Canadian Conference - Pacific Conference on Earthquake Engineering 2023
Vancouver, British Columbia
June 25th – June 30th, 2023

Twelve Years on: Christchurch's Recovery from the 2010/2011 Canterbury Earthquakes

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ABSTRACT

What does the recovery of Christchurch, New Zealand's garden city, look like twelve years on from the 2010/2011 Canterbury earthquake sequence? And what lessons has its long-term recovery offered? To answer these questions, a field trip to Christchurch and in-depth interviews with policymakers, engineering professionals and other recovery practitioners were undertaken in October 2022. The recovery state of Christchurch Central Business District (CBD) was observed. Interviews revealed lessons from CBD's recovery from a longitudinal, retrospective perspective. There was a consensus that between 70 per cent to 80 per cent of damaged buildings in CBD had been repaired or replaced for other functions. Significant delays can be attributed to 1) the scale of the event, with tens of thousands of aftershocks and widespread demolitions in CBD, 2) the delayed decision-making process, 3) overwhelmed legal changes, and 4) limited resource availability. Moreover, it is found that building resilience was emphasised and well incorporated in architectural designs to ensure redundancy provided in newly constructed and retrofitted buildings in CBD. Such consideration also incurred the broad adoption of low-damage designs (e.g., base isolation), despite a slightly higher repair cost. Further, this paper also investigated the effectiveness of recovery agencies and affirmed their essential role in recovery. While New Zealand is proactively preparing for major seismic events such as the Magnitude 8.0 Alpine Fault earthquake (AF8), lessons elicited from Christchurch recovery included the necessity of available training programmes for engineers, a stronger emphasis on building resilience in engineering design, a need for functionality-focused building code, and the development of advanced National Seismic Hazard Model (NSHM) specific to New Zealand. It is hoped that these lessons can collectively translate into enhanced earthquake preparedness and resilience in the future.

Keywords: 2010/2011 Canterbury earthquake sequence, building recovery, building resilience, impeding factors, post-earthquake recovery

INTRODUCTION

Large-scale earthquakes often cause devastating impacts on human society. The February 22nd 2011 Christchurch earthquake, the deadliest aftershock following the September 4th 2010 earthquake, took a great toll on New Zealand. It caused the loss of 185 lives, more than 7,000 injured people, and an estimated $NZD 40 billion in losses [1]. The heavily affected Central Business District (CBD) was cordoned off over two years [2]. The continued aftershocks and costly repair resulted in the demolition of approximately 60% of multi-storey reinforced concrete buildings (3 stories and up) [3]. Since the February 22nd aftershock, there have been thousands of aftershocks recorded [4, 5], as indicated in Figure 1. These aftershocks have further increased the vulnerability of the affected communities and added to the challenges of the recovery process. The uniqueness of this Canterbury earthquake sequence included 1) though the 2010 M7.1 Darfield earthquake only had moderate ground shaking, its subsequent aftershock M6.3 Christchurch earthquake was centred just 8 km from the Christchurch CBD and produced the strongest ground shaking recorded worldwide at the time [6]; 2) the February 22nd earthquake triggered rock fall, cliff collapse, and severe urban liquefaction over large areas of Greater Christchurch, causing the significant disruptions to both infrastructure and building systems; and 3) the unprecedented number of insurance claims and huge financing losses of approximately NZD $40 billion (USD 28 billion), the equivalent of almost 20% of New Zealand's gross domestic product

(GDP), making it the biggest insured event in Aotearoa New Zealand history and at the time the 4th most expensive insured, global natural disaster ever to occur [7].

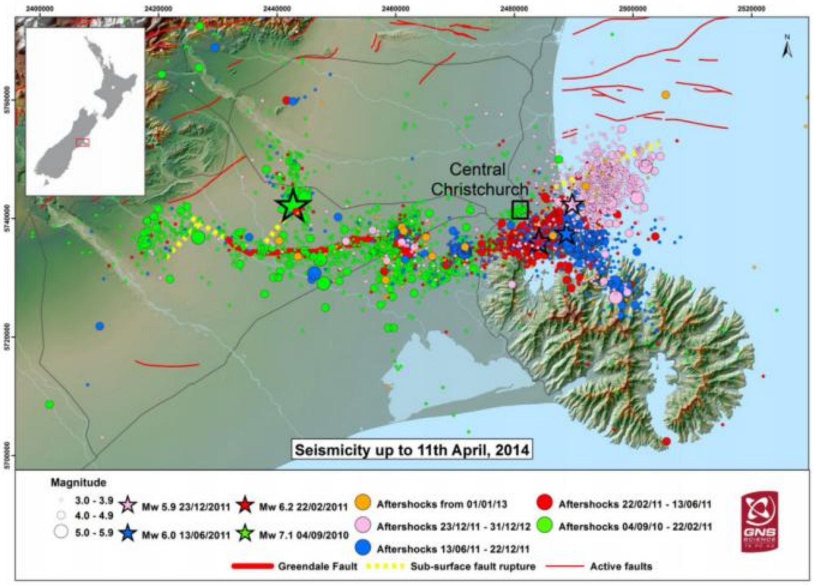


Figure 1. Aftershocks after the 2010 Darfield earthquake (Source: Robert Langridge, GNS Science, 2014).

