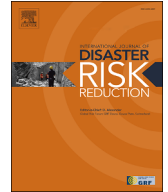


Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdr

Towards a user-focused office building-system functionality for post-earthquake functional recovery

Sally Adofowaa Mireku Nkrumah^{a,*}, Olga Filippova^a, Deborah Levy^a, Fei Ying^b^a University of Auckland, Faculty of Business & Economics, Property Department, New Zealand^b Massey University, School of Built Environment, New Zealand

ARTICLE INFO

Keywords:

Building users
Office building
Building-system functionality
Post-earthquake functional recovery
Socio-technical system (STS) theory

ABSTRACT

Globally, building codes tend to focus on life safety without consideration for the continuous use of buildings after a disaster. Post-earthquake functional recovery is an emerging concept in the built environment that aims at incorporating recovery-based objectives into building codes. However, to date, post-earthquake functional recovery is predominantly recognised from engineering perspectives with minimal inclusion of users' input.

To enhance post-earthquake functional recovery for effective risk reduction, this study introduces conceptual frameworks that expand the scope of building functionality through socio-technical systems (STS) thinking. While engineers focus on the technical aspects of buildings, users emphasise additional facets that include social context. The adoption of the STS theory guides the development of building-system functionality frameworks, examining perspectives at both the micro and macro levels. At the micro level, users prioritise essential building services, while on the macro level, externalities that can impact the overarching functionality of a building are taken into consideration. The building-system functionality frameworks have a significant impact on both functionality and functional recovery following a disaster. By prioritising users' perspectives, the objective of the building-system functionality is to enhance societal engagement in integrating functional recovery criteria into building codes.

1. Introduction

Amongst all types of disasters, earthquakes have accounted for most deaths and destructions caused by the collapse and/or damage of buildings [1,2]. Structural collapse of buildings accounts for 75 % of deaths whilst the remaining 25 % are attributed to non-structural components and cascading hazards such as fire, and landslides among others [3]. Accordingly, building codes and standards regulate the design of buildings to minimise the risk of collapse ensuring life safety. While ensuring the structural designs of buildings reduce the risk of collapse, a building's uninterrupted (albeit reduced) functional capacity is not considered. Thus, the evolution of the post-earthquake functional recovery concept that stemmed from the United States. Functional recovery aims at both life safety and acceptable recovery time for a building to return to functionality after an incident [4,5]. Returning to functionality after an earthquake event is gaining momentum as governments and the private sector endeavour to reduce losses and accelerate recovery, particularly in seismically active areas like New Zealand (NZ), and Japan [6,7]. The functional recovery concept 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 [4,8–10,11]. Yet generally, it remains uncertain how building users regard func-

* Corresponding author.

E-mail address: sally.mireku@auckland.ac.nz (S.A.M. Nkrumah).

tionality. Understanding users' perception of building functionality is crucial for post-earthquake functional recovery [4]. In the context of office buildings, businesses as occupants of office spaces, play a crucial role in identifying and prioritising essential building services to reduce the risk of business interruptions. The office building and its services are integral to ensuring business continuity, which, in turn, has a substantial impact on economic recovery, the well-being of employees, local communities, and the broader economy following a disaster [12,13,14]. Thus, the main emphasis of this paper is to enhance the performance of buildings by employing socio-technical systems thinking, which conceptualises users' perspectives on office building functionality essential in post-earthquake functional recovery.

Notably, buildings are designed and managed by people (experts) to be inhabited by people (users). Office buildings are salient partners of users in performing tasks, accomplishing business goals as well as serving as an accommodation that connects building users to their workspaces [15–17]. Hence, there is a human connection to buildings [18]. The connection between building users and workspaces affects the health, comfort, and productivity of users particularly employees [19–21]. For instance, sick building syndrome is a phenomenon where building users experience health-related issues when in a building such as irritations and lack of concentration. Certain sicknesses like lung disorders and asthma are associated with indoor air quality where moisture and mould are present in buildings [18,22,23,]. Another instance of users' connection with an office building is their interactions and ability to control their workspaces through building system interfaces like indoor temperature using HVAC systems [24]. Considerably, building users are the ones who determine whether a building is performing well or not based on their needs, satisfaction, expectations, and preferences [16,24,25]. Users are the ones to cope with and adjust to suit their level of comfort which is described as “*interactive adaptability*” [24,26,27]. Similarly in the event of post-disaster functional recovery, users are the ones to accept and cope with disruptions till full recovery of buildings. As such, tenant function is considered a significant component of a building's function [13]. Further studies reveal that businesses are dependent on utilities; thus, utility services and restoration are mostly tailored toward the specific needs and requirements of tenants [28,29]. Moreover, the repair schedule algorithm developed by Cook et al [13] operates under the assumption that the building owner and the repair team give priority to restoring functionality unless there are evident structural constraints that logically dictate otherwise. It is upon this premise that the study describes building functionality as an interaction between users and their building. That is, the experience of users (owners and tenants) regarding a building's functionality is inseparable from the physical building - structure, building services, and components [16,30,31]. These entities: users, physical building, and functionality, are intrinsically interconnected and therefore conceptualised to form the basic elements of a system within a building function.

Furthermore, the assessment of building functionality from the perspective of building users is closely intertwined with the concepts of Post Occupancy Evaluation (POE) and usability [32,33]. Whilst usability pertains to quality in the use of workspaces [32,34–36], POE evaluates users' views when a new building is completed, and it is in use for the first few months or years [37,38]. POE obtains feedback regarding the serviceability of a building and examines whether a building meets the specified demands placed upon it [33,37–39]. Essentially, both usability and POE concepts focus on the current state of a building without considerations for continuous use, flexibility, adaptability, and longevity about future uncertainties and the resilience of buildings after a disaster. Building resilience relates to an ability to respond to and recover from the effects of an incident taking cognisance of the time needed to restore basic operations [40]. Therefore, this paper argues that the conventional description of building functionality entangled with usability and POE concepts is inadequate. Subsequently, articulating building-system functionality as a novel approach to foster flexibility, adaptability, and resilience of buildings that will facilitate the post-earthquake functional recovery concept.

Functional recovery spans across interdisciplinary domains, hence, relying solely on structural performance of buildings is inadequate [10,41]. Therefore, for a comprehensive post-earthquake functional recovery concept, there is a need to understand building functionality from diverse aspects such as social, economic, and organisational [42]. Although building experts focus on the technical aspect related to structural performance that is crucial for a building's safety, the continuous use and adaptability of office buildings amidst disruptions highly depend on the building users. The involvement of users is imperative in the successful design of the post-earthquake functional recovery concept [4]. Therefore, the purpose of this study is to:

- Conceptualise users' version of office building functionality.
- Contribute to literature by advancing the application of socio-technical system thinking (STS) in the building industry that will mitigate the impact of cascading hazards that pose great risks to buildings.
- Introduce the building-system functionality frameworks to guide future research in the emerging post-earthquake functional recovery concept.

This paper is structured as follows: section 2 delves into office building functionality. Socio-technical systems (STS) theory which serves as the theoretical lens underpinning the study is considered in section 3. Lastly, the building-system functionality frameworks are presented in section 4 while section 5 discusses and concludes the study.

2. Building functionality

The total workplace is broadly considered to have many aspects like physical, operational, social, and cultural factors [30]. This section examines the facets of office building functionality from physical and social contexts.

