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REVIEW ARTICLE

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Bridging the Gap: A Literature Review of Post-Earthquake Building Functional Recovery through a User-Informed Lens

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ABSTRACT

Post-earthquake functional recovery (FR) is an emerging concept in seismically active regions, emphasizing the integration of recovery-oriented objectives into current building codes that focus on life safety. This study addresses two primary objectives: identifying literature trends through a bibliometric review, and exploring underexamined social dimensions using qualitative assessment. The bibliometric analysis reveals a notable gap regarding the relationship between "*recovery process*" and "*recovery time*". Furthermore, the qualitative assessment shows that existing FR frameworks predominantly concentrate on the physical aspects of buildings, neglecting the critical role of building users. Yet the recovery trajectories of users, which could significantly influence overall recovery timelines following a major event remain underexplored. Including users and their recovery process is vital for achieving a pragmatic post-earthquake FR. Consequently, this study proposes an enhanced mobilization time framework that explicitly incorporates building users' recovery trajectories. This addresses the identified gap in current methodologies. This advancement contributes to a more holistic understanding of post-earthquake FR and provides valuable insights for future empirical research. It supports the crucial goal of integrating user-centric, recovery-based objectives into contemporary building codes.

KEYWORDS
Post-earthquake functional recovery; recovery process; recovery time; building users; social recovery trajectory; mobilization time

1. Introduction

Generally, buildings are designed to adhere to building codes and standards. However, current building codes prioritize life safety following a seismic event (EERI, 2019; Molina Hutt et al., 2022). Societal expectations of building performance especially for modern buildings are that non-critical buildings and new buildings built according to

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modern standards will sustain a minimum level of damage or be repairable after an event (Bonowitz, 2009; Payne et al., 2021; Porter, 2021). Designing buildings that maintain their structural integrity or incur repairable damage can contribute to lowering the frequency of demolitions and the complete shutdown of cities after a major earthquake. Subsequently, professionals in the built environment and policymakers are advocating for the integration of recovery-based objectives into current building codes, thus, the post-earthquake functional recovery (FR) concept. The primary goal of the FR concept is to ensure that buildings can be repaired or maintained to sufficiently support their basic intended use (EERI, 2019). A careful review of the literature shows a strong emphasis on engineering aspects with little attention on the social context particularly from building users' perspectives. As emphasized by Jensø et al. (2004), building usability and functionality are often overlooked concerning a building's performance. This literature review seeks to examine existing trends and patterns while exploring the overlooked social dimensions to improve the practical application of the post-earthquake FR concept.FR)

The emerging post-earthquake FR concept stems from the United States (US) for greater earthquake resilience (CRS, 2021; FEMA, 2021). It is gaining momentum as professionals in the built environment and earthquake-resilient organizations in high-risk seismic countries like New Zealand and Japan are also exploring the phenomenon to advance their building codes and standards (Campbell, 2018). Knowledge advancement, making informed decisions, and ultimately developing robust resilient societies are the concerns for research and engineering groups in earthquake-prone countries (Tung et al., 2020). The incorporation of the post-earthquake FR concept into building codes and standards will facilitate recovery within achievable timeframes.

Significantly, earthquakes and subsequent recovery processes are inherently embedded within social context as they profoundly impact various dimensions of human life, all of which are closely tied to the built environment (Tierney & Oliver-Smith, 2012). Building users, who play a central role in the daily operation and utilization of structures, encompass a diverse group of stakeholders, including tenants, occupants, investors, property owners, operators, maintenance staff and property managers (Preiser, 1994). While the structural integrity of buildings is undeniably critical for recovery, post-earthquake decision-making and recovery processes are not solely determined by structural performance or technical considerations (Comerio, 2006; Marquis et al., 2017). Instead, building functionality is evaluated through technical and interactive dimensions (Cole et al., 2008; Cooper, 2018; Jensø et al., 2004; Lowe et al., 2018). Building professionals, such as engineers, typically focus on the technical aspects of functionality, whereas building users – particularly occupants and tenants emphasize the interactive functionality of buildings (Nkrumah et al., 2024a, 2024b). In the context of property markets, such as office buildings, tenants actively engage with and influence the functionality of buildings, which in turn affects property owners and investors (Bottom et al., 1999). For investors and property owners, buildings serve as investment vehicles that generate returns primarily through income streams or capital appreciation (Baum, 1993). Conversely, corporate tenants evaluate office buildings based on their alignment with and ability to fulfil organisational goals and objectives. This interplay between technical and interactive functionality underscores the complex, multi-stakeholder nature of post-earthquake recovery and the need for a holistic approach that integrates both structural and user-centric perspectives.

Following a significant earthquake event, a building may be deemed non-functional if it remains devoid of its users. The recovery process involves rational and realizable aspects, where the rational aspect pertains to the physical restoration of the building, including repairs and associated costs, while the realizable dimension incorporates social factors (Comerio, 2006). For instance, the decision to undertake post-event repairs is predominantly influenced by property owners (Cook et al., 2022; Terzic et al., 2021). From the perspective of tenants, decisions regarding whether to remain in or vacate an affected building, or relocate functions during the repair phase, significantly influence the overall recovery timeline. The use of transitional spaces, such as community hubs, is intrinsically tied to the real estate dimensions of recovery, as these spaces provide temporary accommodations during the repair period. Their utilization highlights the necessity for adaptable real estate solutions that address immediate needs while simultaneously supporting long-term recovery objectives. Effective management and allocation of such spaces require coordinated efforts within the corporate real estate sector to ensure they are accessible, appropriate, and aligned with both recovery timelines and broader strategic goals. This underscores the importance of integrating user-centric considerations into post-disaster recovery frameworks to enhance resilience and functionality.

Given that functional recovery commences at the micro level with individual buildings, the active involvement of building users is essential for the design and implementation of recovery strategies (FEMA, 2021). Therefore, the primary research question guiding this study is: *What are the current trends and patterns in the literature on post-earthquake functional recovery, and which social dimensions related to this concept remain underexplored*? This question seeks to systematically identify gaps in existing research, particularly in understanding the interplay between physical recovery process and the often-overlooked social factors, which are critical for achieving comprehensive post-earthquake functional recovery.

The remainder of this study is organized as follows: Section 2 provides a methodological structure and workflow of the study. Moving on to Section 3, the results and findings of the study are presented. Section 4 discusses the implications of the findings by reconceptualising the mobilization time framework to incorporate social aspects. Section 5 concludes the study by highlighting key insights.

2. Methods

The study employed a mixed method systematic review, combining bibliometric analysis as a quantitative tool with qualitative methods to achieve a thorough understanding of the literature. This approach aimed to reduce bias and errors in identifying relevant studies and ensure a rigorous assessment of their quality in addressing the research question (Harden & Thomas, 2010; Heyvaert et al., 2016). Employing bibliometric analysis aids in extracting structured information (e.g. keywords, authors, journals, citations, etc.), assessing the extracted data, and performing analyses to generate insights from the large volume of literature. Furthermore, it puts findings from individual studies together into a new arrangement and networks that offer perspectives that are not apparent from reading individual studies in isolation. That is, the visual representations help to simplify and streamline the process of navigating extensive bodies of literature, thus assessing literature on an accumulated level that reduces complexities (Anlesinya & Dadzie, 2023; Sinkovics, 2016; Van Eck & Waltman, 2017). Subsequently, the qualitative technique of interpretive synthesis was adopted to explore the contextual social dimensions of functional recovery studies and generate new ideas for further research (Harden & Thomas, 2010). The methodological structure and workflow of the study is illustrated in Figure 1.

