APPLICATION OF SUSTAINABILITY PRINCIPLES IN POST-DISASTER RECONSTRUCTION

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The link between a sustainability agenda and post-disaster reconstruction is gaining increasing attention. However it is not clear how sustainability thinking affects outcomes of reconstruction programmes. This paper identifies key factors that influence how sustainability principles are integrated into decisions for reconstruction. This is based on empirical research conducted in Christchurch, New Zealand, following earthquakes in 2010 and 2011. The discussion focuses on the role of the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) in the city's reconstruction. SCIRT is a collaborative organisation that was established to deliver the rebuild of infrastructure networks (wastewater, water supply, stormwater and roads) through an alliance agreement for design and construction. Information has been gathered through semi-structured interviews with professionals involved in the reconstruction, supported by an investigation of relevant government reports and project documentation. It is clear that constrained finances place a significant limitation on what can be achieved in post-disaster reconstruction. Working within this limitation however, there are several factors that shape how sustainability principles are incorporated into decisions for the design and construction of infrastructure. Some of the key factors identified through the Christchurch case study are: (a) Decision boundaries: organisational arrangements influence how and what decisions are made regarding the nature of infrastructure reconstruction or repair; (b) Conflicting timescales: there is a trade-off between the short-term need to restore services and longer-term considerations of improved system development and maintenance; (c) Best practice: opportunities to adopt sustainable approaches (as defined in the business-as-usual infrastructure construction) can prove to be elusive where adhering to a pre-conceived level of 'best practice' may not be appropriate; (d) Resilience: the concept of resilience is clearly embedded in options analysis for repairing or rebuilding infrastructure, helping to facilitate a longer-term perspective.

Keywords: decision analysis, post-disaster reconstruction, resilience, sustainability.

INTRODUCTION

The sustainability agenda places emphasis on the *"integration of environmental, social and economic concerns in policy, precaution in the face of uncertainty, viable livelihoods to reduce poverty, the long as well as the short term, inclusive and innovative approaches"* (Handmer and Dovers 2013: 52). Reconstruction can be an opportunity to implement solutions informed by sustainability principles, such as considering the impact of future hazards, climate change and creating safer communities (Hayles 2010). It is an opportunity to address vulnerabilities in the built environment, where the most vulnerable aspects tend to be those that require

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rebuilding (Amaratunga and Haigh 2011). Yet, there is little guidance around how to accurately capture this opportunity and define realistic outcomes.

Kulatunga (2011) suggests that it is impossible to truly define a 'sustainable reconstruction' given the large variance in the nature of a disaster and the context in which it occurs. Reconstruction by its very nature has a number of defining characteristics that are different from business-as-usual infrastructure development. While decision-support tools can help to assist thinking, rigid information-heavy assessments do not necessarily translate to a post-disaster context where decisions must be made in a "*fast-paced, information-poor environment"* (Olshansky and Chang 2009: 206). Reconstruction can also entail ongoing uncertainty over scope and funding long after construction has commenced. Furthermore, perception of what is important can change with the urgency and needs within a post-disaster environment. So the question remains, how do we begin to outline and address sustainability in the changeable, uncertain context of reconstruction?

The aim of this paper is to develop insight into the decision-making processes associated with reconstruction of horizontal infrastructure networks (focusing on wastewater, water supply, stormwater and roads). The argument is based on an initial investigation in an ongoing study into the reconstruction of Christchurch, New Zealand. The research follows an inductive approach where theory is developed from a mixture of literature, observations and experience (Hunter and Kelly, 2008). Approximately 60 semi-qualitative interviews with engineers and executives involved in the reconstruction have been conducted over 2013/14. Information has also been gathered through a review of government and academic reports, infrastructure design guidance and project-specific design reports. Full interview analysis is not yet completed, however sufficient progress has been made to indicate early insights. Quotes used in this paper are anonymous, but context is provided through the interviewee role. Roles are categorised into: leadership (executive), leadership (design), designer and 'other' (this includes finance, planning and environment).

The early insights of the research in Christchurch are linked to key concepts discussed in sustainability and in reconstruction literature. This paper explores factors that impact on the ability to address short- and long-term social, environmental and economic issues. Four key factors are discussed: decision boundaries in reconstruction management, inevitable trade-offs in ambitions, feasibility of implementing perceived 'best practice' environmental initiatives and the role of resilience as a concept that encourages long-term thinking. The first two factors are discussed in relation to the impact of overall governance arrangements. The second two factors are discussed in relation to specific design and construction initiatives.