2.1. Physical office building functionality

The physical context refers to the building structure with its systems and components to serve a purpose. In a given jurisdiction, all buildings are required to conform to the building codes and standards relevant to that specific locality. Building codes primarily set

minimum requirements for how buildings should be designed, constructed, or perform for the safety, health, and well-being of occupants. The codes exhibit notable variations not only between countries but sometimes between different states. In the United States (US) for instance, the decision to adopt the International Building Code (IBC) lies with state or local jurisdictions. These codes are then customised to address the specific requirements and distinctive features of a particular region. To cite some examples, the building code in California places a particular emphasis on addressing earthquake risks, whereas Florida's code incorporates specific measures to address the challenges posed by hurricanes [43]. Additionally, the building code in the US prescribes standards and requirements that govern the design, construction, and maintenance of buildings [44,43]. In New Zealand (NZ), the building code is performance-based. The performance-based approach encourages innovations with technical clauses that buildings must adhere to [45,46]. The technical clauses encompass stability of the structure, durability, protection from fire, access, moisture, services, and facilities, energy efficiency provisions among others [46]. Each technical clause has its social objective, functional requirements, and performance criteria. The functional requirements specified in the NZ Building Code delineate the technical aspects that buildings must comply to fulfil social objectives, prioritising the safety, health, and well-being of occupants. For example, the functional requirement of a building's structure is to ensure the building with its elements stand the loadings they are likely to be subjected to. Nonetheless, on a global scale, existing building codes prioritise protecting lives in hazardous events, but do not explicitly address the functionality required to maintain the operational aspects of buildings after such events [47].

Building experts, particularly engineers describe the functionality of an office building based on technical requirements such as design, construction, performance, and operations of a structure [48]. Structural integrity considers a building's capacity to bear its weight and withstand external forces, such as hazards. Modifications to building structures are also informed by past experiences. To give an illustration, after the 2010–2011 Canterbury earthquakes in New Zealand, commercial buildings in the Central Business District (CBD) were significantly affected which led to the demolition of over 900 buildings representing 70 % of the CBD [49]. Consequently, the building industry first adopted low-damage seismic design (LDSD) before it was embraced by the NZ government. The LDSD is about structural performance to make buildings more resilient and sustain less damage after a major earthquake occurrence [6,50,51]. Similarly, the present emphasis on the concept of post-earthquake functional recovery stems from engineers articulating the need for higher performance of buildings [4,5,8,10,13,47].

From the users' perspective, the physical office building is a resource that partners and contributes to corporate strategy [52]. The office provides a workspace for employees plus a place to meet clients and render services [53]. The physical functionality of office buildings encompasses factors such as the design and layout, dimensions of each floor, the height from floor to ceiling, the effective use of space, the arrangement of columns, the ability to subdivide spaces, and the capacity for supporting floor loads [54]. Furthermore, non-structural elements are critical in maintaining a building's functionality. They include architectural components (e.g., ceiling works), mechanical (e.g., HVAC system, elevators), electrical, plumbing works and building contents. Past earthquakes have demonstrated that while a building may sustain minor structural damage, its functionality can still be compromised due to significant damage to non-structural elements [55]. The non-structural components also account for up to 75 % of a building's economic value [56]. The primary consideration for users regarding the physical functionality of a building is contingent upon the anticipated type of hazard, emphasising the key role of risk management. This involves evaluating acceptable risk levels and safety [57].

2.2. Social context of office building functionality

Apart from the office building providing workspace for employees to perform job activities, it serves as a conduit for innovation, exchange of knowledge and ideas, social interactions amongst employees, cultivating organisational culture, and promoting business image/brand [17,20]. Additionally, some workers value their workspaces such that they are emotionally connected to their work environments [15,17,58]. Users' perception of office building functionality is substantially driven by a series of additional social values and benefits [52].

When choosing workspaces, businesses usually evaluate office buildings to ensure a fit-for-purpose [25]. In other words, to identify suitable accommodation for use that aligns with business goals and culture and is easily accessible for employees and clients. Although leasing office space could be costly, it represents the second most substantial financial overhead following labour expenses [59]. The prevailing trend in the post-pandemic office market is a shift towards quality, emphasising the balance between cost and benefits, with businesses seeking contemporary offices equipped with premium facilities to attract and retain talent [60].

For office users, the functionality of an office goes beyond the physical building to be mainly driven by social benefits. The social benefits encompass the quality of office building including workspace, enhancing business culture, promoting sustainability, and brand image of the business. A quality workspace incorporates different areas that cater to the needs of users such as informal spaces (e.g., for breaks), spaces for collaboration like technology-enabled meeting spaces, and in some cases amenities outside the office like childcare and gym that provide maximum comfort to occupants [19,20,48,61,62]. The flexible workspace allows space division and rearrangement of fit-outs like co-working spaces to accommodate the changing needs of an expanding or downsizing workforce [63,64]. Moreover, the quality of building features such as a modern fit-out and amenities contribute to the grading of office buildings. For instance, grade "A" buildings incorporate the latest innovations in design and technology (e.g. smart buildings where Information Technology (IT) management systems regulate services) while grade "B" buildings may lack such qualities [54,65]. Higher-grade spaces enhance the health, safety, and well-being of employees and facilitate job processes, operations, and productivity [15,66,67]. Establishing quality in a workspace relies on the uniqueness of the business structure, culture as well as individual employee's personality traits and behavioural characteristics [68]. Each tenant, representing a distinct business entity, is likely to have specific needs for essential building services within an office building [13,69].

The functionality of a building plays an essential role in shaping business culture. Business culture includes the values, beliefs, work norms, and policies regarding how a business conducts its operations and interacts with the employees, customers, and society.

Business culture influences the working environment and office layout [67,68,70]. For example, depending on the business culture, workspaces could be enclosed with private offices or open plans with no constraints [15,17,67,70,48,58].

Functionality also adds value to the brand image. For example, modern buildings often achieve sustainability ratings which in turn contributes to businesses' commitment towards minimising impact on the environment. Likewise, technology infrastructure enables efficient communication, data management, and collaboration. These modern features communicate a sense of reliability, stability, and access to the public and investors enhancing the business brand image.

In summary, the review of office building functionality from both physical and social contexts has uncovered differences in viewpoints between building users and experts. Building experts, particularly, engineers prioritise the physical functionality of a building based on technical parameters and performance criteria. Users on the other hand prioritise the social aspect of a building's functionality. They include a fit-for-purpose in aligning with business goals and culture, quality of space that meets the evolving modern work, and branding. The functional requirements of building users inform the physical parameters and structural requirements of office buildings.

3. Theoretical lens

In this section, the socio-technical system theory (STS) that underpins the study is considered. Beyond the researchers who developed the theory, subsequent researchers have expanded the STS theory into broader perspectives. This section illustrates the two key philosophies considered for this study: internal and hexagonal STS theories.

3.1. Overview of the socio-technical system (STS) theory

The general systems theory was first developed where limitations were found regarding different studies of science (living organisms, inanimate things, or social phenomena) as mutually independent philosophies resulting in contradicting philosophies. Consequently, there is a better understanding of philosophy when scientific conceptions that can form a system are considered holistically [71]. A system is frequently described as anything that is first seen as a whole followed by its elements, parts, or components that have relationships that interact between or amongst themselves through actions and reactions [72]. It could be used in any form such as biological (e.g. ecosystem), structural (e.g. railway system), organised ideas (e.g. democratic systems), social (e.g. family), or the interaction of living things and inanimate entities such as employees and the machines they use to perform a task [71,73]. The latter led to the emergence of the socio-technical systems [74,75].