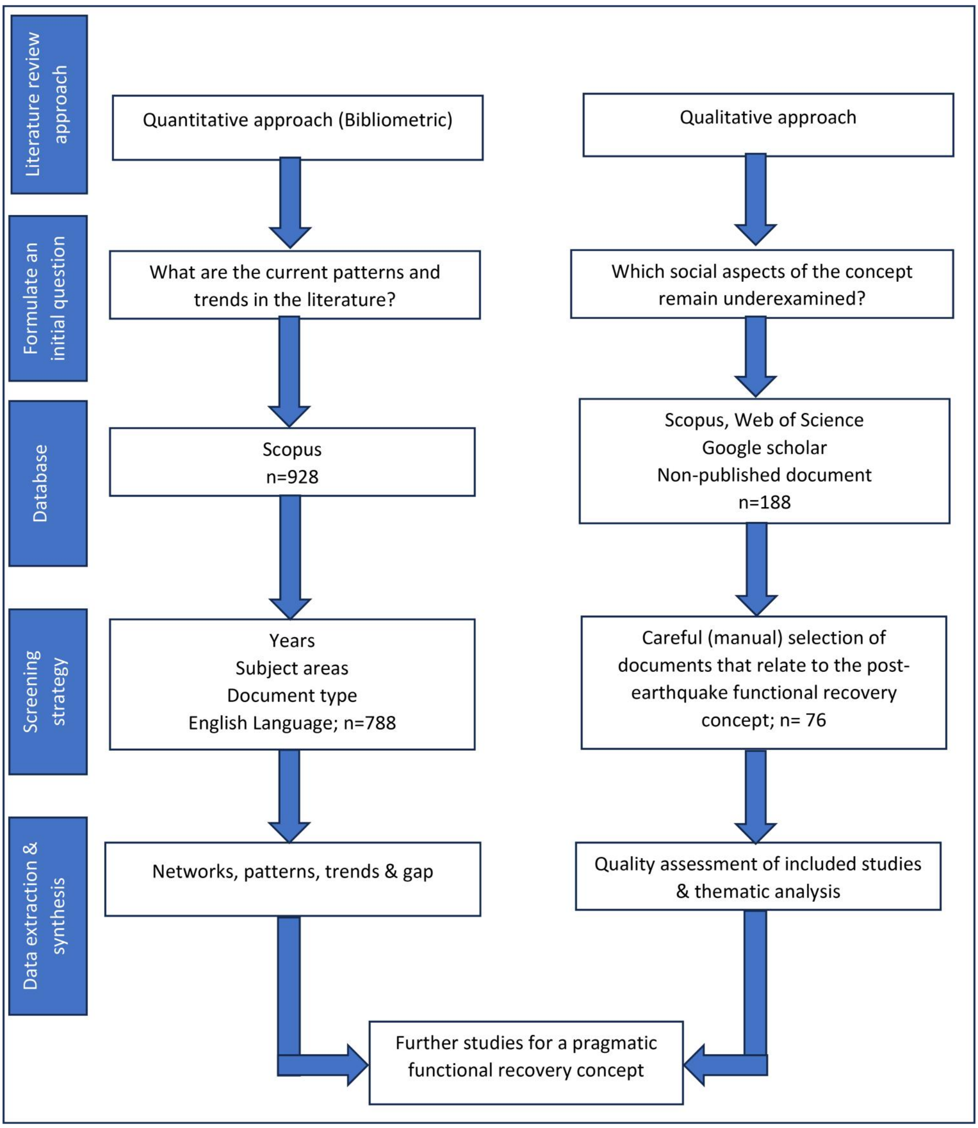


Figure 1. Methodological structure and workflow of the study.

2.1. Bibliometric Analysis

Bibliometric[1] analysis employs mathematically robust quantitative methods to assess research impact and map scientific fields using publication, citation, and textual data by giving a snapshot of significant research activities (Chen, 2006; Klavins & Boyack, 2006; Noyons, 2001; van Raan, 2019). Originating from the broader domains of science mapping and knowledge visualisation, bibliometric analysis is closely associated with fields such as scientometrics, informetrics, cybermetrics and webometrics. It dates back from the 1950s with a pivotal moment from Eugene Gerfield who founded the Institute of Scientific Information (ISI) and launched the Science Citation index (Borner et al., 2003). Each publication can be represented by a subset of keywords, which function like "DNA fingerprints" of the article. By comparing these keyword-based fingerprints, one can determine the degree of similarity between publications: the more keywords two documents share, the greater their similarity and the higher the likelihood that they belong to the same research area or specialty. Following the DNA metaphor, if two publications exhibit sufficiently similar "fingerprints", they can be considered part of the same scientific "species" (Noyons et al., 1999).

The Scopus database served as the primary tool for scouring documents for the bibliometric review because of the extensive coverage as compared to other databases (Chadegani et al., 2013). Keywords and Boolean operations such as "and, or" were strategically applied to enhance the precision of search queries, refine the scope, and retrieve pertinent information for the study. The keywords employed in the search were: "Seismic resilience" OR "earthquake resilience" OR "Post-earthquake" AND "recovery" OR "functional recovery". A total of 928 documents were retrieved. The literature search process, the results, and the final dataset used are summarised in Table 1.

A screening process was subsequently employed to refine the selection, aligning the documents with the research requirements. Following screening for a span of 24 years, from 2000 to 2024, limiting to subject areas, document type, and narrowing the dataset to English language publications, the final dataset retrieved was 788. It is worth noting that the literature search was conducted during the initial months of 2024, specifically in April as illustrated in Figure 2.

Real estate research is inherently interdisciplinary, drawing on the fields such as social sciences, business, economics, engineering and environmental science. This reflects the diverse scope of the discipline, encompassing areas from urban planning to seismic resilience.

Buildings are increasingly recognised as complex systems, involving both physical structures and human components (Becker & Steele, 1990; Bordass & Leaman, 1997). While experts design and construct buildings, it is the users, tenants, investors, and occupants, who ultimately define their functionality through use, perception, and interaction (Ho et al., 2005; Jensø et al., 2004; Nkrumah et al., 2024a, 2024b; Windlinger et al., 2016). The relationship between users and the built environment, and the lived experience of that interaction, provides a critical link between theoretical constructs and practical realities (Alexander, 2005, 2008; Vischer, 2008). This user-centric perspective emphasizes that building performance is shaped not by structural integrity but also by factors such as comfort, usability, and adaptability (Hanc et al., 2019; Haynes, 2007a, 2007b; Leaman & Bordass, 1999; Raw et al., 1993). As

Table 1. Summary of the literature search process for the bibliometric literature review

	Description	Search strategy in Scopus database	Results
A	Keyword search	"Seismic resilience" OR "earthquake resilience" OR "Post-earthquake" AND "recovery" OR "functional recovery"	928
B	Screening		
	Years	2000–2024 (April)	904
	Subject areas	Limit to Engineering, Earth and Planetary science, Social science, Environmental science, Computer science, Material science, Agric & Biological sciences, Energy, Physics & Astronomy, Arts & Humanities, Business Management & Accounting, Decision sciences, Psychology, Economics, Econometrics & Finance, and Multidisciplinary	873
	Document type	Articles, conference papers, book chapters, reviews, and books	865
	Language	Limit to English	**788**

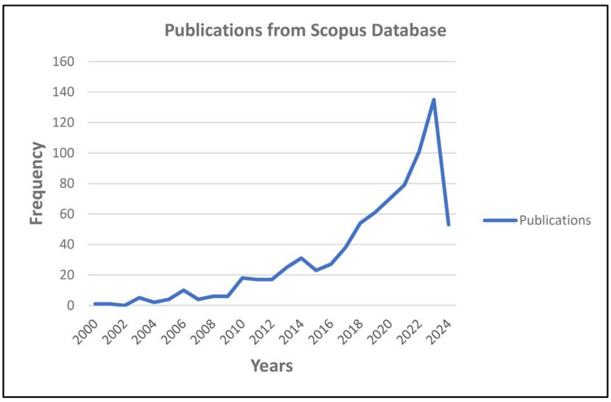


Figure 2. Graph showing year-wise publications.

sustainability becomes an increasingly central concern in building design and operation, Baird (2009) argues that the truly sustainable buildings must integrate users' perspectives in Building Sustainability Rating Tools (BSRTs).

