Post-disaster building functionality: preliminary findings of a systematic review.

B.J. Mayer & M. Boston
University of Waikato, Hamilton, New Zealand.

A. Chang-Richards
University of Auckland, Auckland, New Zealand.

ABSTRACT

During a natural hazard event, buildings are likely to experience some sort of damage, thus limiting their ability to function as intended. The severity of the ensuing consequences for various stakeholders and the community depends on the function of the building and the severity of the damage that occurred. A systematic literature review was performed to investigate post-disaster functionality of various building types after a range of natural hazards. Forty-nine documents were deemed to be eligible for inclusion, with most documents discussing healthcare services and businesses due to the vital role they play in short- and long-term community recovery. The functionality of both facility types was found to be dependent on a complex range of structural and non-structural components, as well as social systems, such as staff and the community. The findings of this paper have been used to inform future research directions to apply post-disaster functionality concepts in the New Zealand context.

1 INTRODUCTION

Buildings are deemed to be fully functional when they can support their intended service or function for the organisations and communities that use and occupy them. Different building types are designed, constructed, and furnished with varying components to ensure they can cater for their unique function without fault or interruption. These components include structural, architectural, and non-structural components, utilities, and building contents. In the aftermath of natural hazards, building functionality typically decreases due to damage caused to these components.

Most design codes differentiate acceptable post-disaster damage and functionality depending on the building's function. For example, in New Zealand, buildings are assigned different importance levels (IL), with generalised design criteria being assigned to each IL. Buildings in IL 1 and 2 are designed for life safety, meaning occupants should be able to escape the building safely; however, limited guidance is provided for functionality or repairability. Buildings deemed essential for recovery, such as emergency services, are classed as IL 3, 4, and 5 have higher performance requirements, with the intent that they will achieve continuous functionality after a hazard event (Building Regulations 1992, cl A3, Standards New Zealand, 2002). Past events have shown that this is typically not the case, as the code requirements are largely related to structural design and do not account for other aspects of the building. Drops in functionality can severely impact the availability and quality of various services, thus aggravating disruptions and prolonging recovery for the impacted community (FEMA 2018, NIST 2018, Sattar et al., 2018).

Various frameworks, such as the Federal Emergency Management Agency's P-58 (ATC 2018), Arup's Resilience-based Engineering Design Initiative (REDi) Rating System (Almufti and Willford, 2013), and the Pacific Earthquake Engineering Research Center's F-Rec Framework (Terzic et al., 2021), have been developed to increase building design beyond life safety. The associated reports outline detailed methodologies to estimate the post-earthquake building performance, losses, and downtime, which stakeholders can use to estimate drops in functionality. These frameworks may be applied during the design phase, or may be applied to existing buildings to determine vulnerable components. The methodologies have been developed with the goal of being suitable for all building types, but do not provide insights into appropriate levels of functionality for individual buildings, or specify the components required to achieve the prescribed level (Qu et al., 2020).

A systematic review is performed to investigate other documents to determine if they address this limitation or propose alternative methodologies to estimate or increase building functionality. The review accounts for journal papers, conference proceedings, and theses, and explores functionality in regard to all natural hazard types. This paper presents the preliminary findings from the systematic review, with a focus on the following research questions:

- What building types have been researched in the field of post-disaster functionality?
- What is the role of these buildings in society? How does this relate to their expected functionality level?
- What components contribute to their functionality?

2 METHODOLOGY

Systematic reviews differ to other types of literature reviews as they follow a pre-defined protocol. A search string is developed based on the research questions, and inclusion and exclusion criteria are specified to ensure only relevant documents are analysed. Once this protocol is developed, the search string is used to source documents from relevant databases. A title, abstract, and full-text screening occur to assess document eligibility, with the removal of irrelevant documents at each stage. Following this rigorous process ensures that all relevant documents are accounted for and minimises bias. Due to the systematic methodology, the review could theoretically be reproduced by an independent reviewer (Page et al., 2021).

