LANDSCAPE REVIEW

THEME

Integrated Urban Grey and Green Infrastructures

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Integrated Urban Grey and Green Infrastructures

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SILVIA TAVARES[2] AND JANIS BIRKELAND[3]

Scope

This special issue, 'Integrated Urban Grey and Green Infrastructures', of *Landscape Review* contributes to the advancement of conceptual and scientific methodologies of grey and green integrative studies at multiple spatial scales. It addresses international research communities and practitioners in the fields of urban ecology, environmental planning, landscape architecture, urban design, architecture, geography, urban sociology and traffic engineering. The issue explores – through case studies – how infrastructure research and practice are being advanced in Australasian cities. The papers in this special issue were presented and discussed at the first Integrated Urban Grey + Green Infrastructure symposium held at the School of Landscape Architecture at Lincoln University, Canterbury, New Zealand, in November 2016. The symposium gathered experts from various disciplines to discuss advances in infrastructure design, planning and management in support of healthier and more resilient cities in the context of significant environmental events and changes. The symposium was convened by chairs Andreas Wesener, Wendy McWilliam and Silvia Tavares. Janis Birkeland – author of *Positive Development* (2008) and *Design for Sustainability* (2012) – was the invited keynote speaker.

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Background

Grey infrastructure (eg, transport networks, including roads and cycleways, stormwater and sewage pipe systems) has long been recognised as providing a vital socioeconomic backbone for city development. Well-designed (public) open spaces, in particular, streets, pedestrian realms, squares and plazas, can make significant contributions to social inclusion (Sauter and Huettenmoser, 2008), community engagement (Hassen and Kaufman, 2016), neighbourhood vitality and diversity (Montgomery, 1998) and sense of place (Watson and Kessler, 2013). Green infrastructure (eg, parks, river corridors, street trees and urban forests, community gardens, green roofs and bio-filtration facilities) has also been recognised as playing an equally vital role, providing important ecosystem services in support of community health, wellbeing and social cohesion (de Vries et al, 2013). Services include food production (Barthel and Isendahl, 2013), microclimate stabilisation (Chiesura, 2004), air filtration (Nowak and Crane, 2006), carbon storage (Nowak and Crane, 2002), water cleansing and stormwater management (Keeley et al, 2013; Nickel et al, 2013), support for biodiversity (Fernández-Juricic, 2000), along with recreational amenity and aesthetic services (Wolch et al, 2014).

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Grey and green infrastructure functions have been viewed as competing in terms of both land use and access to government funding, and grey functions have been prioritised, resulting in the loss or degradation of green functions over time (Tjallingii, 2003). However, in cities vulnerable to extreme environmental events, such as earthquakes, and in the context of climate change and related phenomena, such as induced sea level rise, increased frequency and severity of storm events, heat waves and drought, the relative value of green infrastructure has increased (Gill et al, 2007). Recognition of the role green infrastructure can play in protecting cities from significant environmental events has led to a paradigm shift in urban planning and design toward more adaptive and integrated infrastructures (Hill, 2016), such as coastal protection systems (Sutton-Grier et al, 2015). Furthermore, scholars argue that integrated grey and green infrastructures have the potential to support higher, more efficient and cost-effective performance of both infrastructure types (Boyle et al, 2014), and could help decrease the negative effects associated with their fragmentation (Pauleit et al, 2017). Systemic change has been particularly apparent in the design of innovative stormwater management systems (eg, Wang et al, 2013; Page et al, 2015). However, additional prospective areas of application, including topics such as active modes of urban transport, recreation, social cohesion, flood retention and disaster mitigation, biodiversity, pollution control, and urban microclimates, could potentially improve the health and wellbeing of urban populations (Svendsen et al, 2012). Buildings are often not referred to as 'infrastructure'; however, treating buildings as separate entities seems counterproductive from a systems perspective. Integrated grey–green functions in the context of architecture and built structures are therefore additional relevant fields of research and application (Tiwary and Kumar, 2014).

Content

In the first contribution, Silvia Tavares and Simon Swaffield critically examine Christchurch's post-earthquake central city rebuild, focusing on the integration of compact city principles and green infrastructure and their influence on urban comfort. The authors argue that, while courtyards have been created, the quality of the public realm has been compromised in favour of private commercial development. Their analysis reveals that pre-earthquake efforts to establish best-practice urban design principles have only partly been adopted. Precinct-based planning schemes have led to highly controlled semi-private open spaces with restricted accessibility. Being disconnected from public open spaces, the new developments create only minimal public benefits related to urban comfort.

In the second paper, Josephine Neldner and Simon Kilbane broaden the discussion on infrastructure integration by arguing that landscape itself is infrastructural. The authors explore principles of landscape infrastructure and their application in undergraduate landscape architecture students' design projects in Sydney. Following in the conceptual wake of landscape urbanism, landscape infrastructure principles have evolved primarily in North America. By translating such concepts to the Australian context, the paper identifies generalisable principles and discusses how they could be applied.

Drawing on various examples, including the coastal wetlands in Auckland, the third contribution by Stephen Knight-Lenihan discusses opportunities to offset negative development impacts through the application of net positive environmental benefits. Among other factors, the net environmental benefit model relates to a stronger integration of grey and green infrastructure systems. Green–grey building components that integrate vegetation and micro-ecosystems, and new coastal or urban ecosystems that combine climate, biodiversity and recreational goals are examples of integrative systems discussed in the paper.

The next two papers bring us back to Christchurch. Bryan Jenkins discusses research-informed post-earthquake community-driven development proposals for the Avon–Ōtākaro River Corridor, also known as the 'residential red zone', combining environmental, economic, flood management and socio-cultural goals. One important research area is an assessment of the role of green infrastructure systems in replacing traditional grey infrastructure functions, including flood management, while simultaneously addressing the multiple challenges and opportunities of this vast area.

In the final contribution, Emilio Garcia presents a geographic information systems-based morphological analysis of Christchurch's central business district following the 2010/11 Canterbury earthquakes. The paper discusses changes in green and grey infrastructure with regard to size and diversity and in relation to a resilience framework. Based on three development scenarios, the author challenges compact city paradigms by arguing that Christchurch's post-earthquake urban landscape might be considered as an opportunity to increase the diversity of land uses and, concurrently, the resilience of the urban landscape.

Concluding remarks

The papers in this special issue demonstrate the importance of both grey and, in particular, green infrastructure, in support of community health and wellbeing. Their respective and integrative roles are illustrated in a range of case studies. They make a strong argument in support of repositioning green infrastructure with respect to grey infrastructure toward more sustainable and resilient urban communities. The variety of contributions shows that research on grey–green infrastructure systems has gained momentum in Australia and New Zealand. We hope this special issue of *Landscape Review* marks the beginning of a rich and evolving discussion that helps our cities to adapt to the many volatile and dynamic changes and challenges that are ahead of us.

NOTES

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Urban Comfort in a Future Compact City: Analysis of Open-space Qualities in the Rebuilt Christchurch Central City

SILVIA TAVARES AND SIMON SWAFFIELD

The increase in urban population has required cities to rethink their strategies for minimising greenhouse gas impacts and adapting to climate change. While urban design and planning policy have been guided by principles such as walkability (to reduce the dependence on cars) and green infrastructure (to enhance the quality of open spaces to support conservation and human values), there have been conflicting views on what spatial strategies will best prepare cities for a challenging future. Researchers supporting compact cities based upon public Transit Oriented Development have claimed that walkability, higher density and mixed-uses make cities more sustainable (Owen, 2009) and that, while green spaces in cities are necessary, they are dull in comparison with shopfronts and street vendors (Speck, 2012, p 250). Other researchers claim that green infrastructure is fundamental to improving urban sustainability and attracting public space users with improved urban comfort, consequently encouraging walkability (Pitman and Ely, 2013). Landscape architects tend to assume that 'the greener the better'; however, the efficiency of urban greenery in relation to urban comfort and urbanity depends on its density, distribution and the services provided. Green infrastructure can take many forms (from urban forests to street trees) and provide varied services (amended microclimate, aesthetics, ecology and so forth). In this paper, we evaluate the relevance of current policy in Christchurch regarding both best practice in green infrastructure and urban comfort (Tavares, 2015). We focus on the Christchurch Blueprint for rebuilding the central city, and critically examine the post-earthquake paths the city is following regarding its green and grey infrastructures and the resulting urban environment. We discuss the performance and appropriateness of the current Blueprint in post-earthquake Christchurch, particularly as it relates to the challenges that climate change is creating for cities worldwide.

