the construct of resilient hospitals’ is greater than just having resilient infrastructure (Albanese et al., 2008).

**Time-based evaluation**

Hospital resilience was evaluated using a special measure based on the weighted sum of average non-fulfilled requests and waiting time, compared to the baseline value in normal situations (Shahverdi et al., 2019). In this study, the numerical results of this study were controlled by the particular details of their case study including the system of the studied hospitals, and disaster type and situations. Therefore, the scholars recommended further research considering various disasters and systems. Future studies might consider a wider range of scenarios and strategies (Shahverdi et al., 2019). The time of a hospital stay differed in this research from that used by de Almeida and colleagues who investigated a tertiary hospital after the 2015 earthquake in Nepal. De Almeida and colleagues found that hospital stay was exceptionally long compared to other post-earthquakes studies indicating the increased burden on this hospital in such situations. (Moitinho de Almeida et al., 2019).
Cimellaro and colleagues conducted two studies in 2011 and 2017 using time analysis in correlation to resilience. Both studies estimated the waiting time (WT) before receiving the service; as one parameter. They addressed the response of the Hospital Emergency Department (ED) using waiting time as a key parameter to estimate the disaster resilience index of healthcare facilities. In their first study, they introduced an organizational metamodel to assess the multidimensional aspects of resilience (organizational and technical). This hybrid simulation/analytical model determined the hospital capacity and dynamic response of the (ED) and incorporated the impact of the damage of structural and non-structural components on the organization. Calibration of the model was conducted based on true data gathered during the Northridge earthquake (G. P. Cimellaro et al., 2011). In their second study, the patient waiting time was used as the key response parameter to measure hospital resilience to disasters, in Italy and Monte Carlo. An analytical model was developed using a discrete event simulation model of the ED evaluating the hospital resources, emergency rooms, circulation patterns, and patient codes. An isolated event simulation model was developed for the hospital’s ED with and without the emergency plan. Based on comparing the waiting times in both normal and emergency situations, the efficiency of the applied emergency plan was identified.

The resilience index is directly correlated to the quality of provided care as measured through the waiting time. Besides, this index is correlated to the final loss of healthy people, caused by the healthcare facility performance during a disaster (G. P. Cimellaro et al., 2011).

Crowdedness-based evaluation

Overcrowding leads to prolonged waiting times, impediments, and a decrease in the quality of provided care. ED overcrowding is generally combined with factors e.g. limited surge capacity and patient surge. ED overcrowding is affected by inadequate inpatient beds for patients who enter the hospital through the ED. Accordingly, the patient remains in the ED, using an ED bed even though they no longer require ED-level care, this condition is called boarding (Davis et al., 2019; Salway, Valenzuela, Shoenberger, Mallon, & Viccellio, 2017). Moreover, certain researchers based their assessment on time analysis such as the waiting time and hospital stay timing (G. P. Cimellaro et al., 2011; Moitinho de Almeida et al., 2019).

Davis and colleagues in 2020 designed a modelling framework in collaboration with the Carilion Clinic ED, a trauma centre in Virginia. Their study aimed to address the levels different factors contributed to the resilience of hospital ED during overcrowding disasters. The National Emergency Department Overcrowding Scale (NEDOCS) score was used in measuring ED overcrowding in this study. The researchers designed a novel concept of component resilience and provided a granular model that was used in counting the effect of each contributing factor to an overcrowding event. Hospital managers could enhance resilience and prevent the impact of overcrowding using such a model (Davis et al., 2019).

3.2.4.2 Hospital Safety

The condition of disaster preparedness in hospitals was addressed in Japan by evaluating the four pillars of hospital preparedness using the Hospital Safety Index (HSI). The results of this evaluation showed that the structural, non-structural, and human resource components needing improvement. The functional preparedness was accomplished in most hospitals evaluated (Mulyasari et al., 2013). A document-based evaluation of the content validity of seven existing instruments was conducted to appraise the disaster resilience of hospitals in Malaysia.
As a result, these instruments were highly recommended, presenting the structural and non-structural items as a guideline for design risk reduction (Takim et al., 2016).

The HSI was identified as a significant tool to assess the readiness and resiliency of hospitals in Indonesia. However, it was not suitable to conduct a comprehensive vulnerability study. This tool includes 151 items, which make its administration time consuming (Sumindjo et al., 2019). In contrary to these findings, HSI was described as a quick and reasonable tool to assess a hospital’s safety status and response capacity in Bangladesh (Murshid et al., 2019). The safety assessment included a mixed-type questionnaire, a safe hospital checklist, and document review of structural, non-structural, and functional capacity (Murshid et al., 2019) - see also Attachment 1.