The Collaboration for Environmental Evidence's *Guidelines and Standard's for Evidence Synthesis in Environmental Management* (Collaboration for Environmental Evidence, 2018) were used to plan this review, as no review guidelines or standards currently exist for civil engineering systematic reviews.

Based on the research questions, the following search string was developed for this systematic review:

(disaster$ OR natural$hazard OR earthquake OR seismic* OR tsunami OR flood* OR hurricane OR tornado* OR storm$ OR cyclone OR wildfire$) AND (function* OR opera* OR perform* OR resilien*) AND (time* OR down$time OR recovery$time OR distrupt* OR delay*) AND (buil* OR structur*) AND (capacity OR re$occupanc* OR critic* OR function*level)*

A preliminary search string only accounted for earthquake events; however, it was elected to include other natural hazard types to explore the feasibility of applying lessons learned across multiple event types.

Twelve databases and search engines, summarised in Table 1, were used to find relevant documents, including journal articles, conference proceedings, reports, and theses. Gusenbauer and Haddaway (2020) deemed that most of databases and search engines were appropriate for systematic review. Others were identified based on existing civil engineering systematic reviews.

Table 1: Databases and search engines used in the systematic review

The search string was used in the following databases and search engines:

Scopus	ProQuest Central	EBSCOHost Academic Search Complete
Web of Science Core Collection	Wiley Online Library	MDPI
Taylor & Francis	Sage Journals	SpringerLink*
Cambridge Core*	ASCE*	Google Scholar*

*indicates only the first 200 articles were downloaded (sorted by relevance) due to large number of results (N > 22,600 for each database or search engine).

Documents were deemed eligible for inclusion when a full-text, English version could be sourced. Newspaper and magazine articles, book reviews, and opinion pieces were removed to minimise bias. Documents that did not focus on one or more specified building types, discussed aspects of resilience or recovery unrelated to buildings, focused on a single building component, or only accounted for structural performance were also removed, as they did not align with the research objectives.

3 RESULTS

The methodology outlined above yielded 9,980 documents, with 6,560 remaining after duplicates were removed. After performing a title, abstract, and full-text screening, 49 documents were found to be eligible for inclusion, as shown in Figure 1.

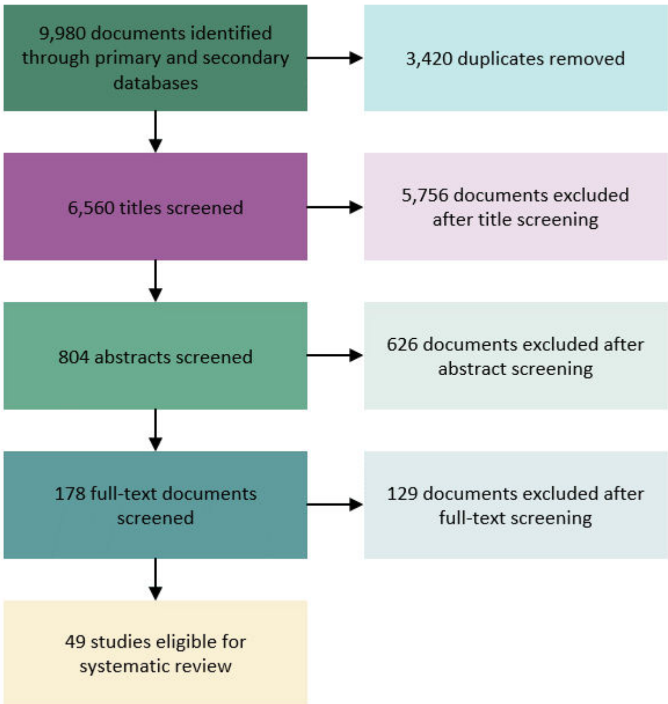

Figure 1: Documents remaining at each stage of the review process (adapted from Bernes et al., 2015)

3.1 Buildings of interest

To be deemed eligible for inclusion, documents had to define a building's function, as the expected level of functionality required after a natural hazard is largely related to the services the building supports (Al-Nammari and Lindell, 2009). The function of the buildings studied in each document were generalised into seven categories, as shown in Figure 2. Note that some documents focused on multiple building types, bringing the total to greater than 49.