The STS theory evolved in the United Kingdom (UK) in 1949 during the industrialised revolution, and post-war reconstruction of industries [74]. Ken Bamforth, a former coal miner and a postgraduate Tavistock Institute Fellow, and Eric Trist, one of the Institute's founders undertook a study in a newly established coal industry that was not performing well. Despite the upgrade in mechanisation, productivity failed to align as anticipated. This was due to a substantial shift in the technical aspects without sufficient consideration for the impact on the social structure and the needs of the employees. Thus, the STS theory considered a paradigm shift of work blending both technical and social components for an effective output [74].

3.2. Philosophies of socio-technical system (STS) theory

One school of thought considers STS theory strictly from the internal processes of an organisation with four key interacting factors. These are people, structure, technology, and tasks as demonstrated in Fig. 1. The people are mainly the employees, whilst the structure relates to coordination, leadership, as well as how reward systems are prescribed within an organisation. With the employees' skills and knowledge, they perform tasks within the organisation with the available raw materials and technological artifacts such as tools, computers, and machinery that enable them to transform input into output. In effect, the technical sub-system should not be over-emphasised at the expense of the social sub-system. Eventually, for efficient output, which is the main aim of organisations, there should be a blend of both social and technical components [75–78] as illustrated in Fig. 1.

Despite the initial development of STS for internal processes of organisations, its application to other areas became intriguing, thus the establishment of the second school of thought; the hexagonal STS framework as illustrated in Fig. 2.

From Fig. 2, the hexagonal STS framework considers six interrelated factors. Further than the internal processes that consider employees and technical components within an organisation, other external factors tend to impact organisations, for instance, end-users. To cite an example, a study conducted by Hughes et al. [80] for effective telehealth service within the National Health Service in the

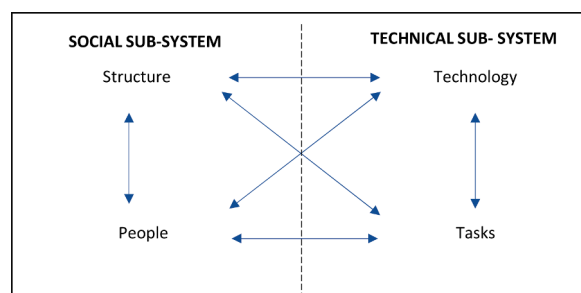


Fig. 1. Interacting variable classes within a working system. Source: Bostrom & Heinen [76].

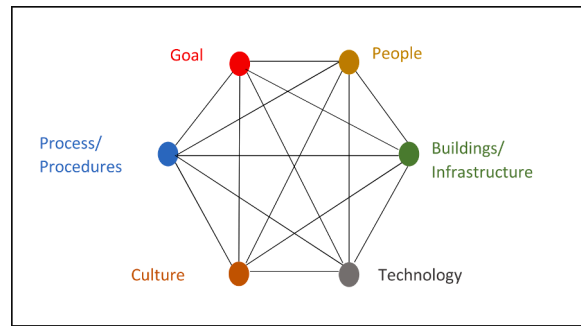


Fig. 2. Hexagonal socio-technical system framework. Source: Challenger & Clegg [79].

United Kingdom (UK) revealed that telecommunication devices used for recording health-related information were not meant for health workers only but the end-users like patients. The patients and/or carers were expected to deliver health-related information such as blood pressure, glucose levels, and heart rates from the patient's home to the clinic using telecommunication devices. With the application of the hexagonal STS theory, the researchers highlighted that the effective output of the clinic included the end-users who used technology to submit the right information to the clinic [80]. Also, STS was used to explain the occurrence of three major crowd-related disasters: the Hillsborough football stadium disaster in 1989, the King's Cross underground fire, and the Bradford City stadium fire in 1987 and 1985 respectively [79]. Using the hexagonal STS for all the disasters, the study underscored that there was a lack of safety concern which was the goal as illustrated in Fig. 2. Culture which is an interrelated factor addresses the attitude and mindset of the people. The people were complacent and thought they were immune to disasters. For the processes and building infrastructure, there was inadequate coordination amongst agencies as well as poor ground conditions and maintenance of facilities like escalators that were insufficiently cleaned and lubricated. Technology included the failure of radios whilst the people who were involved lacked overall control and responsibility. It was therefore accentuated that disasters happen because of mistakes, misjudgements, and poor planning causing unexpected failures of systems [79]. The STS theory facilitates the predictions of future events by identifying significant issues and potential risks. This is primarily based on acknowledging and paying heed to prior experiences as well as identifying factors that contribute to susceptibility to hazards [81]. Whilst it is impossible to prevent the occurrence of disasters like earthquakes, it is feasible to minimise both life safety risks and building damage. The capability of STS theory to predict and elucidate the causes of man-made disasters and malfunctions of complex systems renders it well-suited for the building functionality approach in the built environment. Thus, the adaption of the STS theory to develop building functionality system frameworks.

4. Building-system functionality frameworks

Notably, some researchers assert that there is a need to advance STS thinking and its application to address contemporary issues [75,82]. For instance, its application in Artificial Intelligence (AI) like military intelligence systems [77] and in design science to prevent and forecast future malfunctions of systems [81]. Also, emphasis has been placed on the importance of employing STS as a transformative strategy for enhancing the resilience of engineering systems [75,83–85]. This section presents the application of STS theory in the built environment and the establishment of building-system functionality frameworks with a specific focus on advancing the post-earthquake functional recovery concept.

4.1. Socio-technical system (STS) theory in the built environment

The literature demonstrates the utilisation of STS theory for complex systems. A building is regarded as a complex system especially when the physical and human components are considered [24,30,31]. The involvement of human components particularly building users plays a substantial part in achieving effective design, execution, and optimum performance of buildings. One aspect of human involvement requires interactive processes which necessitates dialogue and communication between experts in providing the technical aspects and users for their satisfaction in the use of buildings [26]. Another part involves interactions between technical components and social elements (users) of buildings which stem from thermal building performances [26,86]. For instance, the internal temperature of a room is operated by heating and cooling systems which are regarded as technical. Yet, building users control the interfaces to provide suitable temperatures for their comfort.

The socio-technical systems (STS) theory is gaining momentum in the built environment as it is becoming more widely adopted. So far, it has mostly been used for indoor environment-behaviour studies. In one study, users adapted to their personal energy conservation strategies rather than programmed adjustments using systems control [24,87]. STS was also used to identify challenges regarding heat metering where it was observed that measurements are influenced by human behaviour such as the opening of windows when heating is in use [88]. Lastly, the STS theory was used to assess the design of higher education learning environments to understand the interactions among learners, physical space, technology, and pedagogical activities [89]. The built environment is continuously evolving, thus the need to progress the discourse and practical implementation of STS principles to improve the resilience of buildings.

4.2. Application of STS theory to develop building-system functionality frameworks

As mentioned earlier, STS theory has been employed to anticipate and mitigate disasters caused by human actions, aiming to lessen the repercussions on systems and organisations. Nonetheless, the built environment has not yet embraced the use of STS theory in addressing cascading disasters. For the development of the post-earthquake functional recovery concept, this conceptual paper focuses on advancing the application of STS theory to develop building-system functionality frameworks. The concept of building functionality represents an innovative approach aimed at promoting the adaptability and resilience of buildings. Bordass and Leaman [31] emphasised the importance of extending the evaluation of building functionality into a broader realm of systems thinking to enhance building performance. Subsequently, the STS theory has been adapted to create building-system functionality frameworks to develop the post-earthquake functional recovery concept in the built environment.

