Bridging engineering and socioeconomic perspectives of post-earthquake functional recovery of commercial buildings in Aotearoa

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ABSTRACT

The emerging post-earthquake functional recovery concept is gaining momentum among building professionals and policymakers. It highlights the importance of incorporating recovery-oriented objectives into building codes, moving beyond the conventional emphasis solely on safety objectives. The current body of literature predominantly focuses on functional recovery from an engineering perspective, with limited consideration of users' viewpoints such as owners and tenants. Thus, the emphasis of this qualitative study is to bridge engineering and socioeconomic aspects for a holistic post-earthquake functional recovery concept.

Differences in perceptions of building functionality exist between engineers and building users. Engineers tend to prioritise technical aspects, while users focus on the social context of functionality. Building users are directly involved in the daily operations of a building, as well as in coping and adjusting until full recovery post-earthquake. Recognising the inherent interconnection between social and technical perspectives, the socio-technical system (STS) theory was adopted to formulate a building-system functionality framework.

Preliminary findings revealed that building users are primarily focused on their investments, business continuity, the return to buildings within reasonable timeframes and prioritising essential building services for continuous use following an earthquake. These insights help engineers in facilitating recovery processes.

The mobilisation time framework for functional recovery has typically focused on the building-level recovery trajectory. This study advances the framework by incorporating socioeconomic parameters that account for user-level recovery trajectory. The significance of the study underscores that, beyond expert perspectives, actively engaging and involving building users and comprehending their recovery process, will foster trust and confidence in the functional recovery concept.

1. INTRODUCTION

Lessons learnt from past earthquake experiences have shaped current building codes and standards. Yet, the present and future expectations can improve the codes. Currently, building codes focus on life safety without the continuous use of non-critical buildings after an earthquake event (Mieler & Mitrani-Reiser, 2018). Hence, the post-earthquake functional recovery concept considers both life and building safety (EERI, 2019). Post-earthquake functional recovery has so far been driven by engineering parameters. Frameworks for evaluating post-earthquake functionality, mobilising resources, repair time, and processes are based on building performance metrics (Molina Hutt et al. 2022; Terzic et al. 2021; Terzic & Kolozvari 2022). However, the building performance alone is inadequate for the post-earthquake functional recovery concept (Molina Hutt et al, 2022). A critical review of the literature reveals a gap in socioeconomic factors that can substantially impact the post-earthquake functional recovery concept. Thus, this is ongoing research that seeks to explore building users' views and expectations of the post-earthquake functional recovery of commercial buildings in major city centres in New Zealand.

New Zealand is a seismically active area and has experienced a series of devastating earthquakes in a span of six years from 2010 to 2016. They consist of the Darfield and Boxing Day earthquakes in 2010, the Lyttelton Christchurch earthquake in 2011, the Seddon and Lake Grassmere earthquakes in 2013, as well as Kaikoura earthquake in 2016 (Rabiepour, Chase & Zhou, 2022). These earthquakes, particularly those that occurred in the Canterbury region (Darfield, Boxing Day, and Christchurch) impacted Christchurch, especially the Central Business District (CBD). About 900 commercial buildings in the CBD were demolished (Tombleson et al, 2018). Additionally, Wellington city which was about 260 kilometres away from the epicentre of the 2016 Kaikoura earthquake was considerably affected such as the BNZ building, Statistics House, Customhouse, and Shed39 (Campbell, 2021). These earthquakes resulted in significant economic losses, lengthy and restricted access to buildings that interrupted businesses (Bruneau & MacRae, 2017). Consequently, the antecedent events demonstrate the possibility of extensive building damage and complete shutdown of major city centres in future major earthquakes (Galloway & Hare, 2012; Bruneau & MacRae, 2017; Puranam et al, 2019).