3.2.4.3 Other evaluation tools

Zhong, and colleagues (2014) recommended an evaluating framework to assess hospital resilience. These scholars built their study on the concept that the evaluation of hospital resilience was thorough and credible when using multidimensional tools rather than evaluating a few features or dimensions. This framework had eight key domains (hospital safety, command, communication, and cooperation system, disaster plan, resource stockpile, staff capability, disaster training and drills, emergency services and surge capability, and recovery and adaptation). They developed a four-factor structure of hospital resilience from micro to the macro levels for, “safety of the hospital, infrastructural ability of medical response in an emergency, methods of disaster management, and disaster sources” (Zhong et al., 2014, p. 1).

A comprehensive approach was used in the study of the experience of Hurricane Sandy in New York and New Jersey. This study developed a checklist of actions for healthcare, public health, nongovernmental organizations, and private entities that were used to strengthen the resilience of their community's health sector during disasters. Semi-structured interviews followed by a focus group addressed the themes developed during these interviews. The recommended checklist for enhancement of resilience included the following: Healthcare Coalitions; Continuity of Operation/Business Continuity Plan; Surge Capacity and Capability Alternative Care Sites; Mobile Healthcare Vehicles and Assets, Crisis Standards of Care Planning; Communication, Public Awareness, and Situational Awareness; Engaging and Supporting Workers; Public Health Legal Preparedness; Flexibility; Infrastructure Continuity and Restoration; Transportation Continuity, Restoration, and Access; and Supply Chains (Toner et al., 2017).

Dobalian and colleagues (2016) examined the development of a preparedness assessment tool for hospitals that are part of the US Department of Veterans Affairs (VA) among 140 VA Medical Centres. They appraised hospital preparedness in six Mission Areas including Program Management; Incident Management; Safety and Security; Resiliency and Continuity; Medical Surge; and Support to External Requirements. Two consecutive assessments appraised the construct validity of these Mission Areas. Their assessment process Comprehensive Emergency Management Program (CEMP) was a comprehensive, reliable, and flexible approach, yet an initial step in developing a reliable and valid measure of hospital preparedness. They recommended a modified version, Phase II of the CEMP for the conceptualization and assessment of hospital preparedness and resiliency (Dobalian et al., 2016).

Given that assessment of resilience is a crucial element in disaster planning and preparedness by hospitals and health care sector Vugrin and colleagues (2015) proposed a dynamic optimization model to examine resilience in hospitals and opportunities for enhancement of such resilience. The model aimed at keeping all patients in the...
best possible level of care during a catastrophe which was achieved by specifically distributing the consumables and supplies (Vugrin et al., 2015).

There was one article describing an adaptive capacity tool, arising from a project at an Eye and Ear Hospital in Australia aiming to build resiliency. This project examined the framework and key issues of Business Continuity Management (BCM) and identified that a project management approach could be applied to establish a framework for BCM (Geelen-Baass & Johnstone, 2008).

4. Discussion

In this section, we reflect on the SLR findings to discuss how hospital leaders could improve their management of staff and infrastructure during disasters. Building on the appreciation of ‘disaster resilient hospitals’ from the reviewed literature, we return to the commonly understood cyclical PPRR process and RE Theory to synthesise a decision-support model for disaster resilient hospitals.

4.1. Model for supporting hospital leaders

These findings draw attention to the urgent need for decision-support that can inform hospital leadership on: 1) the best form of anticipatory action to deal with the likely spectrum of future disasters, 2) the necessary capacity of the organisation to respond, and 3) current and evolving organisational and infrastructure capabilities. Examples of such calls for decision-support can be found in two studies. The Japanese study by Mulyasari and colleagues (2013) considered the evaluation of planning and preparedness using the Hospital Safety Index (HSI). The Belgrade study by Nenkovic-Riznic and colleagues (2018) used the same tool to assess hospitals’ functionality and resilience. Both studies concluded that hospital plans should be available in parallel to technical documentation for effective analysis and assessment (Mulyasari et al., 2013; Nenkovic-Riznic et al., 2018). Researchers, such as Zhong, and his colleagues (2014), caution that both infrastructure and utilities as well as hospital disaster planning and preparedness are required for resilience evaluation (Shuang Zhong, Michele Clark, et al., 2014; S. Zhong et al., 2014).