To ensure a comprehensive post-earthquake functional recovery of office buildings, the two aspects of office building functionality must be considered: physical and social factors. Building experts must work with the understanding that their role is, in part, to provide structural perspectives, technologies, and control systems within which users will choose their actions and devise strategies by making adaptive decisions. These adaptive decisions will be based on users' needs and preferences accompanied by comprehension of essential building services and components [26,31]. Also, individual recovery processes vary from person to person [90]. The prioritisation of essential building services and components is vital for the continuous use of buildings as well as for facilitating recovery following an event. Hence, for this paper, the conceptualisation of building functionality points to an integrated approach that considers both the technical and social aspects of buildings. The interrelationships between the socio-technical components are constructed on micro and macro-level perspectives.

4.2.1. Micro-level building-system functionality framework

The building functionality on the micro level is based on a single-level construct that shows the interactions between building users and the office building/workplace. This is based on factors such as needs, wants, purpose, and level of performance of building systems and components as illustrated in Fig. 3.

Fig. 3 demonstrates the interrelationship between the social and technical components. The social component shows the connection between the users and the building/workspace. The technical component on the other hand shows the link between the building components and the function of a building. The users set the criteria for the use of the building or space which defines its purpose. Without users, a building fails to meet its intended purpose [91]. The purpose of the building also shows the function of the building. When a building fails to fulfil its purpose, it is considered to have not achieved its intended function [92]. Additionally, the needs, wants, and preferences of the users influence the building systems and components to be considered in a building. For instance, an enclosed office space will have a private space such that the user can control the internal environment like the temperature in a room as compared to an open space office layout [93]. The level of performance of the building components determines the functionality of a building. To optimise the use of an office building, the functionality of the building must meet the expectations of the users.

4.2.2. Macro-level building functionality

The macro-level building functionality system considers in a much broader context, multi-level constructs, that relate to both internal and external interconnecting factors. Apart from the four key elements, other factors such as building codes and regulations, culture, and external factors could affect the overall functionality of a building. This philosophical stance is illustrated in Fig. 4.

From Fig. 4, the elements within the hexagonal building-system functionality are interconnected and represented by nodes. These convey the notion that the functionality of a building can be influenced by multifaceted factors that extend beyond the micro-level incorporating all six nodes. Building codes and regulations set the rules, performance, and functional requirements that buildings must adhere to. They also provide clear expectations buildings must meet including functional requirements. Generally, the functional requirements address social concerns regarding the safety, health, and comfort of users. The building infrastructure comprises structural components, utility systems, communication networks, and transportation that are essential for the functionality of a building [94]. Culture is contextual to the local environment. For instance, within a seismically active country, some areas could be designated as high-risk zones whilst some areas will be low-risk. Thus, in prioritising building components and systems for functionality, there

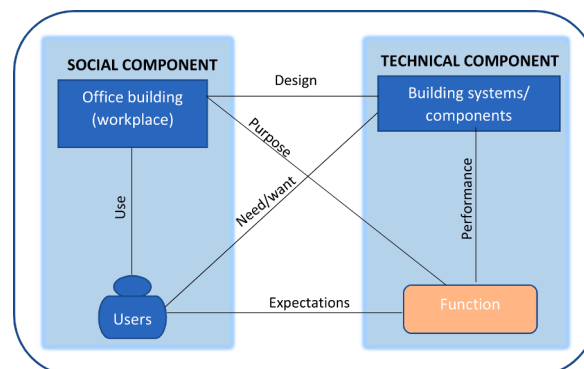


Fig. 3. Building-system functionality (micro-level). Source: Partially adapted from Bostrom & Heinen, [76] & Oosthuizen & Van't Wout, [77].

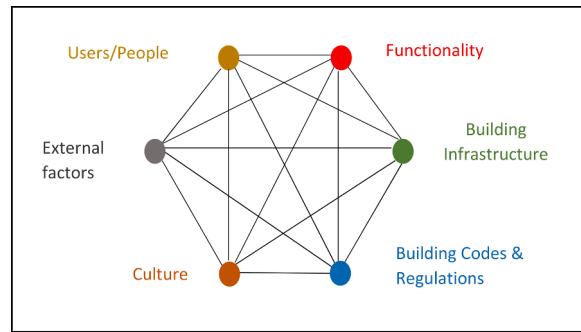


Fig. 4. Hexagonal building-system functionality (macro-level). Source: Adapted from Challenger & Clegg [79].

could be variations based on the needs and preferences of some particular people. Business culture influences the design and layout of office spaces, the work environment, and even how resources such as technology and finance are utilised in managing building systems and components. Externalities affecting functionality refer to consequences to an individual building beyond the users such as hazards and market demands [57]. For instance, the growing acceptance of a hybrid working model post-pandemic is driving the demand for co-working spaces, and hot-desking. This, in turn, is influencing the structural forms, design, and functionality of office buildings.

In summary, whilst the micro-level building-system functionality deliberates on the internal factors such that essential building systems and components can be prioritised from users' perspective, the macro-level construct considers a wide range of factors that can substantially impact the overarching functionality of a building like utility systems.

5. Discussion

Functionality can be described as the overall capacity of a building to fulfil its intended purpose according to building codes and standards as well as meet the needs and expectations of users. Building experts especially engineers regard the physical building with its technical components adhering to building codes and standards while building users look beyond the physical building to consider the social context. The functionality of office buildings, as perceived by users, is often driven by their distinct needs, requirements, and preferences. In essence, while building codes establish the fundamental purpose of a structure, users prioritise their individual needs and specifications when choosing office buildings.

The conceptualisation of users' version of office building functionality is a resource that partners and contributes to corporate strategies. The physical functionality primarily encompasses aspects such as design and layout, size, effective space utilisation, and risk management to ensure an acceptable level of safety for business operations. The social functionality includes a fit-for-purpose that aligns with business goals and culture, quality of building and workspace for the comfort of employees, and social interactions. In New Zealand, earthquake risk influences building user decisions. Tenants obtain structural reports to confirm the level of seismic resilience. The New Zealand Building Act 2004 [95] set the framework for managing earthquake-prone buildings. Although the Act introduced a 34 % New Building Standard (NBS) as the minimum earthquake rating for existing buildings, tenants in high-risk seismic areas target buildings above 67%NBS which results in high vacancies in buildings. To cite an example, in May 2022, the Ministry of Education allowed their employees to work from home as a result of the low earthquake rating of their office building [96]. Moreover, to meet the fit-for-purpose criteria for functionality, the alignment of an office building's structure and workspace layout must satisfy the business goals, culture, and values. For instance, egalitarian organisations will prefer an open-plan workspace design to foster employee interactions, socialisation, and teamwork within a less hierarchical environment [15]. Pertaining to the quality of office buildings, workspaces should be flexible and adaptable to evolving work trends and business needs. For example, the primary strategy for maintaining operations during the pandemic era was centred around remote working. Presently, the office market demand encompasses requirements like meeting facilities, co-working spaces, and hot-desking. Therefore, the functionality of an office building is influenced by social factors as the needs and preferences of users play a crucial role in shaping structural forms and office building designs.

In prior major earthquakes, lengthy and restricted access to commercial buildings forced building users to rent spaces and relocate to spaces that may not have been optimal for their needs [97]. Consequently, it was uncovered that life safety alone as earthquake performance of buildings is inadequate for modern buildings [51]. Following a major earthquake in which a building is declared safe for re-occupation, businesses would want to get back to the building for continuous business operations. However, the responsibility falls on the building users to determine how they can adapt to the disruptions till full recovery. The continuous use and functionality of an affected building highly depend on the building users. As emphasised by Bruneau & MacRae [51], tenants who prioritise reduced operational disruption following an earthquake influence the selection of structural systems for specific buildings. Therefore, the frameworks for building-system functionality offer a proactive approach to the post-earthquake functional recovery concept.