Essentially, businesses are the backbones of economies creating jobs and generating wealth. Using the Christchurch city centre before the earthquake as an example, about 6000 businesses in the CBD employed approximately 50,000 workers which accounted for 25% of the city's employment (EERI, 2011). Moreover, New Zealand's commercial real estate market plays a crucial role as the lead in terms of use and occupancy in the Australasian real estate market (Colliers, 2023). The office market is still evolving, the post-covid 19 era has caused a shift in the trend of "*flight to quality*". Tenants seek extra assurances through lease arrangements like short-term leases, re-occupation, and minimum level of damage after a major earthquake event (Bayleys, 2023). Modern facilities and refurbishment of existing buildings to meet the current demands of the office market mean that contemporary buildings have been designed to meet current codes and standards. Hence, it has become evident that focusing only on life safety as an earthquake performance objective is not enough for contemporary buildings. Building users expect minimum damage or facilitation of repairs after a major earthquake occurrence (Bruneau & MacRae, 2017).

Lately, structural components have been designed to have limited damage and be technically repairable such as the Low Damage Earthquake Design (Hogg, 2013; Bruneau & MacRae, 2017; Campbell, 2018). The Low Damage Earthquake Design (LDSD) makes buildings more resilient and sustains less damage for the building to be usable after a major earthquake event (Hogg, 2013; Bruneau & MacRae, 2017; Campbell, 2018). Yet, non-structural components could be considerably affected by earthquakes even when there is little damage to the structural systems affecting users and a building's functionality (Dhakal, 2010). Essentially, designing buildings to have no damage at all during major earthquakes may not be realistic, but rather, the ability to return to function with achievable and acceptable timeframes is more practical, hence the need to involve building users. The building users considered in the context of this paper are owners and tenants.

Building users are the ones to determine the basic functionality of a building for continuous use, cope with disruptions as well as establish realistic and achievable timeframes till full recovery. Owners have the principal obligation to undertake building repairs after an earthquake occurrence taking into account the requirements and needs of their tenants. Moreover, users' prioritisation of building systems and services will help engineers in facilitating building performances following a major earthquake. For instance, Cook et al, 2022 in their study expanded the building function module to include tenant function, enabling building function to be quantified at the tenant level (ATC, 2021; Cook et al, 2022). Yet, the recovery processes of building users, which substantially impact the overall recovery time, have been cursorily considered. To cite an example, securing finance for repairs following an earthquake occurrence is briefly taken into account in engineering frameworks. Some simulations assume that building owners even those with insurance coverage will need to seek private financing to initiate repairs due to the extended periods and uncertainties regarding insurance claims (ATC, 2021; Chang et al, 2014; Costa, Haukaas, Chang, 2020). It is essential to progress beyond dependence solely on computer simulations and assumptions by integrating empirical data to gain deeper insights into real-world recovery processes (Echeverria et al, 2023).

Subsequently, this paper demonstrates the inherent interconnection between engineering and socioeconomic perspectives for the development of a comprehensive post-earthquake functional recovery concept. Section 2 of the paper presents the categories of building functionality, followed by the application of a socio-technical system (STS) theory to develop the building-system functionality framework in section 3. Research methods and preliminary findings are detailed in section 4 with a discussion on the study's outcomes to advance the mobilisation framework for post-earthquake functional recovery in section 5. The paper concludes with section 6 summarising the study.

2. CATEGORIES OF BUILDING FUNCTIONALITY

There is no universal definition of what building functionality is. The functionality of a building needs to be recognised as a complex entity with diverse aspects such as structural, social, cultural, and economic (Hillier & Pen, 1994). For this study, the nuances of a building's functionalities from literature are categorised into two main perspectives: building users' and building experts'/engineers' stances.

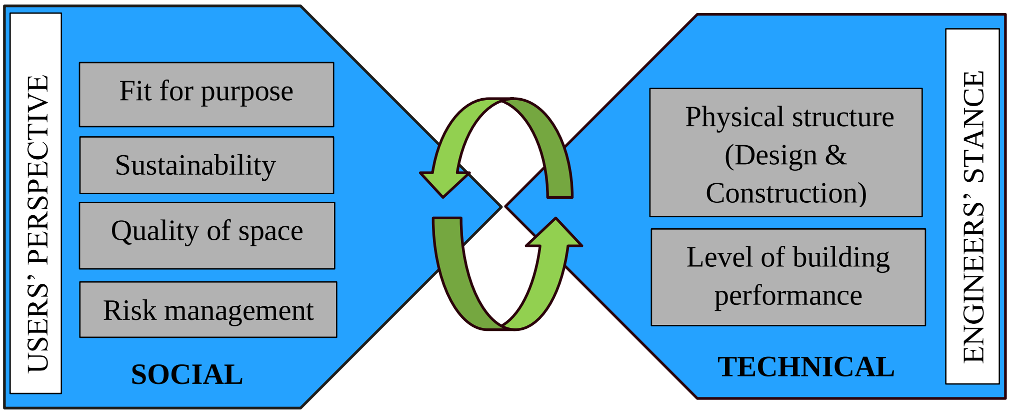

Figure 1: Building functionality from users' and engineers' perspectives
Authors' construct