Following the 2011 Christchurch earthquake, the government quickly established the Canterbury Earthquake Recovery Authority (CERA) under the Canterbury Earthquake Recovery (CER) Act 2011 to lead and coordinate the recovery of the region. In accordance with CERA's lead role in recovery, the Christchurch Central Development Unit (CCDU) was formed to aid the recovery and renewal of the city by planning and executing anchor projects and precincts [8]. Extensive collaboration was carried out between the government and private sectors. Meanwhile, recovery plans were also devised to outline the blueprint and guidelines for a more connected and resilient Christchurch, including the Christchurch Central Recovery Plan. Despite various recovery efforts aimed at expediting the restoration of Christchurch, the restoration is still underway unexpectedly.

Learning from the past is essential in enhancing both community resilience and building resilience in the long term. Following the earthquakes, a variety of research has been undertaken to provide a comprehensive overview and understanding of 1) the underlying mechanisms that resulted in such dramatic damage to both infrastructure systems and buildings in Christchurch [9-11], 2) the response of the government and non-government organisations (NGOs), 3) the effectiveness of associated recovery plans and policies [1, 8, 12-14], and 4) the challenges and issues emerged during the restoration process [15-17]. Despite significant advancements in post-earthquake recovery research, a gap between research and recovery practices still exists, and delayed recovery efforts continue to persist [18]. A longitudinal study is needed to offer a retrospective review of the past recovery efforts and reveal the elements that dominated the delayed reconstruction activities over a decade, which can act as a catalyst for improving recovery practices by identifying areas for improvement and informing future research on post-disaster recovery. Surprisingly, following over a decade of research on the 2010/2011 Canterbury earthquake sequence, there has been a dearth of a retrospective longitudinal study in place. To fill this gap, a field trip was carried out to Christchurch CBD from 5th to 12th October 2022, with a specific emphasis on the buildings located in Christchurch CBD. The purpose was to elicit the most crucial lessons and experiences in recovering the most severely damaged district following the 2010/2011 Canterbury earthquake sequence. Specifically, this research aspires to 1) present an overview of the reconstruction progress of Christchurch CBD to date, 2) identify crucial factors that play out to cause the time delay in CBD reconstruction, and 3) elicit insightful lessons for building resilience to future earthquakes.

LITERATURE REVIEW

Earthquakes are usually perceived with catastrophic consequences, such as casualties, damage to structures, and economic disruption. While code-compliant buildings preserve life and reduce injuries, past earthquakes have highlighted that building performance is inadequate to ensure the seismic resilience of the community in terms of recovery time [19]. For instance, after the Northridge earthquakes in 1994, 33% of the damaged multi-family housing units took more than 2 years to complete repairs [20]. 2 years after the Haiti earthquake in 2010, only 5% of damaged buildings (roughly 10,000) had been repaired, and the remaining requires years to be full recovery [21]. Clearly, the current restoration progress is a far cry from the community's expectation of promptly returning to the pre-earthquake state.

Concentrated research has approached the mechanism and factors for the sluggish pace of recovery. Table 1 provides a concise summary of the factors that contribute to prolonged recovery. Concentrated research has revealed the significant delays resulting from impeding factors before the repairs, which comprise building inspection, engineering mobilisation, financing, contractor mobilisation, and permitting [19, 22, 23]. A detailed description of these impeding factors can refer to Almufti and Willford [24]. With a deeper understanding of potential mechanisms that delayed the restoration, more socio-economic factors (e.g., cordon and resource availability) are recognised to have huge influences on the overall recovery pace. Instead of oversimplifying the impeding factors within recovery frameworks, it is essential to acknowledge that impeding factors can arise at any stage of the recovery process. Literature has affirmed that factors, such as sociocultural characteristics of the community, effectiveness of recovery organisations [25], and released recovery strategies and policies [17, 26], can collectively affect the construction mode and recovery pace in a way [2, 14].

Table 1. Summarised impeding factors associated with the prolonged recovery process.