Contemporary urban design theory highlights the need for compact, walkable and green cities (Owen, 2009; Speck, 2012). Urban green infrastructure can take many shapes and forms (from urban forests to rain gardens) and provide varied services (for example, microclimate, aesthetics, recreation, social meetings, biodiversity) (Ahern, 2007). However, buildings and grey infrastructure can crowd out urban greenery (Dimoudi and Nikolopoulou, 2003; Klemm et al, 2015; Oke, 1987; Pitman and Ely, 2013). Compact cities are prone to become urban heat islands; dense built form can also create undesired shade and increase water runoff and wind gusts. Tension can arise, therefore, between design imperatives for compact cities and those for green infrastructure. Further, a critical factor in the design of outdoor environments, in particular their microclimate, is that the urban environment succeeds as a social setting (Blotevogel et al, 2008; Gehl, 2010; Hebbert, 2005; Lees, 2010; Montgomery, 1998; Stevens, 2007; Whyte, 2001, 2009).

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RESEARCH

A useful perspective on the design integration of compactness with green infrastructure is the quality of urban comfort. *Urban comfort* has been defined as a combination of human thermal comfort, urban life and place-related meanings (Tavares, 2015). It specifically includes considering collective adaptation to microclimate as an achievement (Shove, 2003), extending the conventional framework of microclimate analysis from individual judgement of thermal comfort to focus on how social and cultural values, and meanings developed in a certain time by a certain community, affect experience of urban microclimate. In addition, from this sociocultural perspective, the social meanings of public open space shape people's response to microclimate (Wilson et al, 2007). However, given urban values and meanings may vary from place to place, understanding local lifestyles and preference for urban life is therefore also crucial for planning liveable compact cities.

This paper uses *urban comfort* as an analytical lens to investigate the way compact and green imperatives are being resolved in the rebuild of central Christchurch following the 2010–2011 earthquakes. The investigation is focused on the emerging precincts, streets, courtyards and lanes of the Christchurch central business district (CBD). Before the earthquakes, Christchurch was characterised as a 'Garden City'. While few green streets or spaces existed in the old city centre, the title expressed a distinctive regional culture that valued outdoor recreation and activities, open green space and a provincial style of urban living. The earthquakes radically changed the city's character, with around 800 buildings cleared from the damaged CBD (Carlton, 2013). Over the past six years the central city rebuild has been the concern of a series of design initiatives, which must deal with many of the issues involved in resolving green and compact ideals.

As the first major step towards designing the rebuilt city centre, the Christchurch City Council led a public consultation process called 'Share an Idea' to identify the public aspirations for the city (Carlton, 2013; Christchurch City Council, 2011b). As the central city area was progressively reopened (Backhouse, 2013), 'transitional' projects were undertaken to bring the city back to life and to activate vacant land (Bennett et al, 2013). In 2013 the government announced a new proposal for the redevelopment of the CBD: the Christchurch Blueprint, developed by the Canterbury Earthquake Recovery Authority (CERA) and Warren and Mahoney (Cairns, 2012; CERA, 2015b; Warren and Mahoney, 2016).

In view of the costs of rebuilding the city – initially estimated at around NZ$30 billion (Swaffield, 2013), a figure that is now almost certainly too conservative – a critical part of CERA's Blueprint was to attract private investment. One of its strategies was to establish a 'green frame' to limit the area of the CBD, hold up land prices and support existing land owners. This in turn reinforced the emergence of a compact city form in the CBD. Higher-standard building codes were also introduced and, to ensure redevelopment was commercially viable, CERA's Blueprint was shaped around defined precincts, involving both public and private investment (Suckling, 2016). The precincts, which include retail, justice, arts, health and residential, were centred on projects intended to 'anchor' development around them to attract people into the central city. Among these anchor projects are the proposed Convention Centre, the Metro Sports Facility, the Canterbury Earthquake Memorial and around 900 new residential dwellings.

Individual developers and architects also sought to differentiate their projects in the urban property market by incorporating a variety of design features, some focusing on green building, others on particular styles of earthquake resilience, distinctive mixes of uses, and spatial qualities such as courtyards and laneways.

Public aspirations, governmental objectives and commercial considerations for the rebuild therefore all seek both 'compact' and 'green' ideals, albeit to different degrees. We offer a preliminary analysis of how the potential tensions between these ideals are expressed in the emerging new urban fabric of the city centre, by asking, 'What is the quality of urban comfort in the new central Christchurch?' The analysis focuses on the micro scale, at three points in time, considering the character of streets, lanes and courtyards before the earthquakes, in the transitional phase and in the Blueprint. In the next section, we briefly explain the conceptual basis for the analysis. We then describe the qualitative and map-based methodology, before presenting our analyses of urban comfort in the changing city and discussing the findings.

Urban comfort in a green yet compact future

As the global population becomes urbanised and cities expand and intensify, the need for cities to become more sustainable is growing. Urban models can take many different forms, and the efficiency and effectiveness of various solutions have been much debated in urban design. While some emphasise the potential of compact cities (Hollis, 2009; Jacobs, 1992; Owen, 2009; Speck, 2012), others tend to assume 'the greener the better' (Pitman and Ely, 2013). In this study, the relationship between these two principles is examined through the lens of urban comfort (figure 1).

Compact cities is a term encompassing a range of urban design and planning ideals that all share a focus on the synergy between three principles: medium to higher density land use, typically expressed as a minimum of 45 units or 100 people per hectare (Carmona et al, 2010, p 226); mixed-uses along streets and in buildings to provide economic and social diversity and vitality (Jacobs, 1992); and accessibility – understood as having reliable and dense networks of public facilities and transport that are accessible by walking and cycling, in order to reduce dependence on private cars (Owen, 2009; Speck, 2012).

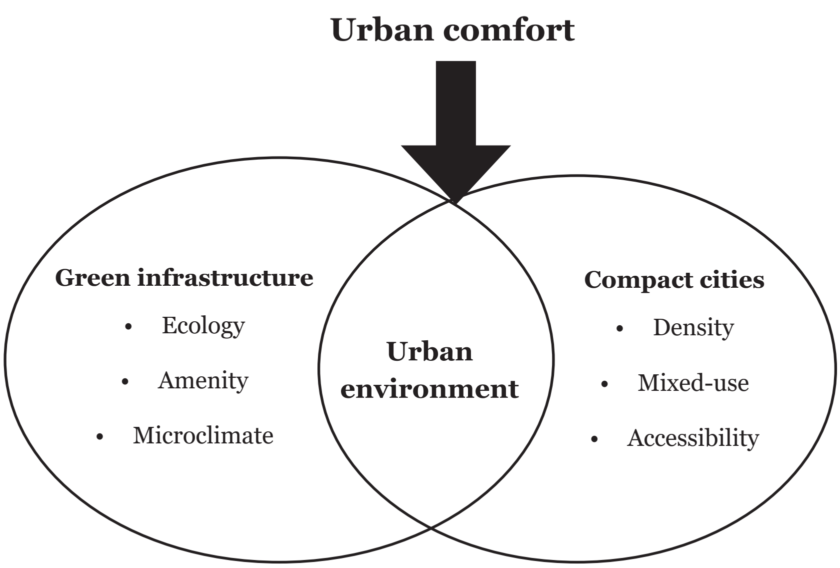

Figure 1: The urban comfort analytical lens

Green infrastructure is also fundamental to urban sustainability as it provides many ecological services and benefits (Benedict and McMahon, 2006). It can increase the amenity values of streets and public space, encouraging walkability (Pitman and Ely, 2013); it can support a healthy urban culture by enabling recreation, providing opportunity for social interactions and enhanced environmental awareness and education (Ahern, 2007); and it is vital in creating an urban microclimate that supports these human activities (Brown, 2010; Brown et al, 2015; Dimoudi and Nikolopoulou, 2003; Erell et al, 2011). Urban green infrastructure can be expressed at a range of scales – from subregional and urban-wide networks to individual street and building design. In this study, while acknowledging the importance of ecological values and networks, we primarily focus on the human qualities needed to make attractive urban spaces, and consider green infrastructure at the human scale of streets, lanes and courtyards rather than larger-scale networks.