RECONSTRUCTION IN CHRISTCHURCH: CONTEXT

Christchurch is the main urban centre in the Canterbury region of New Zealand, with a population of approximately 370,000. The city experienced a series of major earthquakes from 2010 to 2011, with the most damaging earthquake occurring in February 2011. The estimated cost of recovery is \$NZ 40 billion (approximately £20 billion) (New Zealand Treasury 2013). This is almost 20% of New Zealand's annual gross domestic product (GDP) - a substantial impact on the national economy.

Christchurch provides a developed country reconstruction scenario where established infrastructure networks sustained significant damage (see Figure 1 for a visual indication of the damage). Table 1 outlines Christchurch's network characteristics and estimated damage. The estimated cost of repairing wastewater, water supply, stormwater and road networks within the Christchurch City Council (hereafter: Council) boundaries, (i.e. excluding damage in neighbouring rural districts) is $NZ 2.5 billion.

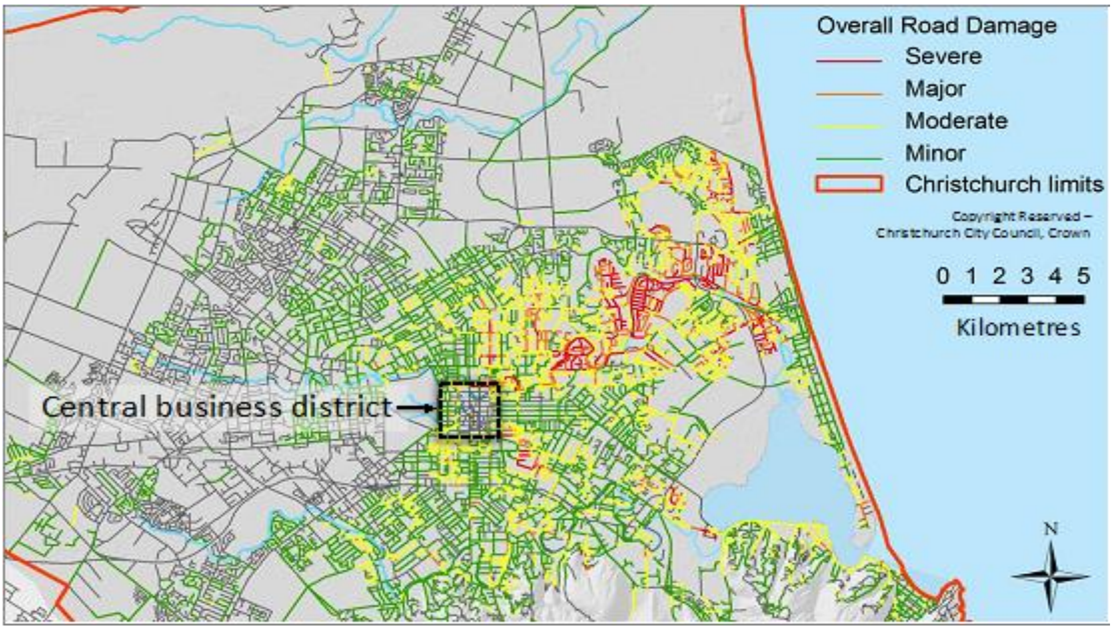

Figure 1. Indication of road network damage. Map sourced from SCIRT.

Table 1: General description and indication of earthquake damage to Council owned and operated infrastructure networks (includes the state highways owned by NZTA). Data is from various sources including liaison with Council and SCIRT staff (numbers are approximate).