Source	Building inspection	Engineering mobilisation	Financing	Contractor mobilisation	Permitting	Decision-making	Other factors
[24]	√	√	√	√	√		
[22]	√	√	√	√	√		
[19]	√	√	√	√	√		
[23]	√	√	√	√	√		
[6, 27-29]	√						
[8]			√			√	
[2, 14]						√	
[25]							Effectiveness of recovery organisations
[17, 26]							Recovery strategy and policy

Furthermore, the recovery pace heavily relies on collective decision-making from both the government and NGOs. Critical decisions (e.g., land zone planning and cordon) can directly affect the construction mode and recovery progress. Underwood and Orchiston [30] and Chang and Taylor [8] examined the underlying mechanisms that led to the establishment of cordons after an earthquake and underscored the impact that recovery organisations and recovery policies can have on expediting post-earthquake recovery. Moreover, Butters [25] illustrated the significance of emergent groups' response in providing essential relief measures during the initial stage of recovery. Chang-Richards and Wilkinson [13] analysed the governance structures of different recovery agencies after the 2010/2011 Canterbury earthquake sequence, which contributed to an improved understanding of what an effective post-earthquake recovery organisation should entail in accelerating the restoration process. In addition, decisions at the governmental level, such as the setting of building code regulations and legislation changes that followed the earthquake also play an important role in the long-term recovery [5, 8]. Particularly, a lack of specific regulations on repairable buildings after 2011 Christchurch earthquake incurred a further extensive evaluation and upgrade of the fire alarm systems and accessibility features, which not only delayed the restoration but also resulted in a substantial repair cost [1, 6].

RESEARCH METHODOLOGY

This research conducted a field trip to Christchurch CBD in October 2022. Data have been collected through field-based observations, interviews, and other qualitative records. When recruiting participants for the interview, two main criteria were utilised: 1) only individuals who had been deeply involved in rebuilding Christchurch CBD were targeted, and 2) participants were selected from diverse backgrounds, such as engineering companies, universities, and various sectors of government agencies, to provide a comprehensive perspective from different stakeholders. In the end, twelve semi-structured interviews were conducted covering the topics of recovery status, reconstruction activities, critical decisions, recovery agencies, encountered challenges and other emerging issues that arose during the rebuild. Specifically, information collected from interviewees included 1) their opinions about the current restoration progress of CBD, 2) their perceptions on factors and mechanisms that caused such time delay in CBD, and 3) some personal stories they shared and lessons they have learned in terms of a more resilient built environment against future earthquakes. Table 2 presents the profile of the interviewees. Additionally, two field observations were conducted around the CBD guided by two interviewees (P4 and P6). Ethics for data collection were approved by the University of Auckland Human Participants Ethics Committee with reference number 19141.

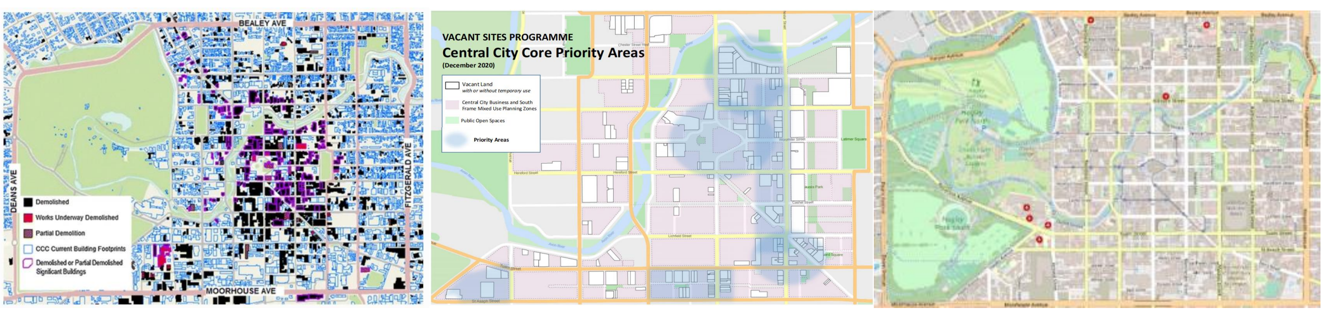
Table 2. Profile of the interviewees.

Role/Type of organisation	Interviewee Code	Role/Work description in the reconstruction progress
Central government agency	P3	Building damage inspection and the construction of a playground.
	P4	School building damage inspection and providing consultation of damaged structures.
	P5	Collecting and analysing various restoration data during the recovery.
	P12	Supplying necessary construction materials on site.
Local government agency	P9	Reconstruction of damaged water utilities.
Contractor	P10	Reconstruction of various infrastructure systems (e.g., roads).
Engineering consultancy	P6	Building damage inspection and assessment, architectural design, and reconstruction of several damaged commercial and residential buildings.
Material supplier	P11	Supplying necessary construction materials on site.
Researcher	P1-P2	Determine societal expectations regarding the seismic performance of buildings.
	P8	Building damage inspection and assessment and architectural design.