This dynamic becomes particularly significant in post-earthquake recovery. As demonstrated during the 2010–2011 Christchurch earthquakes, user decisions such as choosing to reoccupy or invest in repairs, play a critical role in determining whether a building returns to full operational use, even in the absence of essential services such as toilet facilities (Chang et al., 2014). The decision to repair damages and continue using a building for its basic function until full recovery is largely contingent on the actions and attitudes of its users (Preiser & Vischer, 2006; Terzic et al., 2021). These insights underscore the importance of integrating user perspectives into real estate and seismic resilience research.

The year 2023 received the highest frequency with a total of 135 publications, followed by the years 2022 and 2021 with 101 and 79 publications respectively. In contrast, the beginning years from 2000 to 2005 received low publications. Additionally, there has been a steady growth in seismic/earthquake resilience and recovery/functional recovery from the year 2016. The significant increase in literature from 2016 to 2023 can be attributed to the occurrence and impacts of several major earthquakes during this period, the learnings, knowledge advancement through research for making informed decisions and ultimately developing robust resilient societies. The earthquakes within this period include the 2016 Kumamoto earthquake in Japan, the 2016 Kaikoura earthquake in New Zealand, the 2016 Ecuador earthquake, the 2016 Central Italy earthquake, the 2017 Iran-Iraq earthquake, the 2021 Haiti earthquake, and the 2023 Turkey-Syria earthquake. Research during this time examined various aspects, including social aspects such as community engagement, citizens' access to earthquake information, evacuation strategies, and sheltering behaviours (Cela, 2023; Hooper, 2019; Kimura et al., 2017; Peruzza et al., 2017). Although some earthquakes occurred in earlier years, the publication of related findings and lessons in post-disaster management emerged after 2016. For instance, studies on the 2010–2011 Christchurch earthquakes in New Zealand contributed valuable insights (Amore & Hall, 2022; Bellagamba et al., 2019; Cloke et al., 2023; Filippova et al., 2023; Kono, 2022; Marquis et al., 2017; Matthewman & Uekusa, 2022; Shrestha & Orchiston, 2023; Tudor, 2020; Wilson, 2016; Yonson et al., 2020). Additionally, some researchers conducted cross-country comparisons (Oluwafemi et al., 2018; Rahman, 2018; Shrestha et al., 2022). However, given that the search was executed in the early part of 2024 (April), only 53 documents had been published. The 788 publications were exported into a comma-separated values file (CSV) extension and uploaded into the VOSviewer software tool for the bibliometric analysis. This VOSviewer software tool employs a visualization of similarities (VOS) mapping technique to visually represent bibliometric data (Sinkovics, 2016; Van Eck & Waltman, 2010). The tool enables the visualization of networks, densities, identification of growth patterns, major trends as well as research gaps, providing valuable insights for further studies (Linnenluecke et al., 2020; Sinkovics, 2016; Van Eck & Waltman, 2010; Zupic & Čater, 2015).

Despite its recognised strengths, bibliometric analysis is not without criticism. Some scholars acknowledge its limitations, though these do not necessarily undermine its overall effectiveness in supporting science and policy decision-making. For instance, Van Raan (2019) highlights the phenomenon of delayed recognition, also known as "sleeping beauties" where important publications are cited only after many years. Also, while the minimum citation threshold in the citation network mapping reduces visual complexity and enhance interpretability, especially when dealing with large-scale scholarly datasets, this approach inherently disadvantages recently published works, which may not have had sufficient time to accumulate citations (Liu et al., 2013).

To address the limitations of the current study, the second phase (qualitative analysis) incorporated recently published works and additional data sources to enhance the breadth and depth of the review. Specifically, recent publications retrieved from Scopus, Web of Science, Google Scholar, as well as relevant grey literature and unpublished documents, provided valuable complementary insights. This integrated approach was adopted to overcome the constraints of traditional bibliometric tools and to ensure a more comprehensive and nuanced representation of the literature landscape.

2.2. Qualitative Overview

A qualitative approach was employed to investigate the underexamined social aspects of the functional recovery concept. Qualitative research operates within a social and theoretical setting, from which substantive findings emerge; uncovering the meanings of social phenomena to help understand how different elements might connect and interact, to enhance human discourse (Noblit & Hare, 1988; Weed, 2005). Besides publications obtained from the Scopus database, other sources like Web of Science, Google, and Google Scholar were utilized. Additionally, since the study aims at integrating recovery-based objectives into building codes, non-published materials such as Acts from countries, Byelaws from local government authorities, and government reports that are relevant to the study such as FEMA_NIST Functional recovery report, ATC 138-3 Report, FEMA-ATC Functional Recovery Workshop Report among others were considered making a total of 188 documents. A quality assessment was carried out using purposive sampling which involved selecting literature that offers valuable and in-depth information pertinent to the research question (Harden & Thomas, 2010; Heyvaert et al., 2016). A sum of 76 documents were considered for qualitative analysis and thematic analysis was used to group studies with similar or common ideas and subjects.

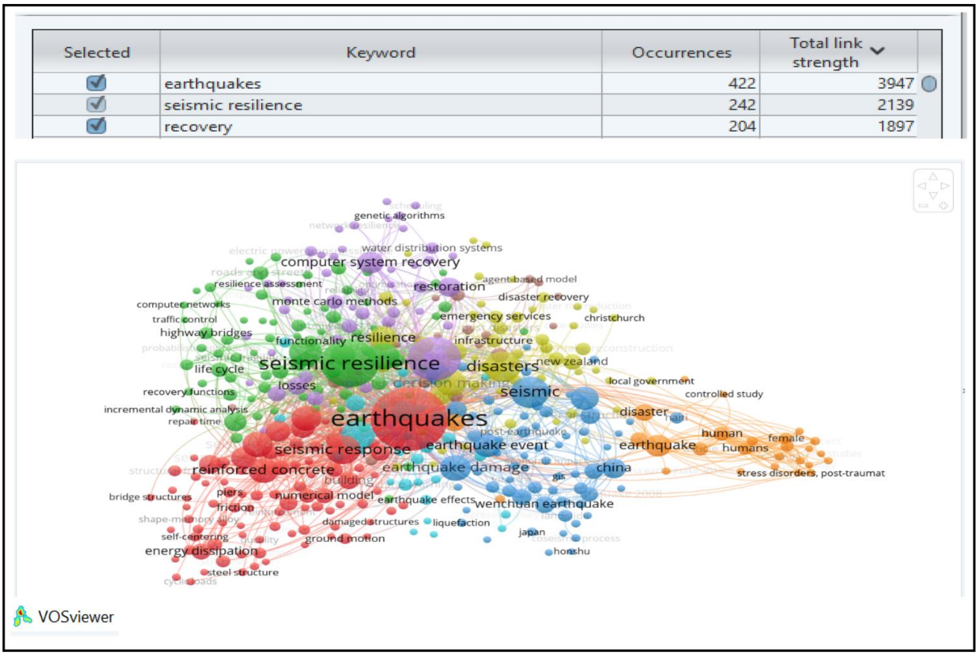
3. Results and Findings

The results of the literature review demonstrate current trends, patterns and gap in the literature. While the bibliometric analysis provides a broad, quantitative overview of the research landscape, the qualitative component delivers a more nuanced, contextual interpretation. It captures dimensions of functional recovery, particularly social and technical factors that may not be fully visible in the bibliometric data. Together, these two approaches offer a comprehensive understanding and contribute to bridging the gap in the literature.

3.1. Bibliometric Analysis

There are two types of maps in bibliometric analysis, the network and thematic map. While the former represents the network of topics, more directly to the work of the authors and publication output, the latter represents the structure of the field on a higher level or aggregation in which the themes are clusters of topics. The thematic map refers more to the utility of the map, rendering an overview of the field and trends (Noyons, 2001). For this study, the analyses are illustrated in Figures 3–9. Firstly, Figure 3 illustrates the network of authors' keywords. The larger the dot, the more frequent the occurrence, followed by the theme maps from Figures 4–7. The themes demonstrated in this study are *functional recovery, recovery time, and recovery process*. The networks are also represented by the range of years from 2000 to 2024. Current keywords are shown in yellowish hue. The missing link and disconnect between the "*recovery process*" and "*recovery time*" is demonstrated in Figure 8. Lastly, the country-specific heat map is included in the Appendix A.