The papers in the SLR included a variety of language to describe key hospital disaster resilience factors, spanning cooperation, training management, infrastructure resources and equipment capability, structural and organisational operating procedures, and planning, education, and training to ensure enough access to protective equipment and materials. Drawing on the language emergent from the SLR, we propose the model depicted in Figure 3, which uses the construct of a hospital-level ‘Disaster Management Plan’ to support leaders in confidently anticipating, responding to and monitoring capacity for dealing with future natural and human-made disasters. It integrates lessons learned from the disaster management literature regarding developing, disseminating, and communicating this plan, implementing it when indicated, and monitoring for further planning and anticipating other types of disasters.
Figure 3. A Decision-Support Model for Disaster Resilient Hospitals

This model could support hospital leaders in improving their hospital performance. Within this model, developing and disseminating the plan represent 'potential' RE and 'PP' in the PPRR model. Implementing this plan denotes the 'actual' RE and response 'R' in PPRR. Finally, the post-disaster update of the plan exemplify the 'critical' RE and 'R' recovery phase (Pariès et al., 2010; Shirali et al., 2016).

4.2. A hybrid method to assist leaders in evaluating hospital resilience

Critical’ RE; means to monitor ongoing developments.; that is enabling hospital resilience through monitoring and management (Pariès et al., 2010; Shirali et al., 2016). HSI, this index was used in some of the reviewed studies as mentioned above and it was originally recommended by PAHO to improve resilience (Murshid et al., 2019; Sunindijo et al., 2019).

We propose that elements of hospital safety index (HSI) and Pan America Health Organization (PAHO) be merged to give a comprehensive classification for the essential items that should be included in evaluating hospital resilience, as visually represented in Figure 4.
Figure 4. Contributing elements to hospital resilience based on Hospital Safety Index (HSI) and Pan America Health Organization (PAHO)

The hospital functionality and safety assessment approach included both hospital functionality and Hospital Safety Index HSI based studies. The reduction of the hospital, functionality is identified as the ratio between the number of services provided following the disaster to this amount provided before the disaster. This functionality could be classified as quality and quantity; measured by the patient waiting time and the number of beds available for the patient respectively. This was the reason for categorising the hospital functionality approach into three subgroups in the results: Fault-tree analysis, time-based approach, and crowdedness-based approach. The HSI, was used in some of the reviewed studies mentioned above. It was originally recommended by Pan America Health Organization PAHO to improve resilience. It is a safe and reasonable tool that can appraise the functional ability of a hospital before, during, and after a disaster. HSI includes a checklist with four sections to covers risks disturbing hospital safety, the hospital roles in managing disasters, structural and non-structural safety, and disaster management. Thus, HSI is a checklist that helps in the assessment of both safety status and the response capacity of the hospitals. It evaluates the possibility that a hospital will stay functioning in emergency situations based on structural, non-structural, and functional factors, these data support decision-makers with their planning. In HSI, elements of emergency and disaster management include planning, co-ordination of relevant activities, human resources, communication and information management, logistics and finance patient care and support services, evacuation, decontamination, and security. Assessment of HSI items is fundamentally based on three data collection methods; namely: structured observation, document review and interview (Kalish et al., 2009; Murshid et al., 2019; Nenkovic-Riznic et al., 2018; Organization, 2015).

Meanwhile, PAHO (2000), included the physical factor including "structural" and "non-structural" components and the social one which represents the "functional" or "operational" factor (Preparedness & Program, 2000). Merging the elements of both tools could provide the hospital managers and decision makers with a comprehensive one; towards evaluating the hospital resilience and monitoring the ongoing development. In the hybrid model the hospital structural safety elements include building integrity and previous occasions and dangers affecting building safety. However, the hospital's non-structural safety elements include architectural safety, infrastructure protection, access, and physical security, critical systems (electrical, water supply, fire protection, waste management, fuel storage, medical gases, heating, ventilation, and air-conditioning (HVAC)), and equipment and...
supplies. Both structural and non-structural constitute the physical section. Meanwhile, the HSI elements of emergency and disaster management compose the functional/operational section.

4.3. SLR limitations

Having strict inclusion and exclusion criteria was necessary to keep the review focussed and manageable when there are so many articles published about disasters. Inevitably, this led to some articles of interest being excluded if they mentioned some, but not all, of the required search terms. For example, those dealing with specific elements of the system such as the supply of pharmaceuticals or blood banks.

This paper presented an analysis of the literature regarding DRH in terms of three of the four capabilities defined by the RE categories, (Actual, Potential, and Critical). Due to the number of papers involved when the fourth ‘Factual’ capability of RE was included (in the order of another 70 papers). This was undertaken as a separate systematic literature review, building on this paper.