The building-system functionality approach is based on the needs and preferences of users, plus external factors that can impact the overall functional recovery of a building following a disaster. At the micro-level, functional recovery is contingent upon the interactive adaptability of users where users identify and prioritise essential building services and systems to facilitate functional recovery. The macro-level considers multi-faceted components that can influence the overall functionality of a building such as the building in-

infrastructure, culture, and building codes. The functionality of an individual building after an earthquake depends on external systems like access to utilities and transportation systems which can prevent a building from functioning ([28]; [57], [94]). For instance, even if a building sustains minor damages after an earthquake, a cordon of an entire neighbourhood or the damage to utility network can significantly impact the functional recovery of an individual building. Additionally, the decision-making process for post-earthquake functional recovery is profoundly influenced by cultural factors, particularly at the community level. The culture of a neighbourhood plays a crucial role in shaping the functional recovery of individual buildings, as the recovery of one structure is intricately connected to the recovery of others within the community [14,58]. Lastly, building codes and regulations can vary standards to expedite recovery processes like fast-tracking building permits for repairs and minimising cordon periods. The macro-level building system functionality extends beyond the scope of an individual structure, encompassing integrated systems and services, plus community culture designed to support functional recovery at the local level.

In contrast to countries like the United States (US), where the International Building Code is the main legislation addressing earthquakes, New Zealand (NZ) relies on the Building Act as its primary legislation for earthquake-related concerns. The NZ Building Code, in this context, serves as a secondary framework outlining specific functional requirements and performance criteria. Yet, the Building Code concentrates on protecting lives but does not explicitly tackle the functionality needed to maintain a building's operations after an earthquake. Nevertheless, there is a clear need to incorporate building functionality into the codes with building owners proactively retrofitting their buildings beyond the minimum code requirements (i.e. > 34%NBS) and the adoption of the low-damage seismic design (LDSD). Following the lengthy cordon of the 2010–2011 Canterbury earthquakes, the typical lease agreement would include clauses to protect tenants if their premises are inaccessible for extended periods with an option to terminate the lease. Apparently, businesses occupying modern office buildings desire a reasonable timeframe to return to their buildings after a major event.

The rationale behind the study lies within the context of the current literature where assessments of post-earthquake functional recovery are primarily driven by engineering approaches including computer simulations like agent-based models (ABM) along with assumptions, stochastic parameters, fault-tree analysis, and quantitative assessments [8–10,12,13]. However, these methods do not provide a holistic estimation of the post-earthquake functional recovery concept. As emphasised by Molina Hutt et al [10], despite the engineering approaches establishing the baseline requirements for the emerging post-earthquake functional recovery concept, the building performance alone is not enough. Researchers underscore the need for empirical data to comprehend real-world recovery processes and repair time such as planning and making decisions [13,14,98,99]. While structural integrity is crucial, certain decisions and recovery processes are not solely dictated by structural factors [100]. To improve the resilience and adaptability of buildings after an event, it is essential to expand the assessment of functionality by embracing a more comprehensive approach rooted in systems thinking. This study utilised the socio-technical systems (STS) theory to ensure the involvement of users in understanding a building's functionality, thereby promoting a practical post-earthquake functional recovery concept.

To integrate recovery-based objectives into building codes effectively, it is crucial to involve stakeholders such as building users as emphasised by Sattar et al [4]. This entails understanding the social context and considering how users perceive the functionality of buildings to facilitate functional recovery. Thus, this research is a bottom-up approach to foster user participation and engagement in the post-earthquake functional recovery concept. The essential building systems and services necessary for continuous operations or the recovery of buildings, along with external factors, will shape the functional recovery criteria to be incorporated into building codes. This approach will prevent the building industry and market from devising their own strategies but instead, promote a standardised practical framework that will contribute to achieving multi-hazard community resilience.

6. Conclusion

A holistic post-earthquake functional recovery concept will require multidisciplinary perspectives. Prior major earthquakes demonstrate significant business interruptions due to lengthy and restricted access to office buildings. Presently, occupants of modern office buildings need a considerable amount of time to return to their buildings after an event. This study conceptualises users' version of office building functionality for post-earthquake functional recovery.

While building experts particularly engineers are focused on the physical structure along with the technical components to determine the functionality of a building, users consider other factors including social context. Beyond the acceptable level of risk and safety that pertain to the physical structural performance, social factors include alignment with business goals and culture under the umbrella of "fit-for-purpose," the quality of space featuring modern fit-outs and technology, collaborative spaces that accommodate office work dynamics and branding. The structural forms, physical designs, and layouts of office buildings are shaped by the social considerations stemming from business needs.

The conventional concept of functional recovery primarily relies on the technical performance of buildings (engineering parameters). Nevertheless, this study adopts a more holistic approach grounded in bridging social and technical perspectives, thus socio-technical systems (STS) thinking. The STS was employed to formulate building-system functionality frameworks to consider social aspects that significantly influence functionality. In the context of post-earthquake functional recovery, which entails maintaining or repairing the operational aspects of buildings, the micro-level building-system framework examines the inherent interconnection between users and their buildings to determine functionality. This approach assists in recognising and prioritising essential building services and systems to expedite functional recovery. On the other hand, the macro-level framework considers external factors that can profoundly influence the overarching functional recovery of a building. This facilitates the efficient allocation of resources to address the most critical issues, thereby streamlining functional recovery efforts at the community level.

To achieve functional recovery and ensure effective risk reduction, the building-system functionality frameworks offer guidance for empirical studies that focus on engaging and involving building users. This proactive step creates a basis for understanding users'

perspectives and needs, which can be adapted and leveraged for different hazards, expediting recovery after a disaster. The user-input engagement brings a layer of social considerations that will enhance quantitative models and computer simulations within realistic timeframes. Ultimately, the involvement of users will build trust and confidence in the post-earthquake functional recovery concept when integrated into building codes.

Disclosure statement

There is no potential conflict of interest.

Funding

This project was (partially) supported by Te Hiranga Rū QuakeCoRE, an Aotearoa New Zealand Tertiary Education Commission-funded Centre. This is QuakeCoRE publication number 939.

CRedit authorship contribution statement

Sally Adofowaa Mireku Nkrumah: Conceptualization. **Olga Filippova:** Supervision. **Deborah Levy:** Supervision. **Fei Ying:** Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Sally Adofowaa Mireku Nkrumah reports financial support was provided by QuakeCoRE. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