Figure 1 is the result of the authors' review of existing literature where the functionality of a building as perceived by building users is fit for purpose, sustainability, quality of space, and risk management whereas experts/engineers are particular about the physical structure with the technical aspects which pertain to design and construction as well as the level of building performance concerning building systems and components. A building is considered to have not fulfilled its purpose if it lacks users, as experts and engineers typically design and construct buildings intending to create habitable spaces for users (Lah & Saruwono, 2017). Although building type and basic intended use may be stipulated under building codes, the actual usage is established by users. So, users use buildings to fit a purpose. Expressed differently, the building must meet the building code and requirements as well as meet the needs and wants of users. The perception of users regarding an office building's functionality goes beyond the physical building. The physical building primarily provides features such as location, floor size, floor ceiling, column layout, space efficiency, sub-divisibility of space, and floor-ceiling height (Ho, Newell, Walker, 2005; Safian & Nawawi, 2013). For businesses, leasing office spaces form the second financial outlay following labour expenditure. An office building's functionality is typically driven by social factors. The office building is an essential resource that contributes to work processes, operations, and work culture by offering spaces for employees to perform their tasks. Office spaces and work environments are incorporated into the performance of businesses which largely depends on sustainable aspects such as efficiency, effectiveness, productivity, and providing a conducive environment for the health, safety, and well-being of the employees (Jan van Ree, 2002). The functionality of an office building significantly contributes to improving both the quality of workspaces and the services provided. Presently in the post-covid 19 era, businesses are seeking premium office buildings that provide meeting facilities and co-working arrangements that influence structural forms and designs (Bayleys, 2023). To cite an example, premium office buildings incorporate the latest innovations in design (e.g. sustainability) and technology while others may lack such qualities (Faulconbridge et al, 2018; Ho, Newell, Walker, 2005). Furthermore, the functionality of a building determines how earthquake risk is managed. The earthquake rating performance of commercial buildings in New Zealand is highly driven by the market. Tenants seek assurance with a minimum level of damage after a major earthquake (Bruneau & MacRae, 2017). Thus, commercial buildings with high earthquake ratings, 67% NBS and above are highly patronised. Illustrating a case of risk management, Matauranga house in Wellington was assessed with a low earthquake rating. Consequently, the Ministry of Education opted to vacate the building and instructed their employees to work from home despite having signed a lease contract till 2030 (Campbell, 2022). Similarly, after the 1989 Loma Prieta earthquake in the United States (US), the University of California developed a 30-day recovery plan likewise Stanford University based on building types and functionalities on their campuses as preparation to improve their recovery capacities against future earthquakes (Comerio, 2006).

For the building experts/engineers, building functionality is mainly considered from the physical structure together with its technical components. These are based on the requirements of the building code which include durability, fire protection, building accessibility, energy efficiency, and mechanical installations among others. For instance, a building's functionality determines the construction material and occupancy in terms of how many people could use the facility which also dictates the allocated space per person. The design of an office building in terms of shape, size, interior spaces, and building occupancy/population capacity will differ from the design of say a school. Thus, a good building design is described as one that fits its purpose (Lah & Saruwono, 2017). Also, a building's functionality determines the systems and components that are needed in a building (Generalov et al; 2018). In a preliminary building design, step-by-step sequence analysis is undertaken for the components. A building component is first identified, followed by the functionality which is decided whether it is a main function or an auxiliary one. For instance, the design of a window as to the material, size, and shape is decided on whether the primary function of the window is to control air temperature while aesthetics could be an auxiliary function. Furthermore, materials such as concrete, steel, or wood to be used for building construction as well as the interior finishes such as sanitary wares depend on a building's functionality.