	General network description (prior to September 2010)	Indication of damage
Waste-water	1900 km of mains; primarily a gravity-fed system dating from the 1890s; a significant portion of pipes in central Christchurch pre-date 1940; pipe material: predominantly concrete, earthenware and UPVC 25, typically laid deeper than water supply; 145 pump stations; 1 main treatment plant serving Christchurch.	Approximately 660 km of pipes; > 80 pump stations; treatment plant damaged but remained partially functional.
Water-supply	Artesian well supply from various sites (154 wells), no treatment required; 8 main reservoirs; 159 pump stations; approximately 1700 km mains and 1700 km sub-mains and cross-overs; pipes dating from early 20th century (although only a small percentage pre-date 1940); pipe material: predominantly HDPE, AC, MDPE80 and PVC (note: presence of AC a result of use in post World War II growth).	Approximately 70 km of pipes; >60 pump stations and reservoirs.
Storm-water	Consists of roadside channels and gutters; 790 km pipes; 130 km open boxed and unlined channels; 30 pump stations; 2600 km streams and tributaries; 80 km rivers; 100 detention basins; 2 lakes; 17 km of levees.	Approximately 30 km of pipes; >10 pump stations; levee settlement and cracking.
Roads	2300 km of roads - 1980 km sealed, 360 km unsealed; 705 km constructed pre-1956 (reference date beyond which roads are constructed with sufficient depth to meet 'modern' traffic loading); approximate average construction age across the network is 50 years; surfacing is predominately single or double coat chipseal (surface dressing) or asphaltic concrete; 325 road bridges; 960 retaining walls.	Approximately 1000 km of carriageway (120 km with major or severe damage, 210 km with moderate damage), >240 retaining walls; 30 bridges significantly damaged.

INTEGRATING SUSTAINABILITY: KEY FACTORS

Decision boundaries

Amongst the key decisions that need to be made in the early phase of recovery is the design of institutional mechanisms for managing the recovery (Global Facility for Disaster Risk Reduction and Recovery - GFDRR 2011). New institutions may be set up or the capacity of existing institutions may be enhanced to manage the increased workload, or some form of hybrid model of the two may be used (GFDRR 2011). Each approach creates organisational boundaries and requires a different distribution of roles and responsibilities, which ultimately impacts on how decisions are made.

The approach in Christchurch could be described as a hybrid model. The Canterbury Earthquake Recovery Authority (CERA) was created under legislation as the overarching lead recovery agency covering the wider region. It is one of the three clients of the Stronger Christchurch Infrastructure Rebuild Team (SCIRT). SCIRT's role forms key element within a wider construction process for the city; it is implementing the repair of the publically owned and operated networks in Christchurch (these networks are described in Table 1). SCIRT was created to facilitate an expedited rebuild, where the extent of damage was considered to be beyond Council's management capacity. Council and the New Zealand Transport Agency (NZTA) are the asset owners and are also clients of SCIRT. SCIRT was created under an alliance agreement (formalised in September 2011). The contract arrangement is distinctive, involving three client organisations and five major contracting organisations (forming five separate construction/delivery teams). Designers from 20 consultancies work within four design teams based in one office. SCIRT was set up with a limited operational lifetime and its work is due for completion in 2016. The alliance agreement sets boundaries for SCIRT's scope of work. The basis of the agreement is to restore services to Christchurch City, with the primary objective: "*To return the infrastructure networks to a condition that meets the levels of service prior to the 4 September 2010 earthquake within the timing constraints of the rebuild*." (Council, NZTA and CERA 2013: 3).

Examining the rebuild of the stormwater network provides insight into the challenges of addressing long-term environmental and social issues. SCIRT's remit is to repair the 'hard-engineered' assets such as pipes and sumps. It excludes responsibility for damage to the open waterway network and the levees along the lower reach of the Avon River. This limits SCIRT's responsibilities and ability to address problems. As one leader in design commented: *"as engineers they [the team] want to go out and resolve the solution"* but it may be that *"SCIRT's requirement [that is, SCIRT's remit to resolve the solution] is nothing - the changes are nothing to do with damaged infrastructure, it's damaged land."*

Flood risk was exacerbated in some areas due to earthquake-induced land settlement. Resolving changes in flood risk in Christchurch is influenced by a complex mix of factors including physical options to remediate, level of protection required, funding, insurance, district planning, legislative requirements and personal circumstances of property owners (Gillooly 2014). The vulnerability of some areas was recently highlighted in both March and April 2014, when rain resulted in repeated flooding of some private properties. It is not under SCIRT's remit to systematically address and provide holistic solutions for flood issues in Christchurch. Council has retained ownership of developing solutions for these issues. This was a governance choice that was made early in the recovery. It was not the only option, but one that was chosen for political and economic reasons. The result is an organisational boundary in the recovery that has ramifications around the coordination of solutions across different agencies. One leader in design commented: *"The difficulty has been SCIRT works at a different pace to council and other organisations through the necessity of our programme and because of that it has been quite difficult to navigate through that process."* The organisational boundaries potentially impact the timing and nature of the technical solutions; however, it is too early in the process to determine the impacts for Christchurch.