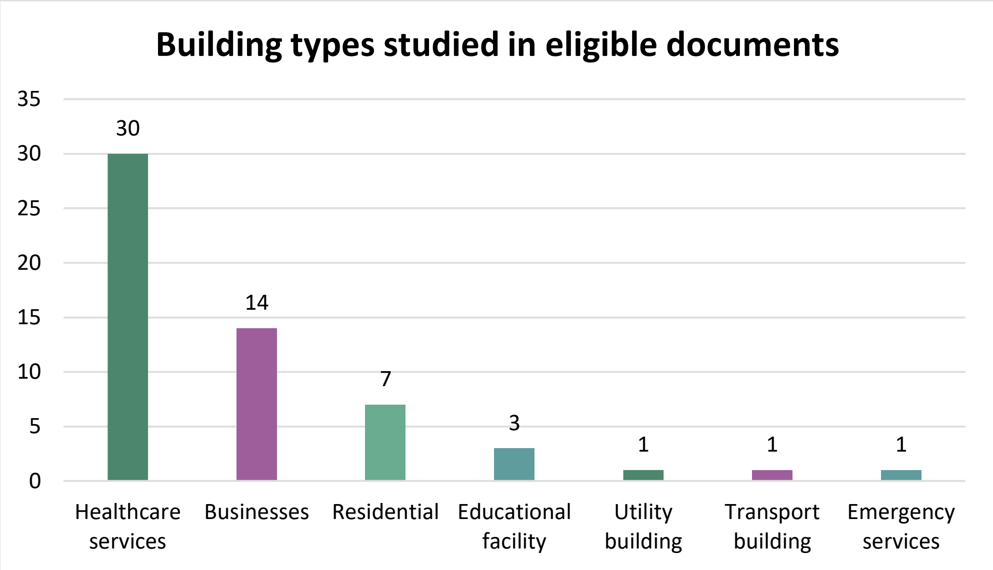

Figure 2: Types of buildings studied in eligible documents

The following discussion will focus on the two building types most studied in the documents: healthcare services and businesses.

3.1.1 Healthcare services

More than half the documents (n = 30) focused on the functionality of healthcare services after hazard events. The predominant healthcare service of interest was hospitals (n = 23), and other services studied included pharmacies, primary healthcare, and general facilities (n = 7).

Healthcare services play a critical role under business as usual and in the aftermath of a natural hazard. They are expected to provide care to existing patients with chronic health conditions and community members with acute conditions (Sharpe and Clennon, 2020), and those injured during the hazard event (Sheikhbardsiri et al., 2017). Facility functionality is paramount to ensure continuity of care for medically vulnerable patients, as they cannot be easily evacuated or transferred to other facilities (Paul and Lin, 2009).

Despite the expected continuity, case studies of past disaster events have shown that healthcare services tend to experience drops in functionality during disaster events (Wahidin et al., 2022), partly due to the complex nature of these facilities and the large number of components they rely on. Some documents simplified components into three broad categories, such as in Jacques et al. (2014): structure, stuff, and staff. Healthcare service structures typically performed well when based on modern building codes; however, damage to non-structural components, including architectural components, supplies, and specialised equipment, typically led to decreased functionality (Yu et al., 2019). Reliance on some external infrastructure systems could be mitigated by having internal back-up systems, such as power generators and water tanks, while others are more difficult to replace, such as transportation networks and supply chains. The human resource component, 'staff', is often not accounted for when analysing functionality through an engineering lens. However, staffing issues commonly lead to decreased function; accounting for this category is therefore critical. Facilities experienced shortages of qualified staff, as some chose to leave the impacted area or prioritised caring for their families over work. Lack of staff coordination and training in emergency procedures was another common issue (Rublee et al., 2021, Phalkey et al., 2012).