In summary, while engineers focus on the physical structure with the technical components, users' perception of an office building's functionality extends beyond the physical structure to include social context such as fit for purpose, sustainability, quality of space and risk management. Currently, the social demand in the office market includes access to meeting facilities and co-working spaces that have an impact on structural forms and designs.

3. SOCIO-TECHNICAL SYSTEM (STS) LENS: BUILDING-SYSTEM FUNCTIONALITY

The socio-technical system (STS) was initially developed in 1950 in a coal mining organisation to emphasise the interconnection between technical and social components (Trist, 1981, Trist & Bamforth, 1951). Although the STS theory was developed for organisations, it is currently being used to address contemporary issues. In the built environment for instance, it has mainly been used for indoor-environment behaviour studies (Morgenstern, Lowe, Chui, 2015; Chui et al, 2014; Lowe, Chui, Oreszczyn, 2018). To illustrate the interconnection between engineering and social perspectives for the development of the post-earthquake functional recovery concept, the study uses socio-technical system (STS) theory as the theoretical lens for the study.

The overall office environment is broadly considered a system that encompasses physical structure and social components interacting together (Becker & Steele, 1990). When human components are considered alongside the physical structure, a building is recognised as a complex system (Lowe, Chiu, Oreszczyn, 2018; Bordass & Leaman, 1997). Whether a building fits a purpose and is performing well or not highly depends on the users based on their needs, preferences, and expectations. Coping with and adjusting to suit some level of comfort within a building is described as "*interactive adaptability*" (Cole et al, 2008; Lowe, Chiu, Oreszcyn, 2018). For instance, users regulate the internal temperature of a room by using heating and cooling systems. Similarly in the event of post-earthquake functional recovery, users are the ones to accept and cope with disruptions till full recovery of buildings. This forms the basis of the study where the entities; users, physical building, and function are intrinsically interconnected and therefore conceptualised to form the basic elements of a system within a building function as illustrated in Figure 2.

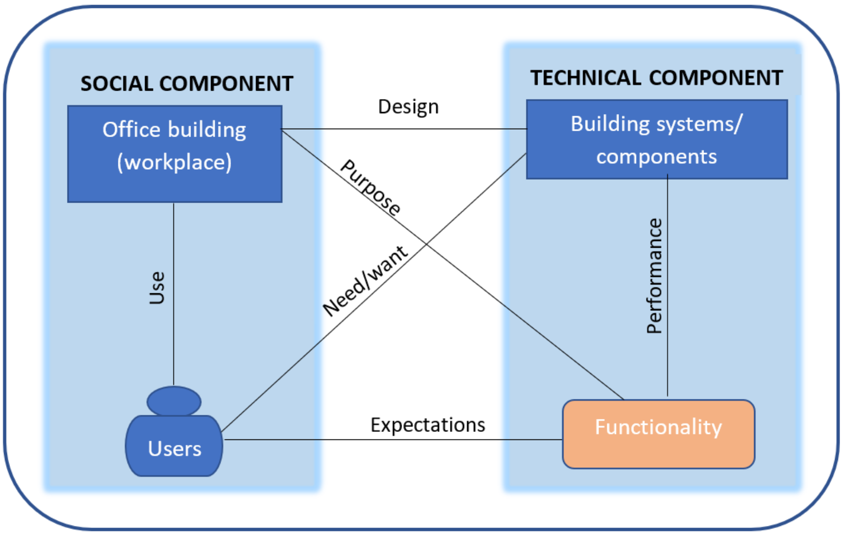

Figure 2 – Building-system functionality (Micro level)
Source: Partially adapted from Bostrom & Heinen 1977 and Oosthuizen & Van't Wout 2019

Figure 2 shows the building-system functionality from the micro level based on a single-level construct. This demonstrates the interactions between engineering and social perspectives for the functionality of an office building. Users determine the functionality based on their needs, wants, and expectations while engineers regard the building structure based on designing the physical structure, determining the systems and components that need to be in place as well as the level of performance to determine functionality.

4. RESEARCH METHOD & PRELIMINARY FINDINGS

This ongoing research employs a qualitative research approach, utilising both primary and secondary data sources as illustrated in Figure 3. Preliminary interviews were conducted in December 2023 and January 2024 to gather primary data from seven participants, predominantly comprising property investors, facilities/property managers and tenants of office buildings in Auckland and Wellington.