Figure 3 presents a network map illustrating the co-occurrence of keywords in the literature, with a minimum threshold of five occurrences. The term "earthquakes" emerged as the most frequently mentioned keyword, followed by "seismic resilience" and "recovery", as also reflected in the accompanying table. The map visualises the relationship between topics based on the co-occurrence of author-assigned keywords. Total Link



Selected	Keyword	Occurrences	Total link strength
☑	earthquakes	422	3947
☑	seismic resilience	242	2139
☑	recovery	204	1897

Figure 3. Network of keywords.

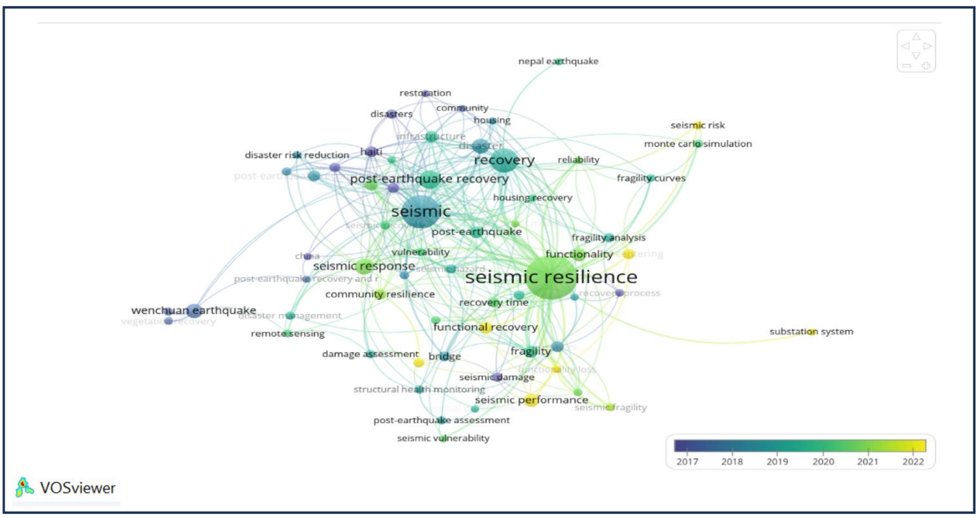


Figure 4. The current trend of research.

Strength (TLS) quantifies the intensity of connections between a given item (e.g. keyword, author and publication) and other items in the dataset. It serves as a key metric in identifying the relative importance of each item within the network. Nodes (representing keywords) are positioned based on their relational proximity, those more closely related appear nearer to each other. Distinct clusters, denoted by different colours, reflect groups of related topics, generated automatically from citation relationships within the dataset (Van Raan, 2019).

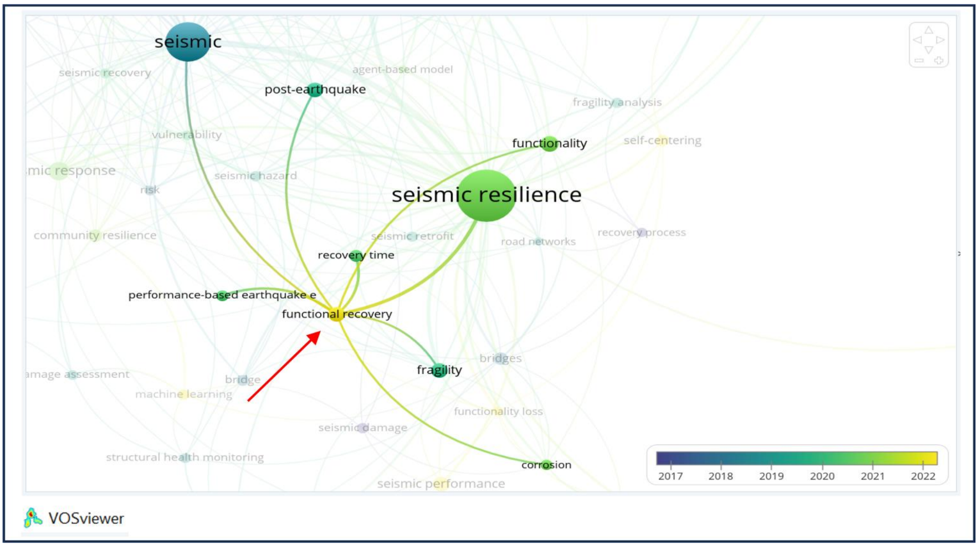


Figure 5. Thematic map "functional recovery"

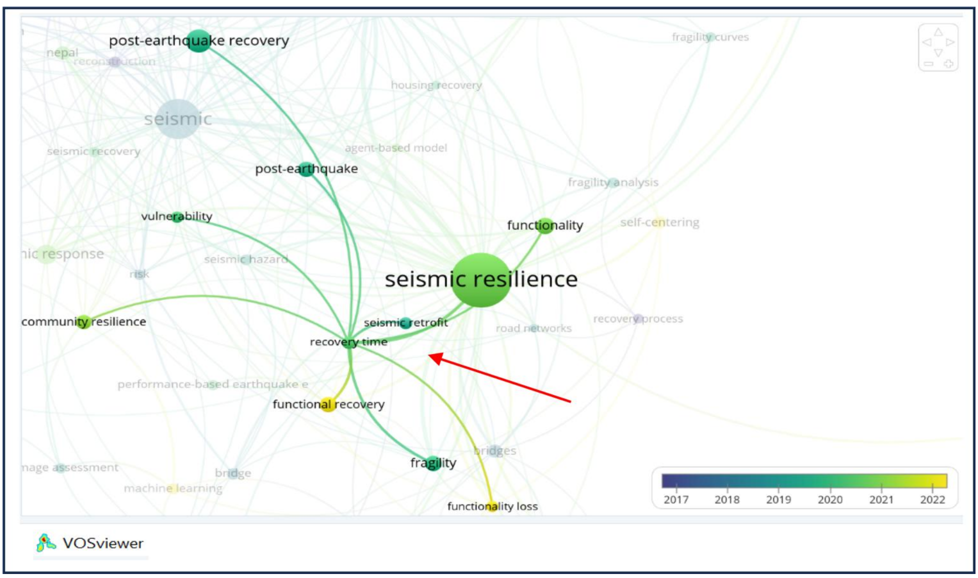


Figure 6. Thematic map "recovery time".

Figure 4 illustrates the trends and patterns in more recent years since 2017. In the timelines, keywords related to seismic resilience since 2022 are highlighted in a yellowish hue. These keywords encompass "functional recovery, functionality loss, machine learning, self-centering, substation system, and seismic risk".

In Figure 5, the theme "functional recovery" is highlighted with a red arrow. Corresponding to the year range of publications, the analysis affirms that the functional recovery concept is new, indicated by a yellowish dot. Also, the visualization reveals connections with other terms such as "fragility, corrosion, recovery time, performance-based earthquake, functionality, post-

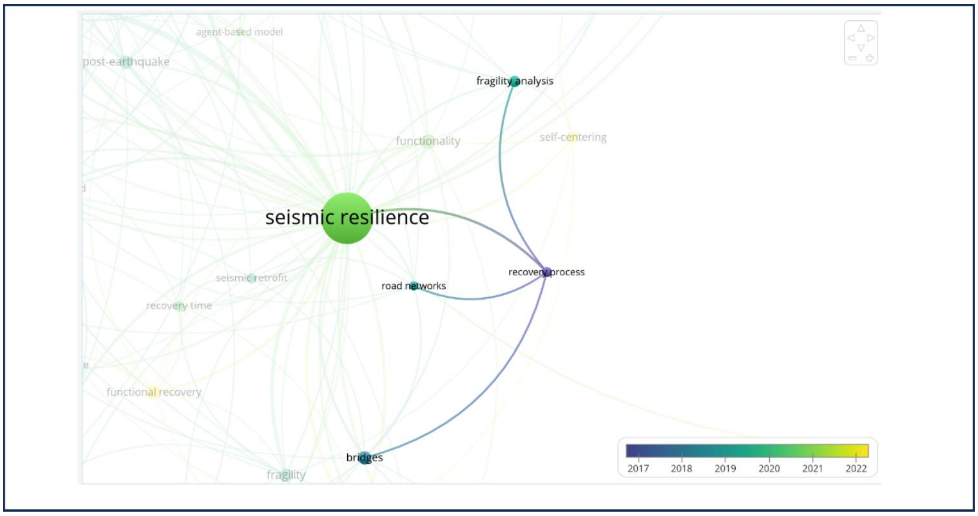


Figure 7. Thematic map "recovery process".