Organisational boundaries are a prominent factor in shaping decision making. These boundaries have an influence on the nature of remaining three factors and will thus continue to arise in discussion as these factors are addressed.

Trade-offs

The United Nations Development Programme and the International Recovery Platform (c2010) identify that one of the major challenges of infrastructure reconstruction is balancing the costs of alternative strategies to reinstate infrastructure services with long-term development benefits. The tension between speed of recovery and deliberation on how to make improvements is ubiquitous to the reconstruction process (Olshansky and Chang 2009). As described above, the longer-term requirements around flood-risk management are not being delivered within the recovery work coordinated by SCIRT. This is causing some delay in SCIRT work. Uncertainty over design arrangements for levees on the Avon River (which is under consideration by Council) impacts on SCIRT reconstruction options for roads adjacent to the levees. Thus, the nature of institutional boundaries is inherently linked to the trade-offs over timing. At the time of writing, this delay is posing a potential risk to the overall programme but is not yet having a material impact.

The pressure to restore services as quickly as possible limits the ability to consider wholesale changes to infrastructure networks (or vice versa). In discussing the strategic planning for a project, an executive commented, *"it is all about time and balancing a rapid response with an appropriate response."* One designer remarked that their ability to explore possible solutions was limited due to the short-term pressure to restore services: *"because of the operational issues… we needed a solution quick and we've got to get started."* Also, SCIRT's work is predicated on a basis of restoring a system 'like for like' using modern equivalent materials. This limits scope of possible change from the outset of the reconstruction programme. Efforts are made to integrate improvements such as increasing pipe capacity or rebuilding a pump station in a less vulnerable location. However, improvements such as increasing capacity may require seeking funds beyond that approved for SCIRT work. Availability of extra funding is limited given the significant base-cost of the rebuild.

Limitation in scope is also attributable to the level of damage sustained, where the extent of damage impacts on the opportunity to consider wholesale change. Network damage in some areas of Christchurch justified a complete rebuild of a section of the wastewater network, but assets in other areas of the city remained in a reasonable or repairable condition. Hallegatte and Dumas (2009) refer to this as 'technological inheritance', which constrains the ability to integrate modern technologies and standards during reconstruction. Despite extensive damage to infrastructure, or the communities it supports, destruction is rarely complete and repair is often lower in up-front cost than replacement. As can be seen in Figure 1 and Table 1, despite extensive damage in some areas in Christchurch, most of the infrastructure remains operational.

Environmental initiatives

Reviewing environmental-based initiatives moves into the realm of what may be viewed as the grassroots of sustainability thinking. For infrastructure, the essence of the ‘environmental’ theme of sustainability assessment is about understanding the overall impact of resource use in a project, reducing material use, eliminating waste and general environmental impact. This is manifested in various practices such as: reducing runoff, using recycled or recyclable materials and management of energy use and greenhouse gas emissions. For SCIRT, waste minimisation is identified as the core element of their *“sustainability culture”* (SCIRT, n.d. a), thus it is worth specifically addressing. Low-carbon design and operational carbon assessment is a related factor but it will not be addressed in detail here given limited space. Suffice to say, it is not an explicit aspect of SCIRT’s approach, although efforts towards reducing waste and lifecycle assessment in design (both described later) may be associated with low-carbon design.

Recycling of material appeared to be a potential opportunity for the reconstruction of roads in Christchurch given the repetitive nature and scale of work across the city. For example, in terms of infrastructure networks, roads directly damaged by earthquakes needed either resurfacing or a full-depth rebuild. Marginally damaged roads may also be trenched to access and fix damaged pipes that lie underneath. These efforts can result in a significant waste stream of discarded pavement and sub-base material.