The concept of *urban comfort* integrates consideration of the two realms of urban microclimate and social life in cities at this human scale. Urban microclimate research and design have largely focused on creating the best possible microclimate in streets and public spaces, based on quantitative modelling and assessments of human thermal comfort as experienced at the individual level, which can be controlled and manipulated through a variety of urban microclimate design strategies and interventions (Chatzipoulka et al, 2015; Lenzholzer, 2008; Lenzholzer and van der Wulp, 2010; Nikolopoulou and Steemers, 2003). It is clear, however, that in some climates – including the cool, temperate climate of Christchurch – for much of the year it is not possible to design urban outdoor spaces in a way that keeps them within human thermal comfort thresholds (see Olgyay, 1963) at all times of the day. Previous research using an urban comfort perspective in Christchurch has shown that in these situations the social quality of space becomes an important factor in the design of liveable streets, courtyards and lanes, and that the social function and character of urban spaces generate different adaptive practices in response to microclimate conditions (Tavares, 2015). In urban *retreat* spaces, the microclimate is one of the most important variables influencing urban comfort, and the environmental attributes of a particular place, including factors such as thermal comfort and green amenity, provide the reason for being there. In urban *social* spaces, on the other hand, vibrancy and activity dynamics are more important than the microclimate. The reasons people choose to be in these spaces include street activity and the presence of other people. Choice between social and retreat spaces is influenced by factors such as age and preferred urban lifestyle. We use these insights into urban comfort to focus on the changing nature of small open spaces within the Christchurch central city as it is rebuilt.

Methodology

Research approach

This study adopts a qualitative methodology to evaluate urban comfort in the emerging new urban spaces in the Christchurch CBD based on assessment of the qualities of microclimate (resulting both from street and building design, and from greenery), quality and amount of greenery, social activity, and social accessibility (see table 1). We used an interpretive approach, for several reasons.

First, our aim is exploratory, to stimulate debate rather than suggest answers, as questions of urban microclimate and green infrastructure provision are not yet central in decision making but are emerging as potential concerns. Second, the city fabric is itself in the process of rapid change, and systematic surveys and measurements would rapidly become outdated. Our approach is therefore intended to be rapid and diagnostic. Third, the qualities we are investigating are spatially and temporally complex, and we have therefore used nominal categories and maps and diagrams to quickly capture the essence of this situation. This is a limitation of the study and we see a more systematic and detailed investigation as necessary once this initial wave of change has passed.

Research design

Case studies are recognised as being well suited to investigating complex and dynamic situations involving multiple dimensions (Yin, 2013), and they should be selected to gain maximum theoretical insight (Flyvbjerg, 2006). The Christchurch rebuild provides opportunity to contrast the pre-earthquake conditions with the planned Blueprint and emerging character of the post-earthquake city. The pre- and post-earthquake situations offer two extremes: on the one hand, a historic city fabric that emerged through 150 years of individual plot-based development, with modest and traditional land-use planning controls (Wilson, 2005); and on the other hand, a comprehensive, precinct-based, top-down government-led rebuild, that in principle could use the best urban design expertise available. Between the two, the transitional city provides an example of bottom-up innovation.

The main green infrastructure element of central Christchurch is the Avon River corridor (Craig et al, 1993). However, despite Christchurch being known as the Garden City, the pre-earthquake central area was dominated by grey infrastructure of streets and laneways, rather than green spaces. We have focused our analysis on the streets, lanes and small green spaces such as courtyards in this central area bounded to the north and west by the Avon, to the south by Lichfield Street, and to the east by Madras Street, as they provide a human-scale indicator of how green might be integrated with grey in the compact city of the future.

Methods

We investigated the status of urban comfort in the Christchurch CBD based on the analysis of conditions at three distinct times: pre-earthquake (2007), immediately post-earthquake temporary sites (2011–2012) and the Blueprint and emerging urban environment (2012–2016). The urban open space conditions were initially investigated through figure-ground maps and photography. The map analysis is inspired by Giambattista Nolli (Tice et al, 2005) because, while figure-ground has a biophysical focus on building footprints, Nolli's approach adds to these building footprints the social life of urban space. Hence we were focused not only on urban form but also on the biophysical character (in regard to microclimate and greenery) and social character (in regard to activity and accessibility) of these open spaces – what we have conceptualised as urban comfort (table 1). A key innovation of Nolli's work was its distinction between public and private space, which he considered both within buildings and outdoors. Although we did not consider interior space such as covered malls, our interest was stimulated by the social character of the emerging courtyards. We therefore analysed the accessibility of spaces, and distinguished between those with 24-hour access (such as public lanes, pedestrian streets and potential movement shortcuts) and open areas within precincts that may have more restricted access (such as private courtyards and lanes). The analysis of social character, including private–public relationships, helped inform our assessment of the potential of the emerging spaces to contribute to urbanity and to urban life in a democratic and open way.

In the case of the pre-earthquake CBD, photos of streets and open space were sourced from Google Street View (Google, 2016), and the character of the transitional city and post-earthquake CBD spaces was recorded through on-site photography. Figure-ground maps were used as a basis to visualise the morphology of the city pre- and post-earthquakes, and the Blueprint itself was analysed based on the plan developed by CERA and Warren and Mahoney (Warren and Mahoney, 2016). In one specific case a simple computer simulation generated on SketchUp shows the shading in the resulting street after the rebuild. We also used documentary sources to assess what people put forward as desirable through public consultations such as 'Share an Idea' (Carlton, 2013; Christchurch City Council, 2011a, 2011b) and as published in the document *Ideas to Reality* (CERA, 2015b). This was an attempt to identify these desired elements and spaces in the emerging city.

Previous research has shown that regional identity in Christchurch is closely connected to peaceful spaces, greenery and social activity in public spaces (Bell and Matthewman, 2004; Craig et al, 1993; Tavares, 2015). These preferences influence Cantabrians' expectations of the city and their response to urban microclimates, making locals scan and search for places where they can be in a peaceful and pleasant microclimate while in contact with nature. These characteristics of local preferences and behaviours constitute the local concept of urban comfort, and have been investigated through four features of the spaces: microclimate, greenery, social activity and social accessibility. The urban comfort in relation to each feature of the spaces was defined as high, moderate or low regarding the new CBD's qualities. Table 1 sets out the criteria used to define each category.

The emerging city was investigated through maps, drawings and photographs to explore the resulting microclimate, presence of greenery, potential for social activity and accessibility. Results of this analysis are discussed next.

Table 1: Matrix of nominal categories based on features of spaces (microclimate, greenery, social activity and social accessibility)

			Urban comfort		
			High	**Moderate**	**Low**
Feature	**Biophysical character**	**Microclimate**	Protection from winds and sufficient insolation	Some protection from winds and insolation throughout the year, but microclimate is not a main feature of the site	No protection from winds and/or insufficient insolation
		Greenery	Trees for shade and planters throughout the space	Some greenery exists in the space	No greenery exists in the space
	Social character	**Social activity**	Active frontages, pedestrians	Active frontages may be present and pedestrians use the space, but the space is not used as a congregation area	No active frontages and a very quiet space
		Social accessibility	Free access to all people at all times	Does not offer free access to all people at all times	Limited access

Results

In this section, we present the results of our analyses and evaluations for the three time periods.