- [1] C. Kenny, Why do people die in earthquakes? The costs, benefits and the Institutions of disaster risk reduction in developing countries, *World Bank Policy research working paper* 4823, 2009.
- [2] Y. Zhang, J.F. Fung, K.J. Johnson, S. Sattar, Review of seismic risk mitigation policies in earthquake-prone countries: lessons for Earthquake Resilience in the United States, *J. Earthq. Eng.* (2021) 1–28, <https://doi.org/10.1080/13632469.2021.1911889>.
- [3] A.W. Coburn, R.J.S. Spence, A. Pomonis, Factors determining human casualty levels in earthquakes: mortality prediction in building collapse, in: *Earthquake Engineering, Tenth World Conference, Balkema, Rotterdam, 1992*, pp. 5989–5994.
- [4] S. Sattar, K. Ryan, L. Arendt, D. Bonowitz, M. Comerio, C. Davis, G. Deierlein, K.J. Johnson, Recommended Options for Improving the Built Environment for Post-earthquake Re-occupancy and Functional Recovery Time, National Institute of Standards and Technology, Gaithersburg, MD, 2021 <https://doi.org/10.6028/NIST.SP.1254>, Special Publication (NIST SP).
- [5] EERI, *Functional Recovery: A Conceptual Framework with Policy Options*, 2019 (Issue 510).
- [6] P. Campbell, Proposed low damage design guidance - a NZ approach, in: 17th U.S.-Japan-New Zealand Workshop on the Improvement of Structural Engineering and Resilience, 2018, pp. 1–8 Retrieved from. <https://www.atcouncil.org/docman/atc-15-16-papers/154-p1-02-campbell/file>.
- [7] D.P. Tung, A.S. Lubell, G.R. Newfield, Prioritization of seismic retrofit using scoring system, in: Annual Conference, NZSEE, 2020, pp. 1–8 Retrieved from. <http://13.237.132.70/handle/nzsee/1716>.
- [8] V. Terzic, P.K. Villanueva, D. Saldana, D.Y. Yoo, Framework for modelling post-earthquake functional recovery of buildings, *Eng. Struct.* 246 (113074) (2021) 1–15, <https://doi.org/10.1016/j.engstruct.2021.113074>.
- [9] V. Terzic, K. Kolozvari, Probabilistic evaluation of post-earthquake functional recovery for a tall RC core wall building using F-Rec framework, *Eng. Struct.* 253 (113785) (2022) 1–15, <https://doi.org/10.1016/j.engstruct.2021.113785>.
- [10] C. Molina Hutt, A.M. Hulsey, P. Kakoty, G.G. Deierlein, A.E. Monfared, Y. Wen-yi, J.D. Hooper, Toward functional recovery performance in the seismic design of modern tall buildings, *Earthq. Spectra* 38 (1) (2022) 283–309, <https://doi.org/10.1177/87552930211033620>.
- [11] G. Cremen, E. Seville, J.W. Baker, Modeling post-earthquake business recovery time: an analytical framework, *Int. J. Disaster Risk Reduc.* 42 (2020) 101328, <https://doi.org/10.1016/j.ijdr.2019.101328>.
- [12] N. Mohammadgholibeyki, M.J. Echeverria, A. Safiey, D. Cook, M. Koliou, A.B. Liel, Assessing the feasibility of achieving functional recovery goals through seismic retrofit of existing reinforced concrete buildings, *Earthq. Spectra* 39 (4) (2023) 2123–2151. doi:10.1177/87552930231197669.
- [13] D.T. Cook, A.B. Liel, C.B. Haselton, M. Koliou, A framework for operationalizing the assessment of post-earthquake functional recovery of buildings, *Earthq. Spectra* 38 (3) (2022) 1972–2007, <https://doi.org/10.1177/87552930221081538>.
- [14] M.J. Echeverria, N. Mohammadgholibeyki, A.B. Liel, M. Koliou, Achieving functional recovery through seismic retrofit of existing buildings: barriers and opportunities, *J. Perform. Constr. Facil.* 37 (4) (2023) 04023027.
- [15] J.C. Vischer, Towards a user-centred theory of the built environment, *Build. Res. Inf.* 36 (3) (2008) 231–240, <https://doi.org/10.1080/09613210801936472>.
- [16] E. Allen, *How Buildings Work: the Natural Order of Architecture*, Oxford University Press, 2005.
- [17] R. Hills, D. Levy, Workspace design and fit-out: what knowledge workers value, *Property Manag.* 32 (5) (2014) 415–432, <https://doi.org/10.1108/PM-02-2014-0011>.
- [18] J.M. Kemp, K. Baker, *Building Community in Buildings: the Design and Culture of Dynamic Workplaces*, Praeger Publishers, 2007.
- [19] B.P. Haynes, Office productivity: a theoretical framework, *J. Corp. R. Estate* 9 (2) (2007) 97–110, <https://doi.org/10.1108/14630010710828108>.
- [20] B.P. Haynes, The impact of the behavioural environment on office productivity, *J. Facil. Manag.* 5 (3) (2007) 158–171, <https://doi.org/10.1108/14725960710775045>.
- [21] M. Hanc, C. McAndrew, M. Ucci, Conceptual approaches to wellbeing in buildings: a scoping review, *Build. Res. Inf.* 47 (6) (2019) 767–783, <https://doi.org/10.1080/09613218.2018.1513695>.
- [22] A. Leaman, B. Bordass, Productivity in buildings: the 'killer' variables, in: *Creating the Productive Workplace*, Taylor & Francis, 2006, pp. 181–208. <https://www.usablebuildings.co.uk/UsableBuildings/Unprotected/KillerProd.pdf>.
- [23] G.J. Raw, M.S. Roys, A. Leaman, Sick building syndrome, productivity and control, *Property J.*, 1993, pp. 17–19. <https://www.usablebuildings.co.uk/UsableBuildings/Unprotected/SBSProductivityControl.pdf>. (Accessed 20 April 2024).