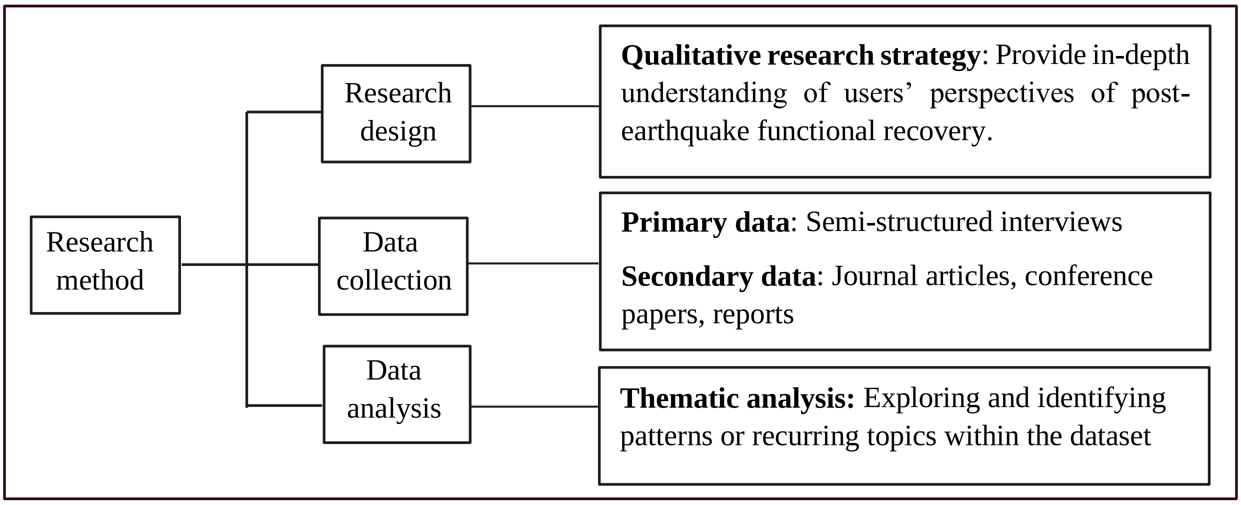

Figure 3 Methodological framework

Preliminary findings from data collected reveal that generally property owners are concerned and interested in building functionality and functional recovery more than tenants. For the owners, they would like to maintain the rental cash flow stream and investment returns while for the tenants, the building is a "means to an end". That is, tenants prioritise safety and the ability to operate their businesses. One interviewee mentioned; "*they want to be safe but don't care about the building post-quake. That's your problem, Mr. Landlord, not mine. They just want to be able to get out of the lease if they can't get back into the building in a reasonable period*". In prior earthquakes, for example, businesses had to sustain their operations by meeting in cafes, hiring spaces, and utilising private residences that could accommodate such needs. The main means of operational continuity during the pandemic was based on working from home (WFH). Thus, many businesses rely on hybrid work arrangements with staff ability to WFH. Presently, the demand in the office market includes the need for access to meeting facilities, co-working spaces, and flexible lease arrangements.

Moreover, functional recovery in New Zealand is influenced by earthquake risk zones and the type of office occupancy specifically corporate and government tenants. Tenants are also sensitive to their exposure to risk. For example, in Auckland seismic activity is relatively low, leading tenants to prioritise sustainability over post-earthquake recovery concerns. Moreover, the office market in Auckland City is mainly influenced by private corporate tenants. For the private corporate tenants, it is not so much attachment to a particular office building but a space where their business culture, values, and ethics can be supported. They would want to get out of a lease if they cannot get back into the building within a reasonable period. Many leases signed post 2010-2011 Canterbury earthquakes include clauses on building access and this is often used as a motivation to terminate the lease and find a new space. Conversely, Wellington City faces higher seismic risks, with the office market primarily driven by government tenants. The government tenants would commonly want to return to the building and continue operations after an earthquake occurrence. It was found that after the 2016 Kaikoura earthquake, some government tenants who wanted to expedite the return to their office building prioritised building services that provided comfort such as air conditioning. Considerably, users' prioritising building systems and services helped engineers in facilitating their building recovery after the earthquake. As expressed by one interviewee;