Pre-earthquakes

The pre-earthquake maps showed a range of types and characters of public spaces. For the purpose of this study, we have classified them as follows.

- **Predominantly pedestrian streets and lanes** are areas planned and designed for congregating people. They are focused on social activity and accessibility (figures 2a, 2b and 2c).
- **Active green spaces** have some greenery and bring people together, generating social activity (figures 2d, 2f and 2g).
- **Functional lanes** offer social accessibility and pedestrian connections, but tend to be unattractive, hard landscapes with little social activity.
- **Arcades** offer social accessibility during business hours, but are privately managed. This is a predominant typology in the emerging central city (see the results on CERA's Blueprint and figure 2e).
- **Car parks** are hard landscapes dedicated to space for parking cars, with no social function.

Figure 2 shows the map and location of a range of central city settings and some examples extracted from the 2007 Google Street View.

In terms of microclimate, the predominant east–west streets in the central city received limited sun, and the significant number of very tall buildings generated strong down-winds and gusts at street level. Cashel Mall was an exception in that it received some sun due to height restrictions on the north side, but it was open to strong easterly winds. New Regent Street was sheltered from the east, but it was also shaded by a large building to the north-west (figure 2a). Three streets had a few large trees, either on public land – Cashel Street between Oxford Terrace and Colombo Street, and Gloucester Street close to Oxford Terrace – or on building setbacks – Manchester Street. Overall, however, pre-earthquake Christchurch CBD streets and lanes did not offer any significant level of thermal comfort or green amenity, and previous research suggests that public perceptions of important streets in the central city were largely negative (Tavares, 2015, pp 137–138).

The main exception was the west-facing portion of Oxford Terrace, where shelter from the east and sun exposure to the west led to development of 'The Strip' (figure 2d), a line of cafés and restaurants with outdoor areas overlooking the green Avon corridor. Two relatively new developments – Sol Square (figure 2f) and Poplar Lane (figure 2g) – showed the possible directions for the future. Developed around existing service lanes, both became prime hospitality sites: Sol Square with several bars, restaurants and shops, and Poplar Lane centred on a craft beer pub. Notably, all three of these developments were social spaces and all three featured nightlife. While Sol Square and Poplar Lane were more intimate spaces, in Oxford Terrace the social character was combined with a favourable microclimate and outlook over the Avon, and was busy from lunchtime onwards. It is no coincidence that this favourable location is the focus of investment in the rebuild.

Figure 2: Pre-earthquake public spaces (Base map: CERA, 2010, used under CC BY 4.0 NZ): (a) New Regent Street (Photo: Google Maps Street View, 2007d); (b) Chancery Lane (Photo: Google Maps Street View, 2007b); (c) Liverpool Street (Photo: Google Maps Street View, 2007c); (d) Oxford Terrace – 'The Strip' (Photo: Michelle Sullivan); (e) Cathedral Junction and Press Lane (Photo: Google Maps Street View, 2007a); (f) Poplar Lane (Photo: Martin Bennett and Google Maps Street View, 2007e); (g) Sol Square (Photo: Google Maps Street View, 2007f, and Neil Macbeth).

Post-earthquake temporary sites

The large range of transitional projects in Christchurch has been widely reported and investigated. Our analysis of this 'in-between time' (Bowring and Swaffield, 2013) is focused on experiments that explored the potential for change and improvement. After damaged buildings were cleared, the central area lost virtually all of its spatial definition and became essentially open brownfield with remnant large buildings (figure 3 highlights the change). However, the clearance also created opportunity, from which a range of 'transitional' projects and programmes was developed, with different aims, such as 'Gap Filler' (Gap Filler,

Figure 3: Pre-earthquake (2010) and post-earthquake (2015) figure-ground maps. (Base maps: CERA, 2010, 2015a, used under CC BY 4.0 NZ.)

2016) and 'Greening the Rubble' (Greening the Rubble, 2016). A notable central city project with implications for urban comfort in the future compact city was the Re:START Mall.

Re:START was a temporary retail mall created with converted shipping containers (figure 4) on vacant land at the west end of Cashel Mall. Four of its features that were important in the context of urban comfort were: first, the limited height of structures (maximum two containers – approximately 6 metres), which allowed sun into the pedestrian areas; second, the configuration of small intimate spaces that provided wind shelter; third, the creation of attractive planting areas; and fourth, the inclusion of a variety of social opportunities and activities, including outdoor cafés and food stalls (see more details in table 2). Interviews with users identified high levels of urban comfort (Tavares, 2015), and a pedestrian survey revealed that Re:START Mall had more foot traffic in 2013 than the old City Mall had in 2008, before the earthquakes (Fairfax, 2013).

CERA's Blueprint and the emerging city

CERA's Blueprint conveys two strong visions relevant to this discussion. The first is that large parts of the future central city will be 'green' (conceived in general terms), particularly when compared with the previous urban configuration. The Blueprint proposes retaining and redesigning the Avon River corridor; creating

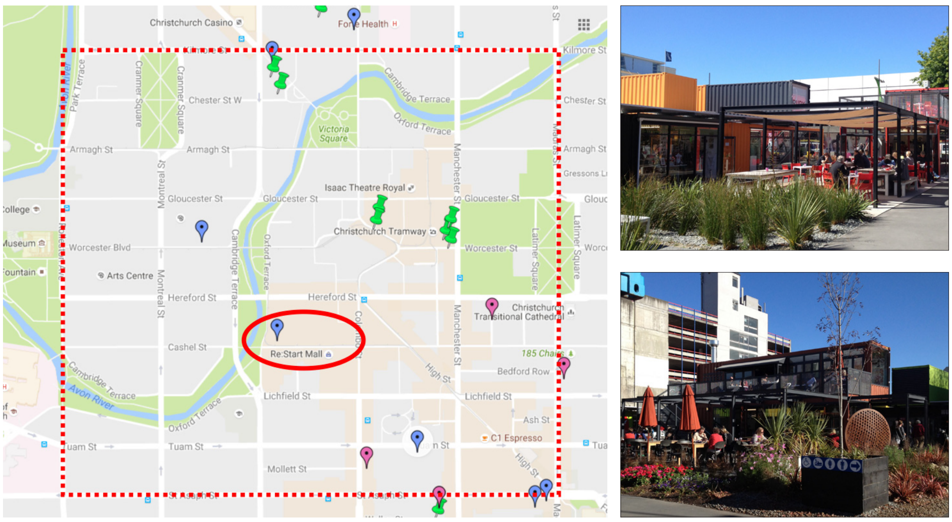

Figure 4: Re:START Mall in its temporary site at Cashel Mall. (Base map: Gap Filler, 2016; Photos: Silvia Tavares.)

eastern and southern 'green frames', which combine with Te Papa Ōtākaro/Avon River Precinct to delimit the new CBD; a new north–south boulevard (Manchester Street); and extensive green streets, squares, lanes and courtyards (figure 5).

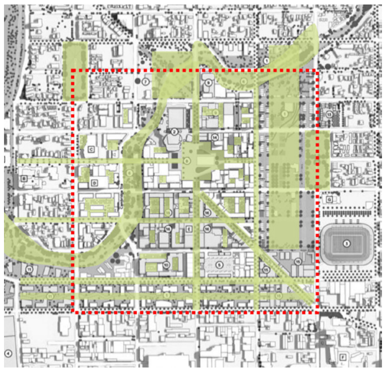

Figure 5: Blueprint and its proposed green spaces. (Base map: CERA, 2012, used under CC BY 3.0 NZ.)