- [24] R. Lowe, L.F. Chiu, T. Oreszczyn, Socio-technical case study method in building performance evaluation, *Build. Res. Inf.* 46 (5) (2018) 469–484, <https://doi.org/10.1080/09613218.2017.1361275>.
- [25] G. Vijverberg, Accommodation functionality assessment in office buildings, *Emerald Insight* 20 (3) (2002), <https://doi.org/10.1108/02632770210423803>.
- [26] R.J. Cole, J. Robinson, Z. Brown, M. O'shea, Recontextualizing the notion of comfort, *Build. Res. Inf.* 36 (4) (2008) 323–336, <https://doi.org/10.1080/09613210802076328>.
- [27] Ian Cooper, The socialization of building science: the emblematic journey of R. J. Cole, *Building Research & Information* 46 (5) (2018) 463–468, <https://doi.org/10.1080/09613218.2018.1400328>.
- [28] M. Aghababaei, M. Koliou, Community resilience assessment via agent-based modeling approach, *Comput. Aided Civ. Infrastruct. Eng.* 38 (7) (2023) 920–939.
- [29] N. Mohammadgholibeyki, M. Koliou, A.B. Liel, Assessing building's post-earthquake functional recovery accounting for utility system disruption, *Resilient Cities Struct.* 2 (3) (2023) 53–73, <https://doi.org/10.1016/j.rcns.2023.06.001>.
- [30] F. Becker, F. Steele, The total workplace, *Facilities* 8 (3) (1990) 9–14, <https://doi.org/10.1108/EUM0000000002099>.
- [31] W. Bordass, A. Leaman, Future buildings and their services, *Build. Res. Inf.* 25 (4) (1997) 190–195, <https://doi.org/10.1080/096132197370309>.
- [32] K. Alexander, The application of usability concepts in the built environment, *J. Facil. Manag.* 4 (4) (2006) 262–270, <https://doi.org/10.1108/14725960610702947>.
- [33] J.A. Granath, K. Alexander, A theoretical reflection on the practice of designing for usability, *European Facility Management Conference* (2006) 379–389.
- [34] L. Windlinger, D. Tuzcuoglu, Usability theory: adding a user-centric perspective to workplace management, in: *A Handbook of Management Theories and Models for Office Environments and Services*, Routledge, 2021, pp. 173–183.
- [35] L. Windlinger, S. Nenonen, K. Airo, Specification and empirical exploration of a usability concept in the workplace, *Facilities* 34 (11–12) (2016) 649–661, <https://doi.org/10.1108/F-01-2015-0003>.
- [36] K. Alexander, M. Fenker, J.A. Granath, T. Haugen, K. Vissanen, Useable workplaces, in: *International Council for Research and Innovation in Building and Construction (CIB) World Building Congress, Toronto, 2004*.
- [37] W.F.E. Preiser, Post-occupancy evaluation: how to make buildings work better, *Facilities* 13 (11) (1995) 19–28, <https://doi.org/10.1108/02632779510097787>.
- [38] B. Bordass, A. Leaman, Making feedback and post-occupancy evaluation routine 1: a portfolio of feedback techniques, *Build. Res. Inf.* 33 (4) (2005) 347–352, <https://doi.org/10.1080/09613210500162016>.
- [39] P.A. Jensen, A. Keith, A. Fronczek-Munter, Towards an agenda for user oriented research in the built environment, in: *6th Nordic Conference on Construction Economics and Organization*, 2011, pp. 55–56.
- [40] D. Bonowitz, Resilience criteria for seismic evaluation of existing buildings: a proposal to supplement ASCE 31 for intermediate performance objectives, in: *Improving the Seismic Performance of Existing Buildings and Other Structures*, 2009, pp. 477–488, [https://doi.org/10.1061/41084\(364\)44](https://doi.org/10.1061/41084(364)44).
- [41] L. Li, A. Chang-Richards, M. Boston, K. Elwood, C.M. Hutt, Post-disaster functional recovery of the built environment: a systematic review and directions for future research, *Int. J. Disaster Risk Reduc.* (2023), <https://doi.org/10.1016/j.ijdr.2023.103899>.
- [42] B. Hillier, A. Penn, Virtuoso circles, building sciences and the science of buildings: using computers to integrate product and process in the built environment, *Des. Stud.* 13 (3) (1994) 332–365.
- [43] Congressional Research Service (2023) Building Codes, Standards, and Regulations: Frequently Asked Questions. CRS Report R47665. <https://crsreports.congress.gov>.
- [44] IBC, *International Building Code*, International Code Council, Washington, DC, 2021.
- [45] A. Nwadike, S. Wilkinson, C. Clifton, Comparative insight on building code paradigm shift practice and updates: International perspectives, *International Conference on Civil, Structural and Transportation Engineering* (2019), <https://doi.org/10.11159/iccste19.143>.
- [46] New Zealand Building Code, *Building Regulations* (1992) SR 1992/150.
- [47] S. Sattar, M. Mahoney, R. Kersting, J. Heintz, K. Johnson, L. Arendt, C. Davis, P. Scott, L. Abrahams, Recommended options for improving the functional recovery of the built environment. 17th World Conference on Earthquake Engineering, 17WCEE, Paper No C002378, 2020, pp. 1–11.
- [48] M.C. Davis, D.J. Leach, C.W. Clegg, The physical environment of the office: contemporary and emerging issues, in: G.P. Hodgkinson, J.K. Ford (Eds.), *International Review of Industrial and Organizational Psychology*, Wiley, 2011, pp. 193–235 26.
- [49] Z.W. Tomblinson, C.J. Dawson, T. Yeow, S. Khakurel, R. Dhakal, Quantifying downtime due to building demolitions in Christchurch. 2018 New Zealand Society for Earthquake Engineering (NZSEE) Conference, 2018. <https://ir.canterbury.ac.nz/server/api/core/bitstreams/0e78c5c0-8fae-4dce-a592-13dc6d0b5343/content>.
- [50] S. Hogg, *Moving to Low-damage Design*, Auckland, New Zealand, 2013.
- [51] Bruneau, G. MacRae, *Reconstructing Christchurch: A Seismic Shift in Building Structural Systems*, 2017 Canterbury, New Zealand.
- [52] J.J.I. Scheffer, B.P. Singer, M.C.c. Van Meerwijk, Enhancing the contribution of corporate real estate to corporate strategy, *J. Corp. R. Estate* 8 (4) (2006) 188–197, <https://doi.org/10.1108/14630010610714862>.
- [53] M.J. Bitner, Servicescapes: the impact of physical surroundings on customers and employees, *Source: J. Market.* 56 (Issue 2) (1992).
- [54] D. Ho, G. Newell, A. Walker, The importance of property-specific attributes in assessing CBD office building quality, *J. Property Invest. Finance* 23 (5) (2005) 424–444, <https://doi.org/10.1108/14635780510616025>.
- [55] R.P. Dhakal, Damage to non-structural components and contents in 2010 Darfield Earthquake, *Bull. N. Z. Soc. Earthq. Eng.* 43 (4) (2010) 404–411.
- [56] C.A. Kircher, A.A. Nassar, O. Kustu, W.T. Holmes, Development of building damage functions for earthquake loss estimation, *Earthq. Spectra* 13 (4) (1997).
- [57] P.J. May, Societal perspectives about earthquake performance: the fallacy of "Acceptable Risk", *Earthquake Spectra* 17 (4) (2001) 725–737.
- [58] G. Inalhan, Attachments: the unrecognised link between employees and their workplace (in change management projects), *J. Corp. R. Estate* 11 (1) (2009) 17–37, <https://doi.org/10.1108/14630010910940534>.
- [59] J.M. McCoy, Linking the physical work environment to creative context, *J. Creativ. Behav.* 39 (3) (2005) 167–189, <https://doi.org/10.1002/j.2162-6057.2005.tb01257.x>.
- [60] Bayleys, Insights and data. Office market update, Auckland CBD Q1, <https://cms-cdn.bayleys.co.nz/00000000-0000-0000-0000-000000000000/892b88e5-c9e0-4cef-a615-64701c456ee2/a9b5c111-3ad6-47db-ac07-3012a9703f55/Auckland-CBD-report-0805.pdf>, 2023. (Accessed 31 October 2023).
- [61] B. Haynes, I. Price, Quantifying the complex adaptive workplace, *Facilities* 22 (2004) 8–18, <https://doi.org/10.1108/02632770410517906>.
- [62] JLL, New Zealand office sentiment survey, <https://www.jll.nz/en/trends-and-insights/research/2023-new-zealand-office-sentiment-survey>, 2023. (Accessed 16 February 2024).
- [63] H. Jan van Ree, The added value of office accommodation to organisational performance, *Work. Stud.* 51 (7) (2002) 357–363, <https://doi.org/10.1108/00438020210449012>.
- [64] McCluskey, D. McCluskey, L.C. Lim, M. McCord, P.T. Davis, et al., Commercial leases in the UK regions: business as usual? *Journal of Corporate Real Estate* 18 (4) (2016) 227–253. <https://doi.org/10.1108/JCRE-12-2015-0048>.
- [65] J. Faulconbridge, N. Cass, J. Connaughton, How market standards affect building design: the case of low energy design in commercial offices, *Environ. Plann.: Econ. Space* 50 (3) (2018) 627–650, <https://doi.org/10.1177/0308518X17752681>.
- [66] W. Szarejko, E. Trocka-Leszczynska, Aspect of functionality in modernization of office buildings, *Emerald Insight* 25 (3/4) (2007) 163–170, <https://doi.org/10.1108/02632770710729755>.
- [67] M.M. Wells, L. Thelen, J. Ruark, Workspace personalization and organizational culture: does your workspace reflect you or your company? *Environ. Behav.* 39 (5) (2007) 616–634, <https://doi.org/10.1177/0013916506295602>.
- [68] K.J. Watson, J. Evans, A. Karvonen, T. Whitley, Re-conceiving building design quality: a review of building users in their social context, *Indoor Built Environ.* 25 (3) (2016) 509–523, <https://doi.org/10.1177/1420326X14557550>.
- [69] Applied Technology Council (ATC), *Seismic Performance Assessment of Buildings. Volume 8 – Methodology for Assessment of Functional Recovery Time, Preliminary Report*, 2021.
- [70] D.M. Heeroma, F.W. Melissen, M.B. Stierand, The problem of addressing culture in workplace strategies, *Facilities* 30 (7/8) (2012) 269–277, <https://doi.org/>