"*they weren't actually focused on having infrastructure, they were more focused on having air conditioning running than we expected, they wanted to be comfortable……. they wanted the lift operating, I mean little things, what are you worried about if you walk up the stairs, but that made a big deal*".In summary, building users influence a building's functionality and its functional recovery following a disaster. While property owners are focused on their investments and cashflows, tenants are concerned about the continuity of business within reasonable timeframes and essential building services for the continuous use of buildings. The level of earthquake risk in a city influences the users' needs and perspectives. Substantially, the prioritisation of building systems and services by users assists engineers in facilitating recovery efforts after an event.

5. DISCUSSION

Until now, post-earthquake functional recovery has predominantly centred around engineering criteria. Frameworks assessing post-earthquake functionality, resource mobilisation, repair timelines and procedures are grounded in building performance metrics. The preliminary findings from the data collected reveal that users play a crucial role in defining the fundamental functionality of a building for continuous use, managing disruptions, and the acceptance of reasonable timeframes to return to the building following an earthquake. Significantly, property owners bear the primary responsibility for executing building repairs post-earthquake to maintain their cashflows and investments by considering the needs and demands of their tenants.

Socioeconomic factors have been mentioned in engineering models and frameworks as impeding factors, however, they are only briefly considered with less input from users (owners and tenants). For instance, obtaining financing can substantially affect the recovery process. Certain computer simulations anticipate that owners, even if they have insurance, may need private financing to commence repairs before receiving insurance payouts due to the extended periods and uncertainties in claim settlements (ATC, 2021). In practical terms, past earthquakes have shown that challenges in securing finance can profoundly impede recovery processes (Chang et al, 2014; Zhang et al, 2021; Comerio, 2006). Hence, researchers emphasise the importance of obtaining empirical data to establish a more realistic and in-depth understanding of recovery processes (Yoo, 2016; Mitrani-Resier, Wu, Beck, 2016; Cook et al, 2022; Comerio, 2006). This study posits that for a comprehensive post-earthquake functional recovery concept, the mobilisation time framework developed by Terzic et al (2021) needs to be expanded to include building users' recovery process as illustrated in Figure 4.