Building codes have different performance expectations depending on the role of the healthcare service. Hospitals are usually designed to a higher standard that other facilities discussed in the documents, such as pharmacies and primary healthcare facilities, despite their essential role in providing continuous care to the community. For example, in New Zealand, hospitals are classified under IL 4, while other healthcare services may be classed under IL 2 or 3 (Building Regulations, 1992).

3.1.2 Businesses

After healthcare services, the second building type most discussed in the documents was businesses (n = 14). The approach to studying businesses differed across the documents: some authors chose to broadly classify businesses based on the number of employees (e.g. small, medium, or large businesses); others classed them based on the generic service they offered (e.g. retail); and some documents specified the type of business they were examining (e.g. supermarket, furniture manufacturer, wine store).

Businesses are typically not deemed as important as healthcare services when considering post-disaster functionality, as they tend not to offer critical emergency services like healthcare services discussed previously. However, the documents highlighted the important role businesses play in long-term community recovery. They provide goods and services required by the community as it recovers, meaning governments and relief organisations may not have to provide as many basic requirements like food and necessities (Tyler and Sadiq, 2019). Businesses contribute positively to the region's economy, and community members are reliant on their place of work for a regular income (Xiao and Peacock, 2014).

A range of components were found to impact business functionality, including damage to structural and architectural components. Loss of external infrastructure systems, including power and internet, increased recovery time, as the businesses examined did not typically have back-up systems. Business inventory was also an issue if it was damaged, suppliers experienced drops in functionality, or supply chains were disrupted (Sydnor et al., 2017).

Customer demand also contributes to functionality. Tyler and Sadiq (2019) provided an example of a hardware store that experienced a spike in demand as the community purchased supplies to strengthen their homes against an approaching hurricane. This created challenges for the store, as it was already experiencing staffing shortages. Customer demand may decrease after an event due to outmigration or decreased need for the provided services or goods. This can lead to decreased revenue and financial struggles, thus impacting a business' ability to perform repairs and increase functionality (Sydnor et al., 2017).

3.2 Lessons learned across healthcare services and businesses

Despite the difference between the roles played by healthcare services and businesses in the aftermath of natural hazards, the review highlighted that lessons learned from one building type may be applied to the other. The functionality of both building types were found to be reliant on the same basic components, 'structure, stuff, and staff', as described in Section 3.1.1, although documents relating to businesses tended to not explicitly categorise components in this manner.

Vulnerabilities of infrastructure systems and non-structural components leads to delays in regaining functionality in both building types. Common components found in both healthcare services and businesses can apply the same design methodologies and mitigations to minimise disruptions. Concerns were also expressed about staff availability, training, and qualifications in documents relating to both building types, with recommendations to increase research and actions around emergency preparedness.

4 CONCLUSIONS AND FUTURE WORKS

This paper presented the preliminary findings of a systematic literature review aimed at investigating the expected post-disaster functionality of various building types and the components, summarised as structure, stuff, and staff, that contribute to their functionality. It was found that most documents focused on healthcare services and businesses, indicating that there is a potential gap to investigate functionality of other building types in future works, such as educational facilities and residential buildings. There was also a substantial focus on non-structural components required for functionality, highlighting their importance for service continuity and the need for further research to strengthen them.

It is intended to further analyse the eligible documents and address other questions that motivated the systematic review, including the application of findings across different hazard types, methods used to quantify functionality, and actions taken to increase functionality and decrease time to recovery.

5 ACKNOWLEDGEMENTS

This project was supported by QuakeCoRE, a New Zealand Tertiary Education Commission-funded Centre. This is QuakeCoRE publication number 0818.

The authors wish to thank the reviewers for their valuable comments that were used to improve this paper.

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