- 10.1108/02632771211220077.
- [71] L. Von Bertalanffy, An outline of general system theory, *Br. J. Philos. Sci.* 1 (2) (1950) 134–165.
- [72] D. Cabrera, L. Cabrera, E. Powers, A unifying theory of systems thinking with psychosocial applications, *Syst. Res. Behav. Sci.* 32 (5) (2015) 534–545, <https://doi.org/10.1002/sres.2351>.
- [73] D. Cabrera, L. Colosi, C. Lobdell, *Systems thinking, Evaluation and program planning* 31 (3) (2008) 299–310.
- [74] E. Trist, The evolution of socio-technical systems: a conceptual framework and an action research program, *Occas. Pap.* 2 (1981) 1–67 doi.org/10.1002/0-7743-6286-3.
- [75] G. Walker, Come back sociotechnical systems theory, all is forgiven, *Civ. Eng. Environ. Syst.* 32 (1–2) (2015) 170–179, <https://doi.org/10.1080/10286608.2015.1024112>.
- [76] R.P. Bostrom, J.S. Heinen, MIS problems and failures: a socio-technical perspective. Part 1: the causes, *MIS Q.* 1 (3) (1977) 17–32, <https://doi.org/10.2307/248710>.
- [77] R. Oosthuizen, C. Van't Wout, Sociotechnical system perspective on artificial intelligence implementation for a modern intelligence system, *International Command and Control Research and Technology Symposium (24th ICCRTS)* (2019) 1–13.
- [78] R. Cooper, M. Foster, Sociotechnical systems, *Am. Psychol.* 26 (5) (1971) 467–474, <https://doi.org/10.4018/jskd.2011010101>.
- [79] R. Challenger, C.W. Clegg, Crowd disasters: a sociotechnical systems perspective, *Contemp. Soc. Sci.* 6 (3) (2011) 343–360, <https://doi.org/10.1080/21582041.2011.619862>.
- [80] H.P.N. Hughes, C.W. Clegg, L.E. Bolton, L.C. Machon, Systems scenarios: a tool for facilitating the socio-technical design of work systems, *Ergonomics* 60 (10) (2017) 1319–1335, <https://doi.org/10.1080/00140139.2017.1288272>.
- [81] C.W. Clegg, M.A. Robinson, M.C. Davis, L.E. Bolton, R.L. Pieniasek, A. McKay, Applying organizational psychology as a design science: a method for predicting malfunctions in socio-technical systems (PreMISTS), *Des. Sci.* 3 (2017) 1–31, <https://doi.org/10.1017/dsj.2017.4>.
- [82] M.C. Davis, R. Challenger, D.N.W. Jayewardene, C.W. Clegg, Advancing socio-technical systems thinking: a call for bravery, *Appl. Ergon.* 45 (2014) 171–180, <https://doi.org/10.1016/j.apergo.2013.02.009>.
- [83] T. Naumann, Theory of social systems engineering, in: *DS 84: Proceedings of the DESIGN 2016 14th International Design Conference, 2016*, pp. 45–56.
- [84] P. Kroes, M. Franssen, I.V.D. Poel, M. Ottens, Treating socio-technical systems as engineering systems: some conceptual problems, *Syst. Res. Behav. Sci.* 23 (6) (2006) 803–814, <https://doi.org/10.1002/sres.703>.
- [85] E. Mumford, A socio-technical approach to systems design, *Requir. Eng.* 5 (2000) 125–133, <https://doi.org/10.1007/PL00010345>.
- [86] E. Shove, H. Chappells, L. Lutzenhiser, HacOctober, Comfort in a lower carbon society, *Build. Res. Inf.* 36 (4) (2008) 307–311, <https://doi.org/10.1080/09613210802079322>.
- [87] L.F. Chiu, R. Lowe, R. Raslan, H. Altamirano-Medina, J. Wingfield, A socio-technical approach to post-occupancy evaluation: interactive adaptability in domestic retrofit, *Build. Res. Inf.* 42 (5) (2014) 574–590, <https://doi.org/10.1080/09613218.2014.912539>.
- [88] P. Morgenstern, R. Lowe, L.F. Chiu, Heat metering: socio-technical challenges in district-heated social housing, *Build. Res. Inf.* 43 (2) (2015) 197–209, <https://doi.org/10.1080/09613218.2014.932639>.
- [89] E. Navarro-Bringas, G. Bowles, G.H. Walker, Embracing complexity: a sociotechnical systems approach for the design and evaluation of higher education learning environments, *Theor. Issues Ergon. Sci.* 21 (5) (2020), <https://doi.org/10.1080/1463922X.2020.1723037>.
- [90] K. Terumoto, Y. Tsuchiya, R. Otagiri, H. Nakabayashi, I. Nakabayashi, Individual disaster recovery: a framework in the long-term recovery process after the Great East Japan Earthquake, *Int. J. Disaster Risk Reduc.* 60 (2021) 102280, <https://doi.org/10.1016/j.ijdrr.2021.102280>.
- [91] V. Shllaku, Factors that contributed to the failure of the Pruitt-Igoe housing, UBT International Conference 356 (2020), <https://doi.org/10.33107/ubtic.2020.28>, https://knowledgecenter.ubt-uni.net/conference/2020/all_events/356.
- [92] N.A.A. Lah, M. Saruwono, Analysing functional performance of commercial premises using metaphysical approach and standard commercial guidelines (SCG), *Pertanika J. Soc. Sci. Humanit.* 25 (2017) 59–70.
- [93] A. Leaman, B. Bordass, Productivity in buildings: the ‘killer’ variables, *Build. Res. Inf.* 27 (1) (1999) 4–19, <https://doi.org/10.1080/096132199369615>.
- [94] J. Buckalew, A. Lang, R. Mayes, K. Wade, SEAOC Resilience Committee Update and Report to the Membership, 2019.
- [95] *Building Act, New Zealand Building Act 2004*, 2004.
- [96] G. Campbell, Ministry of Education staff working from home after quake risk found in building, *NZ Herald*, 2022. <https://www.newstalkzb.co.nz/news/wellington/ministry-of-education-staff-working-from-home-after-quake-risk-found-in-building>. (Accessed 20 April 2024).
- [97] S.E. Chang, J.E. Taylor, K.J. Elwood, E. Seville, D. Brunson, M. Gartner, Urban disaster recovery in Christchurch: the central business district cordon and other critical decisions, *Earthq. Spectra* 30 (1) (2014) 513–532.
- [98] M.C. Comerio, Estimating downtime in loss modeling, *Earthq. Spectra* 22 (2) (2006) 349–365, <https://doi.org/10.1193/1.2191017>.
- [99] J. Mitrani-Resier, S. Wu, J.L. Beck, Virtual Inspector and its application to immediate pre-event and post-event earthquake loss and safety assessment of buildings, *Natural hazards* 81 (2016) 1861–1878.
- [100] F. Marquis, J.J. Kim, K.J. Elwood, S.E. Chang, Understanding post-earthquake decisions on multi-storey concrete buildings in Christchurch, New Zealand, *Bull. Earthq. Eng.* 15 (2017) 731–758, <https://doi.org/10.1007/s10518-015-9772-8>.