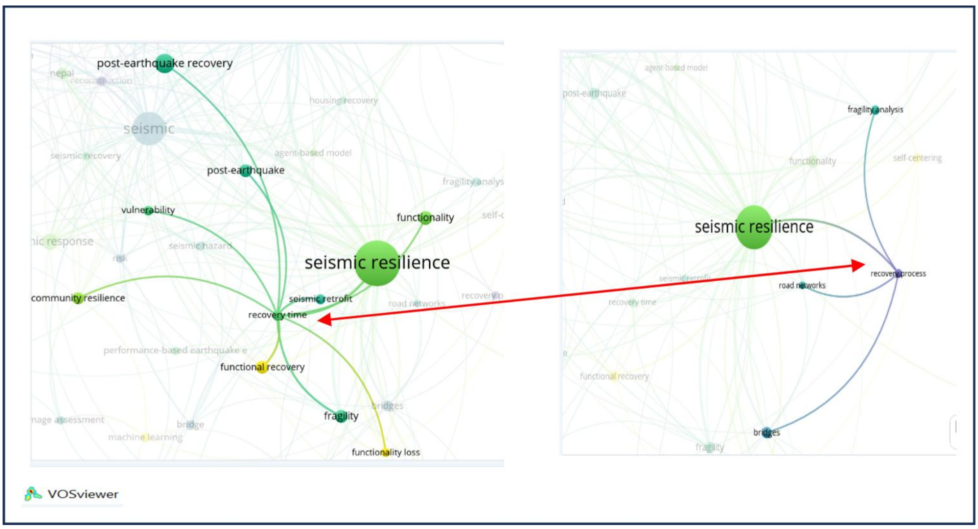


Figure 8. Missing link/disconnection/gap between the "recovery process and recovery time".

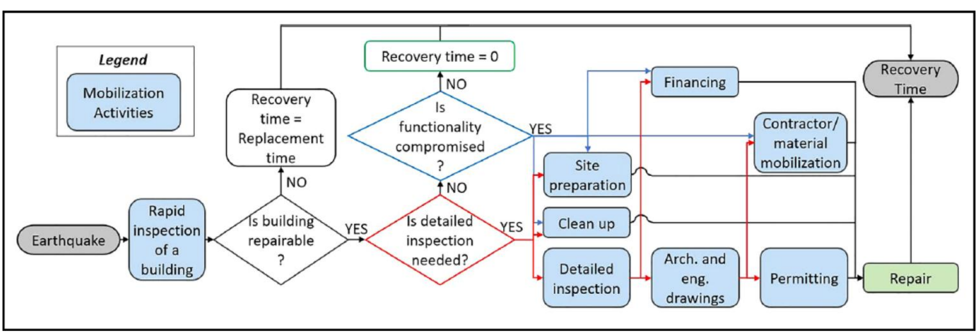


Figure 9. Mobilization time framework. *Source*: Terzic et al., 2021.

earthquake, seismic, and seismic resilience". Notably, the map shows the connection between functional recovery and recovery time. Yet it can be observed that there is no direct link or connection between "functional recovery" and the "recovery process".

From Figure 6, the theme "recovery time" is connected to "functional recovery, fragility, functionality loss, community resilience, seismic retrofit, seismic resilience, functionality, post-earthquake resilience". The current trend of recovery time is associated with functional recovery and functionality loss.

In Figure 7, the theme "recovery process" illustrates its connections with "road networks, bridges, fragility analysis, and seismic resilience". This highlights a prevalent emphasis on technical and engineering perspectives within the recovery process.

According to Noyons (2001), it is essential to focus on the most relevant insights rather than become overwhelmed by the vast amount of analytical data typically generated in mapping studies. Notably, Figures 5–7 illustrate key thematic relationship within the literature, showing that "functional recovery" is a relatively new concept, closely linked with "recovery time", "functionality loss" and "seismic resilience". Conversely, "recovery process" is primarily associated with technical and engineering terms such as "road networks, bridges", and "fragility analysis".

Figure 8 reveals a critical research gap: there is no direct connection between "recovery process" and "recovery time". This indicates that existing studies largely treat these concepts in isolation, suggesting a need for integrated research that bridges the procedural aspects of recovery with the temporal dimension, linking how recovery unfolds (process) how long it takes (time). Moreover, some scholars argue that a purely technical focus on functional recovery is inadequate. For instance, Molina Hutt et al. (2022) emphasize that technical measures alone do not capture the full scope of recovery. Similarly, Marquis et al. (2017) and Comerio (2006) highlight that recovery outcomes are not solely determine, by structural damage, but are also heavily influenced by the needs, experiences and decisions of building users. Thus, a qualitative approach is employed to further explore the gap.

3.2. Qualitative Overview

The qualitative analysis in this study complements the bibliometric findings by exploring the limited body of research that links "recovery processes" and "recovery time", particularly through both technical and social lenses. Developers of bibliometric techniques argue that one of the most effective ways to validate bibliometric maps is by comparing them with qualitative assessments (Boyack et al., 2005; Klavans & Boyack, 2006). Accordingly, this study integrates a qualitative research approach to deepen understanding of the concept of functional recovery, enriching the interpretation of the bibliometric results. Since post-earthquake functional recovery is an emerging concept in the built environment, the qualitative review mainly focused on post-earthquake recovery along with methods, theories, and frameworks directly connected to the functional recovery concept. Six themes were identified and categorised under two primary dimensions: social and technical, as shown in Table 2.

3.2.1. Social Dimension

3.2.1.1. Disaster Preparedness. Human behavior forms part of the disaster preparedness and recovery process. Pre-earthquake actions and preparations are the most effective

Table 2. Summary of the qualitative literature review.

Key dimensions (Social/technical)	Themes	Description	References
Social	Disaster preparedness	Aligning disaster preparedness with societal expectations to ensure a balance between technical disaster planning and the expectations of the public.	Ajzen (1991), Bandura (1999), Becker et al. (2012), Bonowitz (2009), Costa et al. (2021), Hosseini et al. (2009), Kwok et al. (2016), Marshall and Schrank (2014), Miles and Chang (2006), Olshansky (2005, 2012), Rubin (2009), Rubin et al. (1985), Song et al. (2017), Tanner et al. (2020), Terumoto et al. (2021), Xiang et al. (2021)
	Mobilizing resources	This focuses on how resources are mobilized and how decisions are made in the recovery process.	Al-Nammari et al. (2009), Asgary and Willis (1997), Burton et al. (2019), Chang (2010), Chang et al. (2014), Comerio (2006), Contreras et al. (2018), Cremen et al. (2020), Galloway and Hare (2012), Lindell and Perry (2012), Marquis et al. (2017), Mitrani-Resier et al. (2016), Mulilis and Duval (1995), Pamidimukkala et al. (2020), Paton (2003), Tierney and Oliver-Smith (2012)
			Echeverria et al. (2023), Tas et al. (2007), Underwood et al. (2020)
	Methods and frameworks	Methods and frameworks that directly relate to building users regarding the functional recovery concept.	Cook et al. (2022), Costa et al. (2021), Kolozvari and Terzic et al. (2023), Menassa and Baer (2014), Mohammadgholibeyki et al. (2023), Nkrumah et al. (2024a)
Technical	Seismic assessment of buildings	Evaluation of physical building damage; structural and non-structural components.	Bruneau and MacRae (2017), Coburn et al. (1992), Dhakal (2010), Jacques et al. (2014), Khakurel et al. (2023), Kircher et al. (1997), McEntire et al. (2012), Mieler and Mitrani Reiser (2018), Miranda et al. (2012), Terzic et al. (2021), Tokas (2011), Tung et al. (2020), Underwood et al. (2020)
	Methods and frameworks	Proposed frameworks evaluating the post-earthquake functional recovery of buildings and recovery time.	Almufti and Willford (2014), Burton et al. (2016), Campbell (2018), Cimellaro et al. (2010), Cook et al. (2022), FEMA P 58 (2012), Furley et al. (2021), Hamburger (2014), Lin and Wang (2017), Molina Hutt et al. (2022), Terzic and Kolozvari (2022), Terzic et al. (2021)
	Lifeline infrastructure	Aligning the recovery of lifeline infrastructure with a building's functionality	Buckalew and Engineers (2019), Davis et al. (2024), Kammouh et al. (2018), May (2001), Mohammadgholibeyki et al. (2024), Mowll et al. (2023)