5. Conclusions

Our review of research regarding hospitals and disaster resilience supports hospital leaders to manage the performance of staff and infrastructure during disasters. Our proposed decision-support model for disaster resilient hospitals synthesises the literature from the last decade to help leaders anticipate, respond to and monitor capacity, towards business continuity in the face of future natural and human-made disasters. From this study, we confirmed the need to evaluate hospital resilience from many angles. Also, we conclude that elements of HSI and PAHO could be merged to give a comprehensive classification of the essential elements that should be included in evaluating hospital resilience. Such hybrid method will assist leaders in evaluating hospital resilience.

Building on this appreciation of literature, we are undertaking a separate SLR to focus on the fourth capability of RE which was not addressed in this study, regarding how hospitals undertake continual improvement through distilling lessons learned and acting upon them. It is anticipated that the lessons learnt from disasters will be addressed in a further study, it will give beneficial guidance towards disaster resilient hospitals.

The review noted recommendations for future research by researchers on several topics:

- Due to the lack of standard pre-disaster resilience indicators and the changeability of disasters; hospital resilience in disasters is recommended to be investigated via a longitudinal study.
- Preparedness capacity building, including operational plans and staff education and scenario training, needs further research.
- Further research is recommended to support improved communication and information technology in hospitals during disasters.
- Further investigation could be conducted on a complete evaluation of hospital functionality
- Further research is also recommended to focus on the relationships between physical infrastructure failures, staff responses, and their influence on the hospital’s functionality, for predictive purposes in catastrophic events in other parts of the world.
- The willingness of the workforce to work is a fundamental area in research that requires continuous exploration.
These SLR findings have immediate implications for supporting hospital leadership strategically and operationally, ensuring that the RE contexts of anticipation, response and monitoring are adequately considered in the process of disaster prevention, planning, response, and recovery.

**Declaration of interest**

The authors report no declarations of interest.

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**Highlights**

- A systematic literature review is presented, considering 49 papers relating to hospitals and disaster resilience.
- Both organisational and infrastructure resilience are critical to hospital resilience.
- A decision-support model for disaster resilient hospitals is proposed.
- A novel combined methods approach for evaluating hospital resilience is described.
References


Rivera-Royero, D., Galindo, G., & Yie-Pinedo, R. (2020). Planning the delivery of relief supplies upon the occurrence of a natural disaster while considering the assembly process of the relief kits. Socio-Economic Planning Sciences, 69, 100682.


Attachment 1. A four-module approach for hospitals to consider hazards, safety, and emergencies

<table>
<thead>
<tr>
<th>Module 1: Hazards and the role of hospital in emergency and disaster management</th>
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<tbody>
<tr>
<td>The hazards or dangers and geotechnical properties of soils at the site of the hospital and hazards, which could lead to emergencies and disasters for which the hospital would be expected to provide health services in emergency response</td>
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<table>
<thead>
<tr>
<th>Module 2: Structural safety</th>
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<tbody>
<tr>
<td>The structural integrity and functional capacity of the hospital in cases of emergencies and disasters</td>
</tr>
<tr>
<td>2.1 Prior events and hazards affecting structural safety</td>
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<tr>
<td>2.2 Building integrity</td>
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<thead>
<tr>
<th>Module 3: Non-structural safety</th>
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<tbody>
<tr>
<td>Non-structural elements critical to the functioning of the hospital with attention on occupied buildings and those that contribute most to acute care services</td>
</tr>
<tr>
<td>3.1 Architectural safety</td>
</tr>
<tr>
<td>3.2 Infrastructure protection, access, and physical security</td>
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<td>3.3 Critical systems</td>
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<td>3.4 Equipment and supplies</td>
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<tr>
<th>Module 4: Emergency and disaster management</th>
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<tbody>
<tr>
<td>The preparedness of the hospital in response to emergencies and disasters</td>
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<tr>
<td>4.1 Coordination of emergency and disaster management activities</td>
</tr>
<tr>
<td>4.2 Hospital emergency and disaster management response and recovery planning</td>
</tr>
<tr>
<td>4.3 Communication and information Management</td>
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<td>4.4 Human resources</td>
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<td>4.5 Logistics and finance</td>
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<tr>
<td>4.6 Patient care and support services</td>
</tr>
<tr>
<td>4.7 Evacuation, decontamination, and security</td>
</tr>
</tbody>
</table>

Source: Adapted from (Organization, 2015; Sunindijo et al., 2019)