RESULTS

Recovery status of Christchurch CBD

The Christchurch CBD includes approximately 110 city blocks bounded by four avenues: Deans, Bealey, Fitzgerald, and Moorhouse. At the time of the earthquakes, there were approximately 3,000 buildings within the CBD, consisting primarily of commercial, light industrial, and residential buildings [31]. It is reported that a total of 984 buildings were partly or fully demolished in CBD by September 2013 [32], and over 60% of concrete buildings with 3+ stories in CBD were demolished [33]. Through interviewing engineers, contractors and academic staff in Christchurch CBD, an important finding was that participants consistently believed the current recovery status in CBD was reasonably good. Most buildings (70%~80%) had been repaired or rebuilt (see Figure 2), and most Anchor projects and Precinct has been successfully delivered, such as South Frame, Bus Interchange, Central City Transport Project, Canterbury Earthquake National Memorial, and Te Pae Christchurch Convention Centre, though there are still lots of vacant areas in CBD. Based on the significant progress achieved so far, the majority of interviewees thought that the restoration efforts in Christchurch were advancing well.



(a) (b) (c)

Figure 2. Comparison of buildings in CBD at the different timelines of the recovery: (a) Overview of building demolitions in Christchurch CBD-November 2014. (Figure from Marquis and Kim [1]), (b) Vacant sites in Christchurch CBD on December 2020. (Source: CCC), (c) Overview of buildings in Christchurch CBD in April 2023 (Source: OpenStreetMap).

A variety of interview questions have been further designed to reveal factors contributing to the delayed restoration activities. A predominant impeding factor for delayed building repairs can still be attributed to insurance today. Unlike other countries, New Zealand has comprehensive insurance penetration/coverage for commercial and residential structures. Approximately 80% of the losses in the 2010/2011 Canterbury earthquake sequence were covered by insurance [1]. The heavy reliance on insurance payment can unavoidably shape the pace of recovery as construction activities can only be initiated and continuously conducted if finance is available. It is found that significant time has been taken on the negotiations about the damage and payments by the insurance companies, and the negotiations to settle the disparity items caused by the continued aftershocks have even been more time-consuming.

Though the current recovery status is reasonably good, some buildings are still left unoccupied and have fallen into a state of disrepair. Even some buildings are regarded as barriers that hinder the regeneration of the central city [34]. Through the interviews with P4, P3, and P6, this research confirmed that decision-making played an essential role in restoring buildings in Christchurch CBD. For example, Cathedral has been put aside for an extended period of time due to disagreement among different stakeholders. The decision-making on Cathedral even takes much longer to settle numerous coordinating issues and determine a satisfactory restoration plan. Surprisingly, the restoration of the surrounding buildings was also impacted by the status of the Cathedral. Stakeholders are more cautious about repairing their buildings if the adjacent landmark building remains unrepaired. The influence of adjacent buildings became a crucial impeding factor in the decision-making process. It is worth noting that the reinstatement of Christchurch Cathedral has started recently, though it might take another several years to complete all construction activities, as is indicated in Figure 3.

(a) *(b)*

Figure 3. The repairs of Christchurch Cathedral: (a) Construction activities on the facade of the Cathedral (Courtesy of Lianyan Li), (b) Construction activities on the sides of the Cathedral (Courtesy of Beth Mayer).

Building resilience

Witnessed significant damage sustained by buildings in the aftermath of the 2010/2011 Canterbury earthquakes, construction practices have paid extreme attention to the seismic performance of existing and new buildings. In order to have more resilient buildings against future earthquakes, the government released a new Earthquake Prone Building Policy in 2013, which clearly stated that every building should be assessed within a very precise timeframe (5 years at the latest) and buildings below 33% of the New Building Standard are required to be strengthened (within 15 years from the new policy) above that level [35]. The implementation of this regulation can effectively enhance the seismic performance of the existing building. However, it is unlikely that any insurers will fund improvements significantly greater than 33% [36], which was further confirmed by P3, P4, P6, and P8. A lack of appropriate implementation and supporting measures will be hard to bring those envisions into reality.