However, this opportunity is constrained by a number of factors. Recycling material in-situ is being implemented in some cases for pavement rehabilitation. Yet the quality of in-situ road base can be highly variable, even within a street. Therefore, specifying re-use of this material poses a risk to the quality and durability of the construction work. As one leader in design expressed: *“We would like to use a lot of the materials that we are digging out, for reuse – but again it comes down to cost... No matter what people talk about, cost is the driver”*. Also, a particular factor for Christchurch is that there is an abundant supply of locally sourced, low-cost, high-quality aggregate for the road base and for backfilling trenches. This significantly reduces the incentive to recycle material, as it cannot be justified economically. This is critical when funds are highly constrained; funds not invested roads could be allocated to other aspects of the reconstruction. The availability of cheap aggregate also reduces the viability of investigating other innovative alternatives. One interviewee concerned with environmental management mentioned a potential initiative around recycling cement kiln dust. This involved using cement kiln dust in trench backfilling. However the idea did not gain traction due to cost and uncertainty over performance of the material in the ground.

Waste minimisation is a performance target for delivery teams at SCIRT and is perhaps the most visible environmental initiative beyond compliance with environmental consent requirements. There are incentives in place to promote more sustainable practice; efforts towards waste minimisation impacts on delivery team performance rating. This rating has commercial ramifications as it influences the percentage of work allocated across the five contracting organisations. While SCIRT is an alliance organisation, this incentive (amongst others) has been set up to maintain an element of competition between the delivery teams and to support improvement in performance throughout the five-year contract.

It is worth taking a moment to look at sustainability assessment of infrastructure in a business-as-usual context. Sustainability rating schemes for civil infrastructure (current schemes are CEEQUAL in the United Kingdom, Envision in the United States and the Infrastructure Sustainability Council of Australia's IS Scheme) specify goals for recycling materials, diverting waste from landfill, and maximising use of local materials. This is often done through stating percentage by volume of project materials that that should reused or recycled to meet certain performance criteria. To an extent, these tools may provide some guidance around potential issues to address in reconstruction, but the same priorities and possibilities do not necessarily apply in a post-disaster scenario. Determining 'best practice' performance that could be consistently applied to different recoveries is perhaps not even feasible given that every disaster is different. The challenge around developing a waste minimisation scheme for SCIRT's work is discussed below.

It took approximately two years to develop a waste-stream reporting framework across the five delivery teams (who also manage sub-contractors). The process started with developing a waste management audit tool, which was designed to provide delivery teams with a consistent basis on which to track waste. This has since been advanced to capture percentage of waste eliminated, reused, recycled or disposed. However there is not yet enough reliable historic information to track trends. This may seem like slow progress but it needs to be viewed in the context of the disaster. For example, immediately after the event, environmental consent requirements were relaxed to allow direct discharge of wastewater into waterways. The imperative was to avoid waste-associated health issues. Moving into reconstruction, SCIRT had a role in creating formalised, consistent approaches to decision making. The initial focus was on ensuring compliance with consent requirements. Once some basic processes were in place, the organisation could then start to move beyond compliance and create waste minimisation goals. These goals are reviewed as performance improves.

Resilience: a concept for long-term thinking

While environmental initiatives represent traditional thinking around sustainability, resilience-based thinking has gained political currency more recently with concern around the impact of natural hazards on infrastructure performance and ultimately, community wellbeing. With this in mind, this section first provides general context to resilience as a concept that supports decision-making processes in reconstruction. This leads into a specific example of how resilience is used in decision making at SCIRT.

Within the infrastructure sector alone there are various nuances in the use of the term 'resilience'. A common theme or underlying essence of resilience is the capacity to adapt. While there is much debate over meaning and no widely accepted definition, the following conceptual definition for infrastructure resilience provides a good synthesis, suggesting that "*resilience entails three interrelated dimensions: reduced failure probabilities; reduced negative consequences when failure does occur; and reduced time required to recover. This suggests that infrastructure resilience to disasters is not purely a technical problem, but involves societal dimensions*" (Chang 2009: 1). Achieving these dimensions may involve averting failure through adaptation, increasing flexibility and increasing robustness (Fiksel 2006).

There is no real consensus on operationalising resilience (Blackmore and Plant 2008). The general basis of resilience assessment is to provide a structured, systematic analysis to assess vulnerabilities in a system, determine appropriate points of intervention and to prioritise investment. A resilience framework is not designed to lead to a specific decision, but to support a better-informed decision processes (Mansouri *et al*. 2009). Considering resilience of an infrastructure network can contribute to understanding the broader context of design in order to evaluate costs, benefits and risks from a systems perspective (Fiksel 2006).