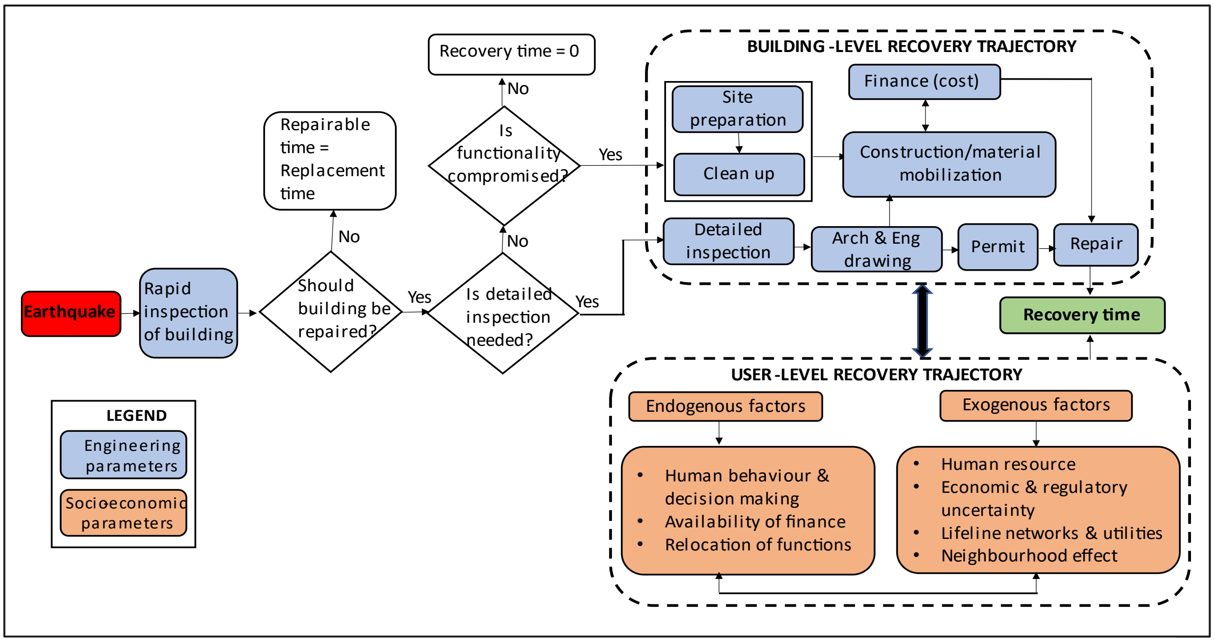

Figure 4 – Mobilisation framework integrating engineering and socioeconomic perspectives. Source: Adapted from Terzic et al (2022) and Comerio (2006)

Figure 4 shows the interconnection between engineering (building-level recovery trajectory) and socioeconomic (user-level recovery trajectory). The user-level recovery trajectory is considered under two factors: endogenous and exogenous context. Endogenous factors are the internal factors that directly relate to the building users while exogenous factors are external aspects beyond the control of the users. The endogenous factors include human behaviour and decision-making, availability of finance, and relocation of functions. The decision to repair damages and continue using the building amidst disruptions highly depends on building users. Having the right attitude implies that users will be psychologically steady to mobilise resources, plan, bid for contractors, and negotiate when the need arises. Regarding securing finance, past experiences like the 2010-2011 Canterbury earthquakes have shown that insurance claims and payouts could be full of uncertainties, complex, and time-consuming in terms of the length of claims settlement (Chang et al, 2014). Relocating functions to temporary structures to pave the way for repairs could also take considerable time impacting recovery time.

Moreover, where there is a major earthquake and widespread impact, exogenous factors could impact recovery time. This encompasses human resources, economic and regulatory uncertainty, lifeline networks and utilities plus neighbourhood effect. Usually, there are shortages of skilled and trained labour to inspect and conduct repairs which can cause substantial delays (Terzic et al, 2021; Khakaurel et al, 2023; Comerio, 2006). Considering economic uncertainty, there could be challenges to an entire nation or economy which can cause difficulties in securing finance and resources like building materials (Burton et al, 2016). Lifeline utilities and infrastructure which include water supply and distribution, power, gas, electricity grids, and communication networks affect a society's function. Lastly, neighbourhood effects such as hazards posed by adjacent buildings, cordoning an affected area and the socioeconomic status of an area could affect recovery time. The socioeconomic status of an area plays a role in the recovery process. Neighbourhoods with higher-income status and owner-occupied tend to recover faster than lower-income, renter-occupied, or immigrant neighbourhoods (Chang et al, 2014; Costa, Haukaas, Chang, 2020).

6. CONCLUSION

The effectiveness of a building's functionality and functional recovery following a disaster is about connecting the physical building aspects (technical design and specifications) with the social values the building provides to users. This underscores the critical significance of bridging the perspectives of both engineers and users in shaping the emerging post-earthquake functional recovery concept. While engineers are focused on the technical aspects, users prioritise the social context of a building's functionality. Presently, the demand of the office market that considers social context includes the need for access to meeting facilities and co-working spaces which have an impact on physical structural forms and designs.

Establishing trust and confidence in integrating post-earthquake functional recovery objectives into building codes necessitates the active engagement of building users. Users are pivotal in delineating the basic functionality of a building, managing disruptions, and prioritising essential building systems and services for continuous use post-earthquake. Hence, the adaption of the sociotechnical system (STS) theory to formulate the building-system functionality framework.

Furthermore, despite engineering frameworks and models establishing the baseline requirements for post-earthquake functional recovery, relying solely on building performance is insufficient (Molina Hutt et al, 2022). Hence, researchers underscore the importance of obtaining empirical data, particularly about unpredictable factors such as mobilising resources and making decisions after an earthquake (Yoo, 2016; Mitrani-Resier, Wu, Beck, 2016; Cook et al, 2022; Comerio, 2006). Thus, this study advances the mobilisation framework established by Terzic et al (2021) to include socioeconomic parameters that consider a building user's recovery process grouped into endogenous and exogenous factors. This is ongoing research that aims at providing users' views and expectations for the development of the post-earthquake functional recovery concept.

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