Through the interviews, most participants believed the legislative changes were effective in embracing the enhanced building resilience in the long term. Specifically, the seismic hazard factor for the Canterbury region was increased from 0.22 to 0.3 after the earthquakes to account for increased seismic activity within an estimated 10-20 year period after the February 2011 earthquake [37]. This regulation informs the higher seismic safety for new or future retrofitted buildings and affects the design and construction of most public and commercial buildings, particularly in Christchurch CBD. Also, P6 confirmed the concept of redundancy received more attention after the earthquake. For example, base-isolation was broadly adopted in newly constructed buildings to ensure sufficient redundancy against future disasters, such as the Art gallery (see Figure 4). With redundancy better conveyed to construction practices, buildings are more capable of satisfying functional requirements in the event of a disruption, degradation, or loss of functionality [38]. However, how to add redundancy to components that are most likely to fail in the building based on its design has not reached a uniform agreement so far.

(a) *(b)*

Figure 4. Christchurch Art Gallery: (a) Base-isolators in the underground parking garage (Courtesy of Beth Mayer), (b) Amplification details of base-isolators (Courtesy of Beth Mayer).

In the aftermath of the 2010/2011 Canterbury earthquakes, another essential consideration regarding building resilience is to specify requirements for building function and the recovery timeframe before initiating repair or rebuild activities. Specifically, P4 confirmed that new school buildings must remain usable after significant earthquake shaking (SLS2) now. Damage is allowed, but repairs must be able to be carried out within reasonable timeframes (e.g., school holiday periods: 2 – 8 weeks) and have no impact on safety or access and egress [39]. Notably, the consideration of easy repairs and easy access is demonstrated in various guidelines to facilitate the restoration in case of hazards [40].

Low-damage design

In order to prevent significant damage from occurring again, low-damage designs have been adopted broadly due to their high seismic performance. As such, newly constructed buildings in the Christchurch CBD feature a range of structural forms, including seismic isolation, buckling restrained braces (BRB) frames, traditional moment-resisting frames (MRFs), and MRFs with reduced beam sections. In this context, some interview questions were devised to gather the opinions of stakeholders regarding the advocacy of low-damage design. P3, P4, P6, and P8 indicated that there was a substantial perceptional shift for the community to accept low-damage designs with slightly higher repair costs, even though the government did not mandate the use of low-damage technologies.

One of the Anchor projects that used low-damage design is the new Christchurch central library Tūrang (see Figure 5), which was constructed with modern low-damage technology by incorporating a dual seismic resisting system, primarily consisting of an integrated, self-centring mechanism in the form of hybrid concrete shear walls that can rock to isolate the building from peak earthquake accelerations [41].

(a) *(b)*

Figure 5. Tūranga Library: (a) Interior of the library (Courtesy of Lianyan Li), (b) Global view (Courtesy of Beth Mayer).

Through interviewing with P3, P4, P6, and P8, participants consistently believed that the use of base-isolation systems was more prevalent in newly constructed buildings compared to other low-damage designs. Two typical buildings during the observational tours are 151 Cambridge Terrace and Awly building. Both buildings used a base-isolation system, as indicated in Figure 6 and Figure 7. 151 Cambridge Terrace is the first building in New Zealand to incorporate Triple Pendulum base isolation bearings into its design, making it one of the most earthquake-resilient buildings in the country. Specifically, its bearings were supported on concrete columns from the concrete foundation. The supporting structure is a steel frame throughout, except for the beams framing the parking ramp that provides access to the lower level.

(a) *(b)*

Figure 6. 151 Cambridge Terrace: (a) Global view (Courtesy of Lianyan Li), (b) Base-isolator (Courtesy of Mark Willard).

Located on the southwest corner of Durham Street North and Armagh Street, Awly building is the first building in the post-earthquake city to achieve a 5-star rating from the New Zealand Green Building Council (NZGBC) [42]. Unlike 151 Cambridge Terrace, it adopted a hybrid structure to satisfy specific seismic requirements (see Figure 7). It is equipped with base isolators to reduce swaying and shaking and limit damage to the building. Meanwhile, it is coupled with diagonal seismic bracing, visible through the high-performance façade, for lateral stability.

(a) *(b)*

Figure 7. Awly Building: (a) Global view (Courtesy of Lianyan Li), (b) Hybrid structure during construction in March 2016 (Courtesy of Mark Willard).

Involvement of public agencies

To inform the development of more efficient recovery agencies after disasters, it is crucial to retrospect the effectiveness of recovery agencies by integrating perspectives from different stakeholders. In the early emergency response stage, the Canterbury Earthquake Recovery Authority (CERA) was established as the central recovery agency to lead and coordinate the recovery effort. A variety of public agencies are involved regarding different structures, such as housing and infrastructure [13]. A summary of involved public agencies is delineated in Table 3.

Table 3. Summary of involved public agencies.