The Blueprint's second key vision is of a 'precinct' approach to the redevelopment, designating different areas of the CBD for different types of activity – for example the Retail Precinct, the Health Precinct, the Performing Arts Precinct and the Justice and Emergency Services Precinct. Across the plan too is a series of 'anchor' projects designed to encourage further development in the central city. Implementation of this approach is distributed between Crown agencies and the city council, working in partnership with large developers. The precincts most advanced in their development are the Retail (figure 6) and Justice and Emergency Services (figure 8) precincts. We include illustrations from them, together with a recently completed major private development (the Awly building – figure 9) that is across the Avon to the north-west of the central city and illustrates the style of development that predominates across the rebuild.

The Retail Precinct is centred between Colombo Street and the Avon, and includes the site of the former Re:START Mall. Several large developments to the north of Cashel Street are well advanced, and plans include courtyards and lanes (figure 6).

Figure 7 shows the potential for using basic modelling tools to create appropriate windbreaks and buildings that respond to sun geometry. Local climate is influenced strongly by rapidly changing winds. Cool north-easterly winds are common; hot, dry north-westerlies are possible at any time and can raise temperatures by 10–15°C within an hour, generating summer maximums of more than 30°C. Cold south-westerlies are also present all year, but more frequent in winter, bringing rain as well as reducing temperatures and thermal comfort (McGann, 1983). In this climatic context, the potential of east–west streets is stronger than it is for north–south streets because, for most of the day, one façade could be in the sun. In north–south streets the wind is less of a problem, but sun during the day in less consistent.

Figure 6: Retail Precinct. (Photos: Silvia Tavares; Base map: CERA, 2012, used under CC BY 3.0 NZ.)

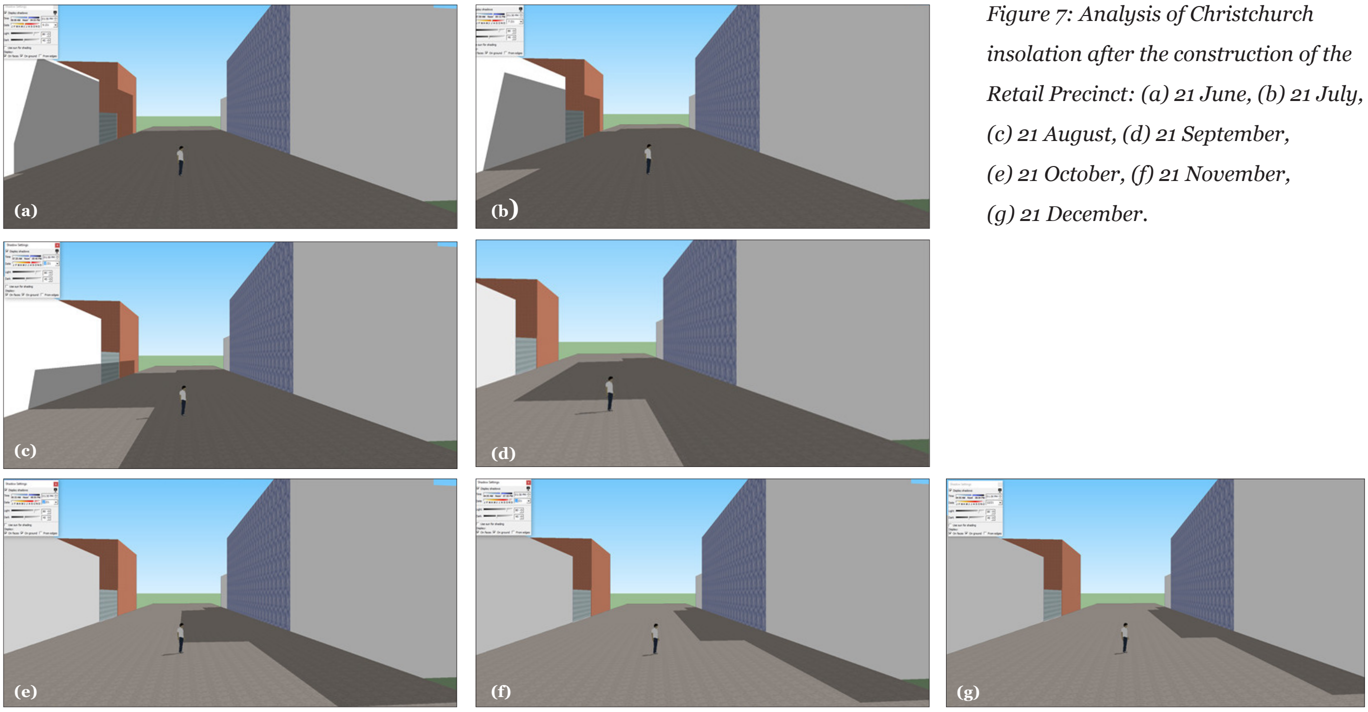

Figure 7: Analysis of Christchurch insolation after the construction of the Retail Precinct: (a) 21 June, (b) 21 July, (c) 21 August, (d) 21 September, (e) 21 October, (f) 21 November, (g) 21 December.

As a comparison, figure 4 shows the same street during the transitional phase. Not only did Re:START receive greater foot traffic than pre-earthquake Cashel Street (Fairfax, 2013), it may also prove to have outperformed the street post-earthquakes.

The Justice and Emergency Services Precinct (figure 8) is located a block further south, running east–west along Lichfield Street. It also has lanes and courtyards.

The Awly building (figure 9) is a private development located west of Durham Street, opposite the historic Provincial Buildings. It includes a courtyard as well.

Figure 8: Justice and Emergency Services Precinct. (Photos: Silvia Tavares; Base map: CERA, 2012, used under CC BY 3.0 NZ.)

Summary of results

Table 2 summarises the results from the analysis of the central city pre-earthquakes and the two times post-earthquakes – the initial temporary sites and the longer-term Blueprint. It classifies the qualities of the spaces into high, moderate and low, according to their microclimate, greenery and social activity and social accessibility, as we explained in the research design section.

Table 2: Summary of results from the pre-earthquake, temporary sites and Blueprint analysis

Sites		Urban comfort: Microclimate	Greenery	Social activity	Social accessibility	Notes
Pre-earthquakes	New Regent Street	🟨	🟥	🟩	🟩	N-S street, no green features, active frontages, people on the street
	Chancery Lane	N/A	🟥	🟩	🟨	N-S lane, no green features, some shops, but in an indoor area
	Liverpool Street	🟨	🟥	🟨	🟩	N-S street, no green features, no active frontages, public free access but few pedestrians
	Oxford Terrace	🟩	🟩	🟩	🟩	West-facing strip, protected from easterly winds, facing the Avon River
	Cathedral Junction / Press Lane	N/A	🟥	🟩	🟨	Covered pathways/lanes, no green features, some shops, but in an indoor area
	Poplar Lane	🟨	🟨	🟩	🟩	Courtyard protected from the wind, but little sun access apart from midday. Few green features and largely used by bars and restaurants generating the social character
	Sol Square	🟨	🟥	🟩	🟩	Courtyard protected from wind, but little sun access apart from midday. No green features and largely used by bars and restaurants generating the social character
Transitional city	Cashel Street	🟨	🟩	🟨	🟩	E-W street unprotected from easterly winds but with reasonable sun access due to the low height of containers
	Re:START courtyards	🟩	🟩	🟩	🟩	Sunny and wind-sheltered courtyards with some green features and predominantly social character due to shops, food containers and bars
Blueprint, post-earthquakes	New Retail Precinct	🟩	🟨	🟩	🟨	Part of the new Retail Precinct is the previous Oxford Terrace. It also has a courtyard that is protected from winds and will be sunny up to mid-season (little sun during the winter), but it belongs to a private development and will be closed or privately secured after hours. Active frontages with retail establishments on the ground floor
	Justice and Emergency Services Precinct	🟨	🟨	🟥	🟥	The building has a courtyard that is protected from winds and will be sunny up to mid-season (little sun during the winter), but it belongs to a private development and will be closed or privately secured after hours. Ground frontages are offices and therefore not active. Public areas are not fully visible from streets
	Awly building	🟨	🟨	🟨	🟨	The building has a courtyard that is protected from winds and will be sunny up to mid-season (little sun during the winter), but it belongs to a private development and will be closed or privately secured after hours. Active frontages with retail establishments on the ground floor

Key: 🟩 = high; 🟨 = moderate; 🟥 = low; E-W = east–west; N-S = north–south

Discussion

This study was aimed at investigating the trends in urban comfort, such as preferences for social activity and for peaceful retreat spaces with a comfortable microclimate and contact with nature in the city. The comparison between the pre-earthquake central city and the proposed Blueprint maps shows an apparently dramatic increase in green areas (see figures 5 and 10). However, the post-earthquake 'transitional city' sites are greener than the permanent Blueprint solutions, and the Blueprint has decreased the public accessibility of green and pleasant microclimates by concentrating on private or semi-private courtyards.