ways to expedite recovery and the quality of the recovery process (Costa et al., 2021; Miles & Chang, 2006; Olshansky, 2005). While some people have a passive response and accept earthquakes as an "act of God", others on the other hand, have a pro-active stance of putting in measures to mitigate the effect. Understanding earthquake risk requires examining how individuals and institutions perceive and respond to hazards. Several theoretical models have been developed to explain these behaviours, including Person-relative-to-Event (PrE) model (Mulilis & Duval, 1995), the Theory of Planned Behaviour (Ajzen, 1991), the Protective Action Decision Model (Lindell & Perry, 2012), and the Social Cognitive Theory (Bandura, 1999; Paton, 2003). For instance, the PrE model posits that an individual's willingness to adapt to earthquake risks depends on how they perceive the threat in relation to their available resources to mitigate it.

Risk perception is influenced by both emotional responses (feelings) and rational evaluations (analysis), shaping how individuals prepare for and respond to disasters (Becker et al., 2012, 2017). In institutional settings, particularly in environments with diverse building types, such as hospitals, schools and industrial campuses, understanding building function is critical to effective risk identification and management. Previous experience has demonstrated that preparedness planning significantly enhances institutional resilience. For example, following the 1989 Loma Prieta earthquake, Universities such as University of California, Berkeley, and Stanford University implemented 30-day recovery strategies to improve their readiness for future events (Comerio, 2006). While critical infrastructure such as hospitals, emergency units, and fire stations is typically designed to maintain post-earthquake functionality, much of the general buildings stock remain vulnerable to significant damage potentially displacing millions of people and disrupting hundreds of thousands of businesses (Mieler & Mitrani-Reiser, 2018; Porter, 2016). However, there is growing public awareness of the importance of ensuring rapid post-earthquake recovery for non-essential buildings. This increasing concern highlights the need to involve the public in discussions around how risk is measured and how to effectively balance acceptable levels of risk with recovery expectations (Bonowitz, 2009; May, 2001; Porter, 2016).

3.2.1.2. Mobilizing Resources. The social recovery phase may be experienced differently by diverse groups - nations, communities, and individuals of which the scale and unit of analysis encompasses macro, meso, and micro levels (Rubin et al., 1985; Tierney & Oliver-Smith, 2012). Decision-making finalizes all levels of social recovery analysis. Recovery can be considered as a return to the status quo ante or toward a new normal. Building owners require a significant amount of time to assess the necessary actions, determine whether to repair or rebuild after an event, develop a plan, and mobilize resources (Comerio, 2006; Comerio & Blecher, 2010; Marquis et al., 2017). Research conducted by Comerio after the Loma Prieta and Northridge earthquakes in 1989 and 1994, respectively revealed that there are rational and irrational components of the recovery process following an earthquake. While the rational component considers the physical building in terms of construction cost and time needed for repairs, the irrational consists of social factors such as availability and access to finance, relocation of functions, human resources, and economic uncertainties that impact the recovery time.

Additionally, various variables such as physiological needs, psychological, sociocultural, and economic factors influence decision-making. As explained by Maslow's hierarchy of needs, human beings need to have physiological needs essentially referred to as basic needs such as food and clothing. Although physiological needs are lower in the hierarchy of needs, they are powerful and determine the psychological state and health of an individual (Lester, 2013).

3.2.1.3. Methods and Frameworks for the Recovery of Building Users. To date, the concept of functional recovery concerning building users has remained largely theoretical. The building is regarded as a system, with users representing the social component and the physical structure serving as the technical component (Nkrumah et al., 2024a). The interaction between building users and the physical structure plays a key role in determining a building's functionality which is based on the needs and expectations of the users. Also, the building function model developed by Cook et al. (2022) highlights the importance of prioritizing tenant-specific requirements while the repair scheduling algorithm assumes that the repair team together with the building owner will focus on restoring functionality. In the aftermath of a seismic event, the utilities necessary for a building's functional recovery should be customized to meet the specific needs of the tenants (Mohammadgholibeyki et al., 2023). Therefore, building users described as owners and tenants play a key role in the functional recovery of buildings following an event.

3.2.2. Technical Aspect

3.2.2.1. Seismic Assessment of Buildings. The building inspection phase after a seismic event requires a rapid inspection to determine damages and usability of affected buildings after placards and tags are issued; red, yellow, green/white. A red tag label indicates that the building is heavily damaged where access is prohibited while a yellow tag may indicate moderate damage which will require restrictions regarding entry and usage. For green or white labels depending on a specific country's regulations, the building may be declared structurally safe for re-occupancy with either slight/minor damages or no damages at all following the earthquake (Khakurel et al., 2023; McEntire et al., 2012; Underwood et al., 2020). Nevertheless, the red or yellow tags may change based on additional technical evaluations by engineers described as level 2 assessments of buildings. There is a considerable amount of time for the entire building inspection phase, which is based on the total number of damaged buildings that need to be assessed, the number of engineers who are available to undertake the inspections, and the average time needed to inspect each affected building. Most owners of less-critical buildings are generally willing to wait until the surge in demand for engineers subsides. This results in a notable time gap between level 1 and level 2 assessments of buildings (Khakurel et al., 2023).

Furthermore, there are some instances that it will be uneconomical to repair a building especially when there are large residual drifts, collapse, and/or significant structural and non-structural damages such that the loss ratio is greater than 50% (Terzic et al., 2021). However, where there are minor damages or repairs are economically feasible, there is the potential to operate either partially or fully and adapt successfully after the earthquake. Therefore, post-earthquake functional recovery is essential to ensure the continuity of normal daily routines.

3.2.2.2. Methods and Frameworks for Post-Earthquake Functional Recovery of buildings. Prior models and frameworks provide a foundation for the post-earthquake functional recovery concept. They include the performance-based earthquake engineering (PBEE) framework established in 2012 by the Pacific Earthquake Engineering Research Centre

(PEER). The PBEE framework provided a quantitative basis for seismic design and retrofitting as well as considered various recovery levels of a building such as immediate occupancy, life safety, and damage control. Moreover, it was integrated into the FEMA P-58 methodology for seismic risk assessment (Burton et al., 2016; Hamburger, 2014). Also, the FEMA P-58 methodology considered seismic performance measures of individual buildings that pertained to the extent of damage, the potential casualties, loss of use or occupancy as well as repair and construction cost (FEMA P-58, 2012). Subsequently, in 2013, Resilience-based Earthquake Design Initiative (REDi) rating system was established by ARUP. They proposed a new downtime model where mobilization time is estimated based on the damage state of the most severely damaged component (Almufti & Willford, 2014; Terzic et al., 2021). Notably, whereas the PBEE framework and FEMA P-58 quantify repair time from the initiation to repair, the REDi rating system considers factors that may influence repair time, such as delays in commencing repairs. These facets are described as impeding factors or mobilization activities, including post-earthquake inspections, engineering assessments, securing funds for repairs, mobilizing engineers and contractors as well as obtaining a permit (Almufti & Willford, 2014; Terzic et al., 2021). For the post-earthquake functional recovery of buildings, the predominant focus has been the mobilization of activities from the technical aspect impacting the initiation of repairs. Ultimately, the completion of building repairs leads to recovery time as illustrated in Figure 9.