Sector	Leading agency
Overall recovery governance	Canterbury Earthquake Recovery Authority (CERA)
Housing	Earthquake Commission (EQC) and commercial insurers, and their Project Management Offices (PMOs)
Infrastructure	Stronger Christchurch Infrastructure Rebuild Team (SCIRT)
Commercial buildings in the CBD	Christchurch Central Development Unit (CCDU) Christchurch City Council (CCC)

Several interview questions were devised to ascertain the perspectives of professionals regarding the effectiveness of those agencies' responses to earthquakes. Consistently, P1, P2, P3, P6, and P8 confirmed the imperative role of CERA in the initial six months of recovery. In particular, CERA successfully coordinated different recovery efforts by developing an overarching recovery strategy and completed the critical work of assessing buildings, cordoning off the red zone, and demolishing unfit buildings [26]. However, P3 and P8 pointed out that CERA was clearly overwhelmed later due to the legislation loopholes exposed in the Canterbury Earthquake Recovery Act (CER Act) and the continuous intervention of ministers. Further, EQC was created by the government to serve as the leading agency that provides insurance coverage. It is important to note that many building owners had to secure coverage with their insurance company when the value of their possessions exceeded the maximum amount of EQC coverage [13]. This mechanism has shaped the way of undertaking the repairs and rebuilds of residential housing post-earthquake and dominated the recovery speed in a way. It was widely acknowledged that both EQC and their PMOs played a significant role in the reconstruction of Christchurch. However, most participants (6 out of 12, 50%) believed EQC did not perform well later due to the complex assessment processes resulting from repeated aftershocks, which accounted for a significant delay in recovery.

In addition, SCIRT was established to be responsible for infrastructure repairs and rebuilds. P3, P8 and P9 believed SCIRT had performed well in delivering emergency repairs following the earthquake. SCIRT adopted the alliance model as the governance structure, which proved to be efficient in coordinating the widespread collaboration between clients, consultants, and contractors. Furthermore, CCDU was put in place to ensure the implementation of the blueprint plan. The role of CCDU in rebuilding Christchurch is controversial. On the one hand, P3 and P6 believed that the blueprint plan implemented by CCDU did not completely incorporate local knowledge and it was a total reflection of political views that resulted in the wipe-out of some buildings in Christchurch CBD, though community engagement can be found in a few projects, such as Margaret Mahy Playground, where CCDU ran a playground design competition to make the design fully incorporated with the ideas of all end-users (children) when determining the conceptual design of the playground [43]. Another vital element that has contributed to a less satisfactory perception of CCDU is the outdated plan. Though the blueprint plan was released in 2012, the delays were fuelled due to repetitive aftershocks, land acquisition for anchor projects, land remediation work and funding arrangements, which means the previous plan needs more efforts to revisit, evaluate, and even redesign. All of those reworks have contributed to significant delays in delivering Anchor projects.

Furthermore, most participants consistently believed that CCC played an essential role in rebuilding Christchurch and expediting the recovery space by releasing the central city plan and buying out several thousand homes on the worst liquefaction-affected lands. Specifically, CCC paid former residential red zone owners 100% of the 2007/08 rateable value for uninsured homes, regardless of insurance status, and purchased privately-owned red zone properties if the owners were interested in selling their property [44]. Moreover, CCC, as the funder of some Anchor projects and Precincts, made considerable contributions to promote the construction of these critical projects and reduce the possible delay resulting from financial mobilisation. For example, Tūranga, as the only anchor project over which CCC has complete control, can be opened two years after the construction starts. Te Pae Christchurch Convention Centre, another Anchor project funded by the government, was able to be completed from 2017 to 2021. With sufficient funding and a leading role from the government, projects are more likely to be delivered on time.

DISCUSSIONS

Given the current restoration progress made so far, the full recovery of CBD from the Christchurch earthquake still requires further years. Through an in-depth field trip to Christchurch CBD, the identified factors that delayed the reconstruction process include building damage inspection, engineering mobilisation, financing, permitting, and contractor mobilisation, which are commonly discussed in existing literature [19, 22, 23]. Importantly, this study identified certain distinctive factors that contributed to the considerable delay in the recovery of CBD, which include 1) the scale of the event, 2) delayed decision-making, 3) overwhelmed legal systems, and 4) limited resource availability, as is shown in Figure 8.