Greening of the public realm is another aspect that appears to be aspirational rather than specific. Many 'green' zones are intended, in practice, to be largely built-up. The amount of greenery appears to be linked to funding sources for upgrades. Projects funded by central government seem to be generously treed. Major effort has been focused on reconfiguring the Avon corridor, including the Margaret Mahy Playground. Notably, however, proposals to dramatically remodel Victoria Square were toned down in the face of public protest. In contrast, the street projects that the Christchurch City Council is funding appear less well-endowed with greenery due to capital constraints. Private investment is focused internally within projects, as street frontage setbacks are no longer required, and the size of new courtyards means most greening is on a small scale, not providing the desired ecological or cultural services Ahern (2007) suggests. Few new buildings have adopted soft-green strategies such as green roofs, but most use green building technologies particularly for energy efficiency.

In terms of social character, a key principle for compact cities is mixed-use – ideally within each building. Many European cities used as models for the compact city ideal have retail and hospitality on the ground floor, offices above and living in the upper part of buildings (see Carmona et al, 2010). In other situations, a variety of functions is gathered around small squares or streets. The

Figure 9: Awly building. (Photos: Silvia Tavares; Base map: CERA, 2012, used under CC BY 3.0 NZ.)

precinct model adopted in Christchurch is in many ways a return to the functional differentiation that characterised planning in the 1960s and 1970s (Cocozza, 2007; El-Dahdah, 2005). An interesting comparison can be made between Poplar Lane as it was developing pre-earthquakes and the Retail Precinct. The pre-earthquake, 100-metre stretch of Poplar Lane from Tuam Street to Lichfield Street included bars and restaurants, specialist retail, art workshops, offices, residential accommodation and other hospitality functions, offering the diversity expected from cities. In contrast, the new precinct has a corporate 'quasi-mall' character that, as Carmona (2010, p 139) points out, generates 'a loss of authenticity and growth of "placelessness"'. The Retail Precinct is also shaping up to feature a more limited range of functions – essentially branded retail, restaurants and bars, and professional offices. The street frontages will be largely offices and retail that do not use the street space; therefore streets will be predominantly used for movement, not contributing to social spaces.

CERA (2015c) made the emerging courtyards a requirement to ensure the precincts incorporate outdoor space (Harvie, 2016). The way CERA describes these courtyards is aligned with what we have previously identified as retreat spaces:

> Courtyards are small open spaces typically located towards the interior of blocks and enclosed by buildings. Their small scale and inward location create sheltered and comfortable spaces which provide places of respite in the midst of the activity of the city. Their discreet locations make them places to be discovered; access is often via laneways or through existing buildings. In some instances, courtyards are privately managed and maintained but provide public access for most of the day. (CERA, 2015c, p 68)

However, the final sentence signals a significant shift in the character of these spaces – in terms of their ownership and control. Although we have not mapped all public open spaces, from the spaces identified in figure 2, only the ones highlighted in the 2010 map (figure 10a) were private. In the Blueprint (figure 10b), however, the spaces highlighted in red are private courtyards, while the orange areas are spaces that appear open but may not feel so as these new developments and precincts are adopting a variety of control and security strategies. Loukaitou-Sideris and Banerjee (1998) have two categories for space

(a) **(b)**

Figure 10: The shift, with the main green spaces and streets (green), predicted green spaces that may be semi-public (orange) and private courtyards (red). (Base maps: (a) CERA, 2010; and (b) CERA, 2012, used under CC BY 4.0 NZ and CC BY 3.0 NZ.)

control: hard and soft controls. Hard control is active control such as private security and closed-circuit television systems; soft control is passive control, such as solutions that discourage undesirable activities. Following all these changes, the future built form will occupy a smaller net footprint, and significant areas of internal courtyards will be created (see figure 10b).

Hard control has been widely adopted in the new courtyards. Figure 9 shows the relationship between the Awly building and the street, clearly demonstrating the control strategies adopted for security based on gates. Soft control has been suggested for some areas such as the East Frame (Fletcher Living, 2016; RNZ Live News, 2015) and the Justice and Emergency Services Precinct, which give 'hints' that the space is privately managed. Hence, although there are more courtyards, they are essentially *differential collective spaces,* which Scheerlinck and Schoonjans (2016, p 50) define as follows*:*

> The combination of these filter tactics defines the depth sequence: some are physical – like the steps, fence, doors and trees – while others need to be tested by their transparency or visual exposure. One can easily look over or through the fence and visually control the next territory, while in other cases this visual control is avoided explicitly. In this instance, the boundaries with territorial meaning are the fence with the gates and the internal separating door. These are the filter tactics that actually reduce the collective use of space. Each time someone crosses a territorial border, it means a reduction in accessibility, a selection of admitted or wanted users.

Drawing these threads together, the analysis highlights several important changes in the future character of open spaces in the central city of Christchurch. Green infrastructure is concentrated in the legacy area of the Avon corridor, and in selected other government-led projects. The main east–west and north–south public streets are likely to continue to be heavily shaded by buildings and open to the wind, with few setbacks along the building frontages. The microclimate of the public realm appears to have received little attention, and outdoor activity is likely to continue to be focused on areas that have 'legacy' qualities, such as the west-facing Oxford Terrace, as well as on the new internal courtyards within the private developments. The precinct model of development means that the functional diversity that was emerging in parts of pre-earthquake Christchurch is unlikely to be replicated in the central city; frontages are likely to be mono-functional and activity episodic. The ownership patterns of the new precincts also mean that many attractive courtyard spaces will be largely privately owned and controlled. Hence, while they will outwardly offer both retreat and social opportunities, these will be mediated through the economic functions of the surrounding buildings – high-end retail, hospitality, professional offices. A summary evaluation of the likely outcomes is *urban comfort lite*.

Conclusion

In this paper we have analysed and compared the status of urban comfort in pre-earthquake and post-earthquake central Christchurch, based on features that constitute the local concept of urban comfort – access to social activity and peaceful retreat spaces, the possibility of being in a comfortable microclimate and having contact with nature in the city (Tavares, 2015). The intent has been to assess the rebuild of Christchurch as an experiment in integrating green infrastructure and compact city imperatives in urban design. We found that pre-earthquake Christchurch did not have many small public open spaces within the central area that offered any level of urban comfort. However, in the decade before the earthquakes a few examples emerged focused on mixed-use courtyards and lanes, such as Poplar Lane. The 2010–2011 earthquakes effectively swept the board clean, leaving the post-earthquake central city largely empty and full of opportunities. Transitional projects such as Re:START offered the potential to experiment with new solutions and highlighted the value of an active, sheltered and sunny public realm. The Blueprint appeared to offer larger areas of 'green' space and a more compact CBD, drawing on both established principles and public preferences.

However, with the adoption of the precinct model and its configuration of new development into large blocks with single ownership and a limited range of functions, neither established theories (Jacobs, 1992; Speck, 2012) nor lessons from the temporary sites appear to be coming forward strongly in the design and configuration of the new open spaces. While the number of courtyard spaces will increase, most of these are not public and, as Loukaitou-Sideris and Banerjee (1998) point out, the hard control of spaces makes them less accessible. Furthermore, the conventional outer edges of the new precincts do not appear to enhance the urban comfort of the adjoining public streets.