3.2.2.3. Lifeline Infrastructure. Lifeline networks and utilities include water supply and distribution, wastewater, electric power, gas, transportation as well as telecommunication networks. They are essential core elements that contribute to the fundamental functioning of buildings (Terzic et al., 2021). They are important to the recovery of social functions following a seismic event because the lifeline system delivers services to the built infrastructure that relies on human interaction for operation (Davis et al., 2024). Significantly, the lifeline systems and service restoration following an event depend on the magnitude and level of the hazard, the characteristics of the exposed structure, and the availability of human resources (Mohammadgholibeyki et al., 2024; Kammouh et al., 2018). By developing probability restoration curves for four types of lifeline infrastructure; water distribution networks, gas, power, and telecommunications, it was shown that the longer the downtime following the event, the higher the likelihood of infrastructure recovery. Nonetheless, recovery plans, allocated resources, and emergency service provision goals can significantly accelerate the recovery process (Kammouh et al., 2018; Mowll et al., 2023). Considering this, it is recommended that residents and businesses have backup utilities or strive for utility independence, such as installing on-site emergency generators and water storage tanks enabling them to better prepare for events and potential infrastructure outages (Burton et al., 2016; Cremen et al., 2020).

4. Discussion and Conclusion

While building codes set minimum standards for a building's quality, safety and energy efficiency to protect public health and safety (Vaughan & Turner, 2013), past earthquakes have revealed the persistent vulnerability of the built environment. Major seismic events have consistently acted as catalysts for the evolution of building codes and the implementation of retrofitting programmes, particularly for critical infrastructure high-risk structures (Zhang et al., 2022). The focus of seismic design progressively shifted from preventing total collapse and minimising loss of life, to achieving life safety, retrofitting existing buildings and more recently, enabling post-earthquake functional recovery (EERI, 2019; FEMA, 2021). For instance, the 1994 Northridge Earthquake in the United States caused significant damage to modern buildings, especially steel moment-resisting frames previously regarded as seismically robust. In response, updated design guidelines were developed under the National Earthquake Hazards Reduction Program (NEHRP), enabling the Federal Emergency Management Agency (FEMA) to introduce more comprehensive seismic provisions into the International Building Code (Petak & Elahi, 2001). In Japan, the 1995 Kobe earthquake triggered major revisions to the Building Standard Law, introducing stricter requirements for earthquake-resistant design, retrofitting, and foundation performance (Whittaker et al., 1998). Japan also became a global leader in implementing base-isolation and damping technologies, particularly in hospitals and high-rise buildings (Zhang et al., 2022). Similarly, New Zealand adopted a proactive approach following the devastating 2011 Christchurch earthquake. The government enacted the Building (Earthquake-prone Building) Amendment Act 2016, which mandated seismic assessments and the strengthening of vulnerable buildings to improve resilience (He et al., 2019).

The rationale for this study is primarily derived from the international literature, which is predominantly influenced by research originating from the US, as the concept of functional recovery was initially developed and advanced within the US context. This foundational influence has shaped the discourse on post-earthquake recovery, prompting further exploration and adaptation of the concept in other seismically active regions globally. Building on established body of work, this study seeks to expand the understanding of functional recovery, particularly by addressing underexamined social dimensions and their implications for recovery timeframes, thereby contributing to a more comprehensive and holistic approach to the nascent concept.

The assessments of post-earthquake functional recovery predominantly rely on engineering-focused methodologies, including computer simulations like agent-based models (ABM), which are based on assumptions (Cook et al., 2022; Mohammadgholibeyki et al., 2023, 2024; Molina Hutt et al., 2022; Terzic et al., 2021; Terzic & Kolozvari, 2022). Yet, these methods fall short of offering a comprehensive understanding of social aspects that building users encounter following a significant earthquake. For instance, access to finance have been cursorily addressed as impeding factors (Almufti & Willford, 2014; Molina Hutt et al., 2022; Terzic et al., 2021). Past experiences have shown that obtaining finance could be unpredictable, complex and time-consuming (Chang et al., 2014). These financial uncertainties are not captured extensively in the technical methodologies, which can ultimately impact the recovery time. Considerably, financing seismic retrofit is a complex and dynamic process that varies across countries. For instance, countries like the US target buildings based on structural properties/building construction type which is primarily funded by building owners whereas others like Japan and China target buildings by occupancy and potential earthquake risks funded by local government based on the government's plan and budget (Zhang et al., 2022). Comerio

(2006) points out that the definition of repair in government funded cases is often contentious, as local governments and agencies frequently have differing cost estimates compared to building owners. Ultimately, the process and criteria for deciding whether to repair and what specific repairs to undertake remain undefined. For self-funding seismic retrofits, economic-related barriers such as perception of financial involvement, property market conditions, high insurance premiums and deductibles as well as high cost of retrofitting make building owners reluctant to repair their buildings unless when the value of such investments would generate future returns (Egbelakin et al., 2014). As highlighted by Molina Hutt et al. (2022), while engineering approaches establish baseline requirements for the emerging concept of functional recovery, building performance alone does not suffice. Researchers stress the importance of empirical data to understand real-world recovery processes and repair timelines, including planning and decision-making (Comerio, 2006; Cook et al., 2022; Echeverria et al., 2023; Mitrani-Reiser et al., 2016). Although structural integrity is crucial, many recovery processes and decisions are influenced by factors beyond structural considerations (Marquis et al., 2017).

4.1. Conceptual Framework

This study builds on prior studies, methods, and frameworks regarding the recovery process, recovery time, and the involvement of building users. It expands the mobilization time framework developed by Terzic et al. (2021) as illustrated in Figure 10 above. Drawing from Comerio's (2006) research on the rational and realizable aspects of downtime and considering building functionality through the lens of socio-technical systems thinking to develop building-system functionality (Nkrumah et al., 2024a), this study frames the recovery process to encompass both technical (building-level recovery) and social (user-level recovery trajectory) dimensions. Hence, a pragmatic approach to post-earthquake functional recovery is considered, where building experts contribute physical and technical insights, while users

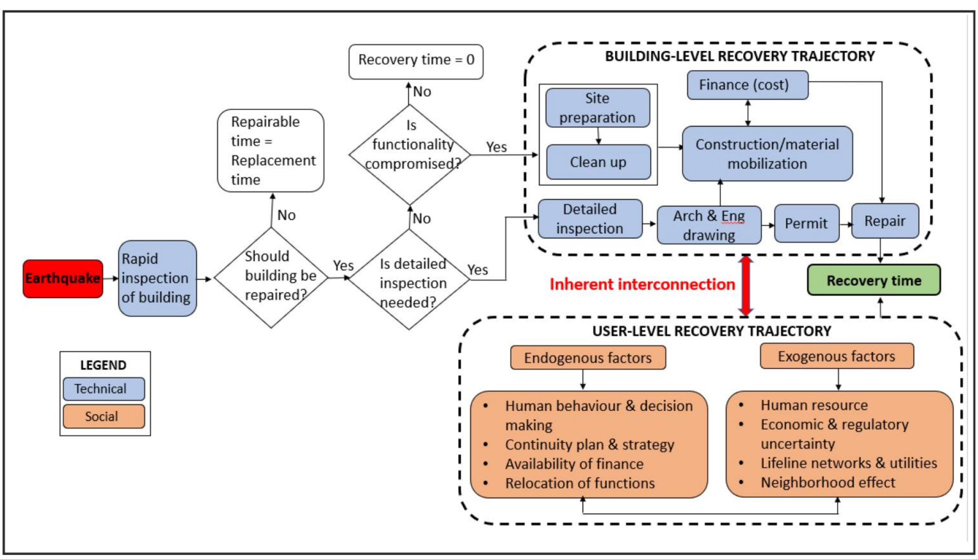


Figure 10. Mobilization time framework integrating building-level and user-level recovery trajectories.

prepare, mobilize resources, and make adaptive decisions, forming an inherent interconnection within a building system, as illustrated in Figure 10.