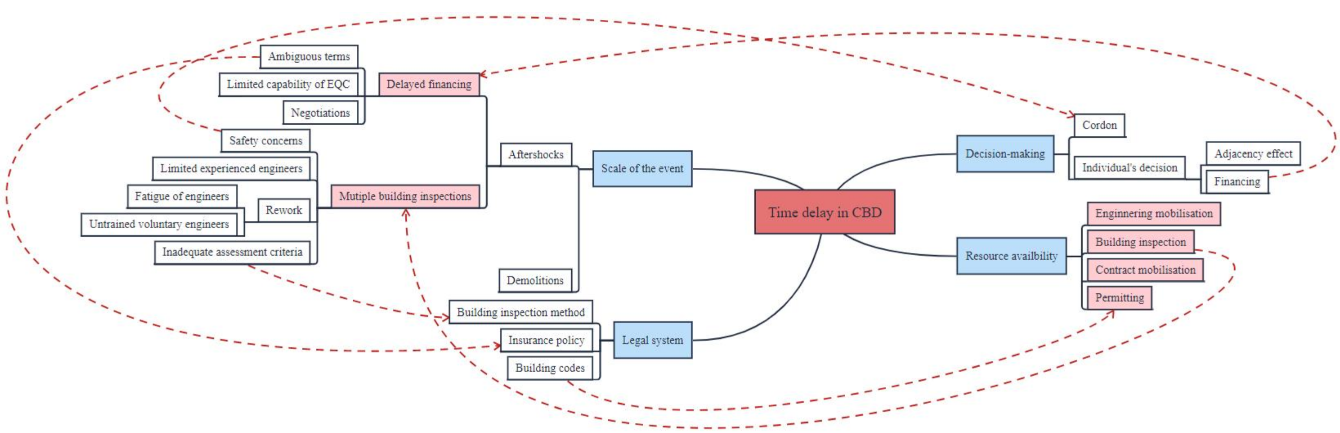


Figure 8. The identified impeding factors causing time delays in the reconstruction of Christchurch CBD.

The scale of the event posed significant challenges throughout the recovery of Christchurch. Unlike other seismic events, there were 14,000 earthquakes between September 2010 and June 2012, and 56 quakes were larger than magnitude 5.0. These earthquakes further caused more damage, meaning further building damage assessments were needed and more costs needed to be apportioned between private insurers and EQC for each event. Specifically, those aftershocks directly incurred the demand for multiple building damage inspections. However, a lack of experienced inspectors cannot meet the demand surge, causing an unavoidable delay in mobilising an inspector on-site. What is worse is that the widespread safety concerns and the following cordon (29 months in CBD) prevented engineers from entering the building, further delaying building inspection. The delays were even exacerbated by the additional burden of rework due to the fatigue of engineers and the limited capability of untrained voluntary engineers. Furthermore, this research revealed that inconsistent assessment criteria among various agencies led to discrepancies in the methods employed, resulting in the need for additional inspections due to the lack of standardised procedures and guidelines. On the other hand, the financing process was also significantly affected by aftershocks. The large volume of claims resulting from aftershocks overwhelmed EQC's capacity to process and assess claims promptly. Also, disputes and litigation arose from differences in the interpretation of insurance policies, coverage, and claim assessments [45], resulting in a substantial time delay in negotiating the acceptable claim amount between building owners and insurance companies. One interesting finding was that many building owners wanted to sell their property 'as is' after receiving insurance payments [46], which drove them to prioritise securing the best deal possible with the insurance company, thereby increasing the workload of the insurance industry and delaying the restoration of Christchurch in the long term. Besides that, widespread demolitions also shaped the recovery of CBD. The extensive demolitions in the CBD not only required significant time and resources input but also diverted resources and attention from other recovery efforts, such as the reconstruction of other damaged buildings and infrastructures, which inevitably slowed down the progress of other recovery efforts, resulting in delays in the overall recovery process of the CBD.

Furthermore, decision-making significantly impacted the overall restoration process in CBD, particularly for decisions at the community level. For example, the decision to cordon off caused the delayed recovery of CBD for 29 months. This paper further uncovered the 'adjacency effect' that can extensively affect decision-making at the individual level. For instance, building owners can be cautious about repairing their buildings if the surrounding building remains unrepaired and poses life-safety risks. As such, it took much longer for individuals in CBD to make final decisions.

Moreover, resource availability played an essential role in the time delay in CBD recovery. The massive scale of the 2010/2011 Canterbury earthquake sequence resulted in a surge in demand for professionals, engineering companies, construction materials, skilled workers, various equipment, and contractors, leading to widespread delays throughout the recovery process. Additionally, the overwhelmed legal system was rooted behind the overall delay in the restoration process. An absence of a robust legal framework and guidelines caused multiple legal disputes concerning land ownership, building codes, and compliance with new regulations, which required extensive negotiation time between various stakeholders to reach a consensus. Meanwhile, the effectiveness of government agencies was adversely affected due to the absence of comprehensive and pragmatic guidelines for handling such large-scale disruptive events. For example, the permitting process faced delays due to the increased complexities of integrating new building regulations into both new and retrofitted building designs, as well as a shortage of skilled workers and resources to process permit applications overburdened the legal system, which further overburdened the legal system.