As Leo Hollis (2009, p 6) puts it, 'the city is not a rational, ordered place but a complex space that has more in common with natural organisms such as beehives or ant colonies'. A few modest changes to the strategy could have generated more satisfactory outcomes in terms of urban comfort, and hence better resolved green and compact urban principles. Specifically:

- microclimate design of the public realm should have been fundamental from the start (Brown, 2010);
- solar access to the street could have been improved with lower buildings or larger setbacks, particularly in the north side of east–west streets, and with greater use of building configurations to create wind shelter for the public realm as well as the private (Erell et al, 2011);
- a higher degree of mixed-use would create more active street frontages and urban diversity (Jacobs, 1992; Owen, 2009; Speck, 2012);
- courtyards and cross-block lanes could have been created as public rights of way and ensured a more inclusive and active public realm across the whole central city (Loukaitou-Sideris and Banerjee, 1998); and
- courtyards could be planned to better respond to both ecological purposes and on-foot mobility (Ahern, 2007).

Overall, despite the investment in iconic projects around the edge of the central city, the quality of the public realm in the central city itself appears to be compromised in favour of private development. Commercial developers are creating high-quality microclimates within their holdings, disconnected from the public spaces. The resulting streetscapes risk becoming a residual realm, corridors linking commercial buildings rather than focal points of activity (Jacobs, 1992). The compact city and green city ideals both argue that public life cannot be an afterthought, and public streets and open space should not be a means to service development but rather a focus of public life that defines the character of the wider urban setting. Regrettably, opportunities for achieving this vision in the Christchurch central city are slipping away, as both green and compact liveable city principles are subsumed by the hard logic of commercial imperatives.

Finally, we must note that this study was aimed at exploring the changes in the nature of the public spaces in the Christchurch central city during a period of rapid change. A limitation is the nature of the qualitative data analysed, which does not allow for an in-depth investigation isolating the features (or variables) such as sun, shading, wind, landscaping and connectivity. This more detailed analysis would be a useful future study, which could focus first on the changes in specific sites, and then project results for the general nature of the emerging city and its public spaces.

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Landscape Infrastructure in Sydney: Exemplars of Landscape Synergies and Capacity by Design

JOSEPHINE NELDNER AND SIMON KILBANE

The landscape architecture undergraduate programme at the University of Technology Sydney introduced landscape infrastructure as a subject into its curriculum in 2016. This subject contained two aims relating to the application of landscape infrastructure to an Australian context, extending beyond its North American origins. First, it aimed to identify and test the principles of landscape infrastructure that could be 'generalisable' and that exist outside of site specifics or a particular context. Second, it sought novel instances of its application in the Sydney region. Principles were distilled through an evaluation of relevant literature and were then tested through two exercises.

The first required students to reimagine *The GreenWay*, a multifunctional landscape corridor in Sydney's Inner West and part of a proposed metropolitan-wide *Green Grid* network. Students then applied the framework of landscape infrastructure through design proposals in one of Australia's fastest-growing urban centres, Parramatta. The findings of this research distilled and clarified the definition of landscape infrastructure; demonstrated the inherent capacity of landscape to act as the conduit for multifunctional, flexible, localised and synergistic infrastructural systems; and highlighted its potential for application in an Australian context. This work supports landscape infrastructure's position to move beyond the integration of infrastructure within landscape and instead proposes that landscape itself is infrastructural.

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RESEARCH

Landscape architecture is a discipline characterised as expansive, diverse, fluid and open, which sits on the boundaries of a range of disciplines including art, engineering, urban design and architecture (Thompson, 2014, pp 22–23). Landscape architecture can also be described by what it aims to achieve; for example, Weller (2006) describes its role as a 'holistic enterprise … that is at best both art and science' (p 71). From a research perspective it is a discipline with a growing demand for the 'production and consumption of knowledge' while simultaneously requiring development concerning how knowledge generation and validation occur (Deming and Swaffield, 2011, pp 1–44).

For its part, landscape infrastructure contributes to the ongoing development of landscape architecture by generating continued discourse and new practice that 'reimagines' infrastructure 'for the advancement of our culture' (Aquino, 2013, p 7). Landscape infrastructure has been described as a methodology (SWA Group, 2015), a set of attributes (Hung, 2013, p 17) and a project (Bélanger, 2012, p 290). Deming and Swaffield propose that emergent ideas in landscape architecture that are yet to develop theoretical status 'should be more correctly termed frameworks' (2011, p 32) and as such cultivate discourse and practice that develop and validate new knowledge. Landscape infrastructure is therefore a framework for discourse in and practice of landscape architecture and one that this research embraces.

An overview of landscape infrastructure

Pierre Bélanger, a leader of the framework's discourse, considers that landscape infrastructure emerged as a response to urban and industrial decline in North American cities. As he explains, the task of determining and consigning infrastructure has previously been allotted to engineers and the 'historic lack of engagement of infrastructure as a territory of design stems from its dystopic [sic] and banal nature' (Bélanger, 2012, p 281). Landscape infrastructure therefore emerges as an alternative to what Bélanger describes as the 'overexertion of engineering and the inertia of urban planning' (ibid, p 276) to reconsider 'a landscape of systems, services, scales, resources, flows, processes and dynamics'. Mossop (2006) also calls for a re-examination of landscape, highlighting that 'all types of spaces are valuable' and therefore worthy of designers' consideration (p 171). It follows that the challenge is to 'engage' with infrastructure *through* landscape, including 'mundane parking facilities, difficult spaces under elevated roads, complex transit interchanges, and landscapes generated by waste processes' (ibid). These types of systems are carried by landscape, are of landscape, and so should be under consideration by landscape architects through landscape infrastructure frameworks.

Landscape's capability to carry and generate infrastructure was first prescribed by landscape urbanism. Landscape urbanism repositions landscape as the primary system at the centre of all systems that determine environments. Corner (2006) describes landscape urbanism as 'first and last an imaginative project, a speculative thickening of the world of possibilities' (p 32) and from its origins a focus on infrastructure is apparent. According to Weller (2006), 'landscape is the infrastructure to which all other infrastructure elements or networks are answerable' (p 79), while Waldheim (2016) suggests it is positioned as 'thinking urbanism through the lens, or lenses, of landscape' (p 2). This notion is carried and translated to landscape infrastructure and is an idea developed further by reimagining historical landscapes, such as the ancient Silk Road (Carlson, 2011) where sites are 'the result of modification or utilisation' or have been shaped in order to achieve 'facilitation of program' – an infrastructural positioning. Landscape becomes capable of conveying infrastructure when landscape itself is understood as infrastructural. Landscape is redefined as capable of generating new strategies for infrastructural systems through their integration within the landscape itself.

Landscape infrastructure, ecology and culture

Landscape urbanism has extended into other new areas of discourse, in particular ecological urbanism. Landscape urbanism is credited by ecological urbanism as the means by which ecology, as it is understood by the design disciplines, was 'brought' into urbanism (Hagan, 2015, p 29). Gray (2011) also suggests that landscape urbanism has been a means to 'reintroduce critical connections with natural and hidden systems'. A focus on ecological systems as essential is inherited by landscape infrastructure, repositioning ecology as an infrastructural system. Landscape is therefore proposed as the carrier for infrastructure in all its forms, and landscape infrastructure recognises not only traditional – sometimes called grey – infrastructure but also blue and green infrastructures, which concern hydrological and ecological systems respectively (Benedict and McMahon, 2006; Kilbane, 2013, Pungetti and Jongman, 2004).

Infrastructural systems (grey, blue and green) are mediated in landscape infrastructure through a position of 'cultural relativity' (Waldheim, 2016, p 50). This is most clearly articulated in relation to ecology, where landscape infrastructure follows landscape urbanism's 'deployment of ecology as model or metaphor' in which ecology is 'a model for understanding the complex interactions between nature and culture' (ibid). Infrastructure systems are therefore culturally and socially dynamic, as well as the deliverers of services, structures and processes needed to sustain urban life (Millennium Ecosystem Assessment, 2005).