From Figure 10, the active engagement of users in the post-earthquake functional recovery concept, along with effective communication between experts and users for collaborative problem-solving within a building system, is essential for a practical recovery time. The social component is grouped into two main aspects: endogenous (internal) and exogenous (external) factors.

- Human behaviour & decision making which determine the willingness and capacity of users to take proactive recovery actions. The decision to repair damages and continue using a building for its basic function till full recovery highly depends on the building users (Terzic et al., 2021). The level of risk tolerance, and the willingness to endure inconveniences and interruptions may vary from person to person. Having the right attitude implies that the building users will be psychologically steady to mobilize resources, plan, bid processes and negotiate when the need arises. Positive behaviour guarantees that the well-being of the building users does not stagnate at a dysfunctional level (Norris et al., 2008).
- Continuity plan and strategy: Pre-earthquake actions and preparations are the most effective ways to expedite recovery and the quality of the recovery process (Costa et al., 2021; Miles & Chang, 2006; Olshansky, 2005). Protocols for immediate response and subsequent recovery efforts are essential.
- Availability of finance: This involves the amount of funds for repairs, availability and affordability of finance, and range of funding sources (Olshansky, 2005). The sources of finance could be personal savings, obtaining loans from either private or public lenders, insurance claims, local and national government grants, donations, and international aid organizations. After an earthquake, it is assumed that individuals will need to prioritize their savings since resources are likely to be constrained. Also, concerning securing funds through lending, the building users may need to have necessary credit histories, particularly for private lending (Costa et al., 2021). Past experiences such as the 2010–2011 Canterbury earthquakes in New Zealand have shown that insurance claim settlement and payout could be unpredictable, full of uncertainties, complex, and time-consuming (Chang et al., 2014). For national and local government intervention, funding repairs is usually based on the government's plan and budget. Most often, disagreements arise primarily due to discrepancies between repair costs and estimates provided by building users and those presented by government agencies which affect recovery time (Comerio, 2006; Zhang et al., 2022).
- Relocation of functions: The capacity to relocate from damaged buildings to alternative or temporary spaces impacts recovery time (Burton et al., 2016; Comerio, 2006; Cremen et al., 2020).

The exogenous factors include:

- Human resource availability: Following major earthquakes, a shortage of skilled professionals to inspect and repair buildings often leads to significant delays. For example, after the 2011 Christchurch earthquake, inspections of non-residential buildings began on Day 1, while residential inspections started on Day 6. Recovery time is futher affected as owners of less critical buildings often wait for demand for engineers to decrease before initiating repairs (Comerio, 2006; Khakaurel et al., 2023; Terzic et al., 2021).

- Economic and regulatory uncertainty: Major earthquakes pose significant challenges to an entire nation or economy which can be a concern in securing finance and resources like building materials (Burton et al., 2016).
- Lifeline network and utilities: Lifeline networks and utilities are integral components of fundamental infrastructure and form part of the basic building function (Burton et al., 2016; Cremen et al., 2020; Terzic et al., 2021).
- Neighborhood effects: This can hinder recovery when damage to adjacent buildings creates hazards or obstructs access. Moreover, the socioeconomic factors influence the pace of recovery; wealthier, homeowner-dominated areas typically recover faster that low-income, renter-heavy, or immigrant communities (Chang et al., 2014; Costa et al., 2021).

The proposed framework guides empirical research on the social dimensions of post-earthquake functional recovery, emphasizing the need for context-specific adaptation. For example, while the International Building Code (IBC) sets a general standard in the US, local jurisdictions customise it to address regional hazards such as earthquakes in California or hurricanes in Florida (Congressional Research Service, 2023). Future research should tailor focus areas: China may prioritize local government financing challenges, the US on self-funding, and New Zealand on insurance issues. Furthermore, cultural and community factors also shape recovery, as the restoration of individual buildings is deeply interconnected with neighbourhood recovery. Understanding users lived experiences is key to linking theoretical models with real-world recovery outcomes (Echeverria et al., 2023).

In conclusion, while building codes in countries such as US, China, Japan and New Zealand have evolved in response to past earthquakes, emerging risks necessitate their continuous refinement. To enhance recovery outcomes, it is essential to integrate social dimensions, particularly the relationship between users and the built environment. The lived experience of building users provides a vital bridge between theoretical framework and practical realities in the advancement of building codes. This research contributes to a more comprehensive understanding of post-earthquake functional recovery and lays the groundwork for future studies centred on user-building interactions and recovery trajectories.

Note

1. The difference between bibliometric and content analysis is that while bibliometric is quantitative and considers analysis with publications (citations, authorship, keywords, year of publication, countries etc.), content analysis is mainly qualitative that involves words, phrases, themes and narratives within the literature (Guo et al., 2024).

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Appendix A

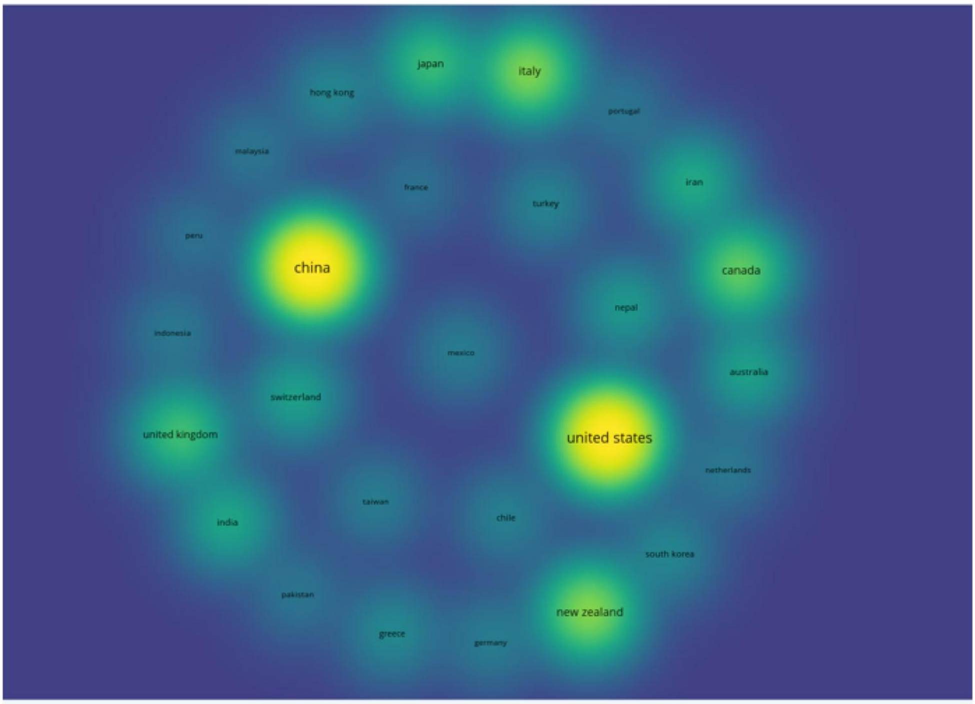

Figure A1. Density visualisation of countries.

China emerged as the leading contributor to the literature, with 210 publications, closely followed by the United States with 206 documents. New Zealand and Italy rank next, with 71 and 65 publications, respectively. As previously noted, the concept of functional recovery originated in the United States and has since gained significant traction, with research efforts expanding to other seismically active regions worldwide. This global dissemination underscores the growing recognition of the importance of functional recovery in enhancing resilience to earthquakes.

Table A1. Summary of list of publications by countries.

List of countries	Number of publications
China	210
United States	206
New Zealand	71
Italy	65
Canada	40
Japan	39
United Kingdom	33
Iran	12
India	10
Malaysia	12
Switzerland	18
Australia	9
Nepal	8
South Korea	8
Greece	7
Turkey	6
Germany	6
Netherlands	5
Hong Kong	5
Mexico	5
Peru	4
Chile	3
Taiwan	3
Portugal	3
	788