After witnessing the catastrophic consequences of the 2010/2011 Canterbury earthquake sequence, New Zealand has shifted its focus towards proactive preparations for future disruptive events. Based on the interviews conducted, participants consistently confirmed several lessons to enhance building resilience, including 1) the need for accessible training programs for engineers, 2) the incorporation of building resilience in engineering design, and 3) the necessity to revise building codes. Specifically, various training programs should be in place to improve the professional competency of engineers, so they can be more capable of inspecting and designing buildings against disruptive events. Furthermore, it is crucial to fully incorporate building resilience into engineering design to ensure that buildings have sufficient redundancy to withstand disruptive events. This can be achieved through various low-damage designs, which should be effectively communicated to communities to increase their understanding and acceptance of such designs. Additionally, building codes should be revised to promote enhanced building resilience and facilitate fast recovery in the face of disasters. This may include adding and clarifying clauses related to repairable buildings to eliminate unnecessary assessments and upgrades of the fire alarm systems and accessibility features. Also, it is crucial to envision the expected building functionality and recovery time in building codes, which can prevent significant financial losses due to uneconomical repair costs, widespread demolitions, and disrupted business, and ensure continued serviceability of buildings in post-earthquake scenarios. Moreover, this research underscored the importance of an available seismic hazard model to provide a robust foundation for response and recovery planning, risk communication and engagement against the deadliest scenarios, such as AF8. Notably, the revised New Zealand National Seismic Hazard Model (NSHM) was released in October 2022, providing more detailed information on possible earthquakes that might happen throughout the country. With more advanced knowledge of potential earthquakes through more precise hazard models, it is possible to develop more sophisticated risk assessment methods and risk management guidelines that guarantee the safety, security and the economy from those disruptive events. Accordingly, more research efforts are needed on the development of more accurate seismic hazard models, and it is equally important to undertake comprehensive interdisciplinary research programs that promote the development of advanced disaster preparation plans.

CONCLUSIONS

The 2010/2011 Canterbury earthquake sequence caused significant damage that resulted in injuries and losses of life, interruption of lifeline services, displacement of residents and businesses, and economic and sociocultural impacts. Tremendous finances and resources have been invested in the reconstruction of Christchurch. Nevertheless, the restoration efforts are still underway, even though it has been 12 years later. This article takes a holistic perspective to look at past restoration endeavours involved in rebuilding Christchurch. In particular, it elicits some crucial lessons drawn from empirical data regarding recovery status, building resilience, low-damage designs and the role of public agencies that were collected from policymakers and recovery practitioners during a field trip to Christchurch CBD.

It is revealed that the majority of buildings (70%~80%) had been repaired or rebuilt. Legal changes, such as the adjustment of seismic hazard factor and the release of the Earthquake Prone Building Policy, are both effective legal responses. Meanwhile, this paper uncovered the emphasis of the concept of building resilience in terms of redundancy in newly constructed buildings and retrofitted buildings. In particular, various low-damage designs (e.g., base-isolation) received widespread adoption in Christchurch CBD. Also, this paper investigated the effectiveness of several public agencies. Most had performed well and played an essential role in the reconstruction of Christchurch.

More importantly, this research found that significant delays for prolonged building recovery, even twelves year on, can be primarily attributed to several factors, including the scale of the event, delayed decision-making, overwhelmed legal system, and limited resource availability. Lessons elicited from past restoration efforts include the necessity of available training programmes for engineers, the stronger emphasis on building resilience in engineering design, the revision of building codes, and the development of more advanced NSHM to better prepare for disruptive events such as the AF8. It is hoped that these lessons can collectively translate into enhanced earthquake preparedness and resilience in the future.

All findings revealed by this paper are drawn from valuable empirical data through interviews. It is important to note that a more comprehensive understanding of past restoration efforts can be available with more professionals engaged in the interview. Future research is suggested to have more thorough investigations of building and community recovery to provide valuable lessons on efficient disaster preparedness.

ACKNOWLEDGMENTS

The first author was supported by a joint doctoral scholarship from the China Scholarship Council (CSC) and the University of Auckland. This project was (partially) supported by QuakeCoRE, a New Zealand Tertiary Education Commission-funded Centre. This is QuakeCoRE publication number 0847. The authors would like to acknowledge the generous cooperation and time provided by the interviewees throughout this study.

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