Lifelines engineering at regional level in New Zealand adopts this type of assessment approach, although it has not been explicitly framed as a 'resilience framework' in the past. Lifelines engineering formally began in New Zealand in 1989 and this eventually led to a report in 1997 that assessed the vulnerabilities of lifelines infrastructure to a range of hazards (Christchurch Engineering Lifelines Group 1997). Subsequent investment by utilities organisations in mitigation of seismic impact helped to reduce the effects of the recent earthquakes (Fenwick 2012).

Resilience is also a concept that has a role in shaping design decisions in the current reconstruction effort. Resilience at SCIRT is: "*the ability for the infrastructure (the roads, pipes etc.) to resist future earthquake damage. Improved infrastructure resilience can be achieved by using better materials, adopting higher construction standards, creating new systems, or minimising hazards*" (SCIRT, n.d. b).

With the exception of the Port Hills in the southeast of the city, Christchurch has a relatively flat topography. The wastewater network is predominately a gravity-based system with pipes laid at a low gradient. These systems proved to be highly vulnerable in areas subject to lateral spread, liquefaction and subsidence in an earthquake. In catchments that sustained heavy damage, SCIRT engineers considered alternative technologies as well as straight 'like for like' replacement of the gravity-fed sewers. The alternative options - low-pressure or vacuum sewers - typically require higher initial capital costs, but are less likely to sustain critical damage in an earthquake large enough to induce liquefaction.

As part of the design process for these catchments, lifecycle assessment of wastewater network options considered the costs of a possible future earthquake sufficient in size to cause liquefaction in Christchurch. Key features of this assessment included analysing costs over 30 years (using an eight per cent discount rate) and incorporating the cost of replacement or repair in five years' time as a result of earthquake damage. The possibility of another earthquake was determined through considering likelihood predictions from geoscience experts. A 'net resilience capital cost' captures the estimated additional cost of an option alternative to the conventional gravity network system. The lifecycle assessment does not include the 'incremental resilience' provided by use of modern materials (SCIRT 2013), which would be used in all options. The lower vulnerability of the alternative options to earthquake damage meant that these options tended to become more cost-competitive through consideration of lifecycle costs, compared to an assessment of capital costs alone. The key benefit of this assessment approach is that it captured the overall value of introducing a system that is more resilient under earthquake loading.

One might criticise this as a technocratic approach to recovery focused on physical reconstruction. However, referring back to the definition of resilience presented earlier, this design process goes some way in addressing the interrelated dimensions of resilience through attempting to reduce the possibility of future damage. It adopts a disaster risk management philosophy; the underlying consideration is to reduce the impact of future earthquake damage on the infrastructure. The key decision lay in balancing cost with the potential for avoided future damage. There is uncertainty associated with the assumptions made in the assessment (e.g. the eight per cent discount rate could be debated) and there are limitations in the factors considered (e.g. neither embodied carbon or the cost of loss of service were a factor). However, the process has served as rational (if somewhat limited) basis for incorporating lifecycle considerations into design.

CONCLUSIONS

Reconstruction presents both opportunities for and challenges to incorporating sustainability principles into decisions. The post-disaster environment is perceived to provide a window of opportunity for improvement that would not have otherwise been possible under business-as-usual development. However, it is highly challenging to address the short-term pressure to reinstate services while also considering long-term social, environmental and economic issues.

Four factors that influence how sustainability principles are integrated into decisions for reconstruction have been discussed. Firstly, it is certain that organisational boundaries affect the nature of decisions and how the reconstruction process is managed. This is an overarching issue that impacts on the other factors. Secondly, it is inevitable that there are trade-offs in ambitions, particularly because 'technological inheritance' will limit the possibility for wholesale change. The opportunity for improvement or change is limited by what existed before, the level of damage sustained and the cost and time implications of doing something different. Thirdly, the feasibility of implementing 'best practice' environmental initiatives is problematic in a post-disaster environment; it is difficult to determine what is 'best practice' and it can take time to establish appropriate targets. However, in a cost-constrained context, commercial incentives help to improve performance. Finally, resilience is a concept that facilitates long-term thinking, which is a fundamental concept of sustainability. Incorporating resilience into decision making for infrastructure in Christchurch has materialised both through pre-disaster action to reduce network vulnerabilities and through post-disaster options assessment.

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