These multifunctional qualities (Ahern, 2007) or polyfunctional and synergistic qualities (Ezban, 2013) are proposed as localised solutions that generate public space and adaptive, productive new landscape forms, particularly those with hydrological focus. In Ezban's 'Aqueous Ecologies' project (2013), ecology and landscape infrastructure are innately connected and mediated by culture. Ezban forecasts landscape's capability to enable 'unique connections to adjacent communities and regional ecologies'. Infrastructural systems and processes become the means of supporting new types of communities and new understanding of how we structure our environments. This is supported by Hung (2013), who sees infrastructural approaches as important to create greater connectivity for 'people to places, communities to communities ... nature to city ... and contribute to the betterment of urban life' (p 19).

Praxis and principles of landscape infrastructure

Landscape infrastructure discourse positions landscape architecture to consider systems and processes previously unconsidered by or unassociated with the discipline. The SWA Group, based in the United States of America, has documented examples of practice for the framework through the recent publication *Landscape Infrastructure: Case Studies by SWA* (The Infrastructure Research Initiative at SWA, 2013). It identifies and emphasises the capacity of landscape to carry infrastructure, explaining that it is landscape's ability to consider the relationships between 'interconnected and interdependent systems' (Hung, 2013, p 14) that gives it credence to reconsider infrastructure. Hung, a member of the SWA Group, discusses the principal differences between infrastructure as traditionally approached and the 'new paradigm' of landscape infrastructure, defining three core principles that were distilled into a table (see table 1) to establish the basis for further enquiry.

- Principle 1: Landscape infrastructure is *flexible and adaptable*.
- Principle 2: Landscape infrastructure considers *decentralised* and locally managed solutions.
- Principle 3: Landscape infrastructure is *multifunctional* such that 'the city and its infrastructure are one and the same' (ibid, p 17).

Table 1: Traditional infrastructure versus landscape infrastructure according to Hung (2013)

Traditional infrastructure		Landscape infrastructure	
Traditional approach	Example	New paradigm	Example
Successional, may quickly become obsolete Performance fixed to set criteria	Streets for vehicular movement Highways for peak-traffic efficiency	**Flexible and adaptable** (Principle 1) Performance not fixed: design for multiple parameters and change (adaptive and resilient)	Streets as pedestrian connections, green corridors, stormwater management and urban heat mitigation
Centralised, single-purpose system	Channelled waterways Rail corridors Energy	**Decentralised** (Principle 2), allowing for localised, multifunctional solutions	Water sensitive, localised stormwater management Rail corridors as recreation trails, promoting ecological connectivity, social and health benefits and sustainable local transport options Local-scale renewable energy generation, such as solar and wind
Efficiency based, focused on one system; does not consider broader or related issues Aims to maximise benefits to one system in isolation	Stormwater and sewage discharge into waterways and seas Roads for vehicular movement only	**Multifunctional** (Principle 3), carries many systems simultaneously Aims for synergistic relationships Diverse, optimised condition; city and infrastructure are one and the same	Urban runoff retention in wetlands, recycled water used for irrigation, resulting in ecological benefits, cost benefits, social benefits through greater open space amenity Roads as corridors for connectivity to open space, public transport hubs, stormwater management, resulting in sustainable transport, greater use of public space, economic development

Other theorists reinforce the paradigm shift and reframing. For instance, Bélanger (2012) explains that landscape infrastructure slides 'across different scales, systems and strategies' (p 301) aligning with the principles of flexibility/adaptability and multifunctionality. In addition, he gives an expanded list of principles that include 'flexible', 'synergistic', 'multidisciplinary', 'distributed and disaggregated' and 'regionalised' or localised (ibid, pp 305–309).[1] The principles of flexibility, synergy and localised systems align with the distillation of principles used by this research.

Research aims

This research had two aims.

1. Identify and test landscape infrastructure principles: Landscape infrastructure offers repeated claims about what constitutes its approach. Based on Hung's (2013) principles, this research sought to understand the

fundamental or 'generalisable' principles of landscape infrastructure that exist beyond a particular geopolitical context and how these differed from traditional approaches to infrastructure design and management. In the first instance, an existing landscape was reimagined as infrastructure in order to test identified principles. In the second instance, new types of landscapes were proposed for a region that has been essential to the growth of Sydney historically and will continue to be so in the near future.

2. Conduct a detailed investigation and application in an Australian context: This research aimed to apply the framework of landscape infrastructure in the Sydney region through a series of investigations and propositional design exercises that effectively communicated the principles identified in meeting the first aim of the research. These were applied to investigate sites through both thinking and design processes described and recognisable as *landscape infrastructure*. To achieve this aim, it was first necessary to consider landscape *as* infrastructural and to understand its potential to carry other infrastructural systems. It was intended that the investigative process would identify and generate examples of potential Australian landscape infrastructure. Emulating the framework's shift away from the master plan towards strategies that embrace open-endedness and uncertainty was fundamental to the success of the application.

Method

Undergraduate landscape architecture students were engaged to critically investigate the novel application of landscape infrastructure in an Australian context. This involved two phases undertaken between March and May 2016, with each phase aligned to its particular geographical location. Students used a variety of tools across a range of scales, including expert briefings and site visits; mapping; design with computer aided drafting (CAD) programs, such as AutoCAD and Rhino; and the construction of sketch and final models to develop designs.

Study area: The GreenWay *and New Parramatta*

To identify potential sites for investigating the application of the framework, it was necessary to return to the literature to identify a means of selection. The literature demonstrates that retrospectively considering existing sites as examples of the framework is an accepted technique applied by academics in the field. Mossop (2006) discusses the designs of Canberra and of Victoria Park and Clear Paddock Creek in Sydney as examples that illustrate infrastructure as 'generative public landscape' (p 171). Carlson (2011), in his 're-contextualising' of historic landscapes as examples of landscape infrastructure, 'expands' and 'solidifies' the redefinition of existing landscapes as infrastructural, suggesting that we understand landscape as 'the operative ground for infrastructure' and characterising 'any landscape intervention as infrastructural'. The SWA Group also retrospectively repositions past project case studies, including the Buffalo Bayou promenade, a project started in the 1980s (Aquino and Hung, 2013). This survey established a method for discussing and claiming existing landscapes as examples of landscape infrastructure. Landscape infrastructure in the Sydney context was – correspondingly – thereby identified through considering the ability of infrastructure to form new types of public space and contribute to quality of life.

Phase one: The GreenWay

The first site students considered was an existing landscape, *The GreenWay* (figure 1), a multi-use corridor in Sydney's Inner West[2] and part of a broader metropolitan-scale *Sydney Green Grid* network (Office of the Government Architect NSW, 2013). *The GreenWay* was investigated as an example of an established landscape also functions as infrastructure as well as a new type of public space. While this site is currently unrecognised more widely as an example of landscape infrastructure (the theory was unknown to those who work within it), the corridor shares several characteristics with SWA case studies, including the Buffalo Bayou promenade, and is crossed by major roads such as the high-volume Parramatta Road.[3] *The GreenWay* corridor includes disused industrial and contemporary rail transportation, along with ecological *bushcare* sites.[4] It is also a popular, active transport trail for cycling and walking and a historical drainage line and canal, which connects Cooks River to Sydney Harbour as well as adjacent parks.

Students were tasked with reimagining *The GreenWay* as an example of landscape infrastructure in Sydney by presenting creative mapping in poster format to communicate how *The GreenWay* corridor operates as landscape infrastructure to an unfamiliar, non-expert audience. After a briefing and tour of the corridor by *The GreenWay* place manager,[5] the exercise involved visiting the site, and mapping and illustrating landscape infrastructural qualities and attributes. To produce a poster the students needed to distil both theory and site

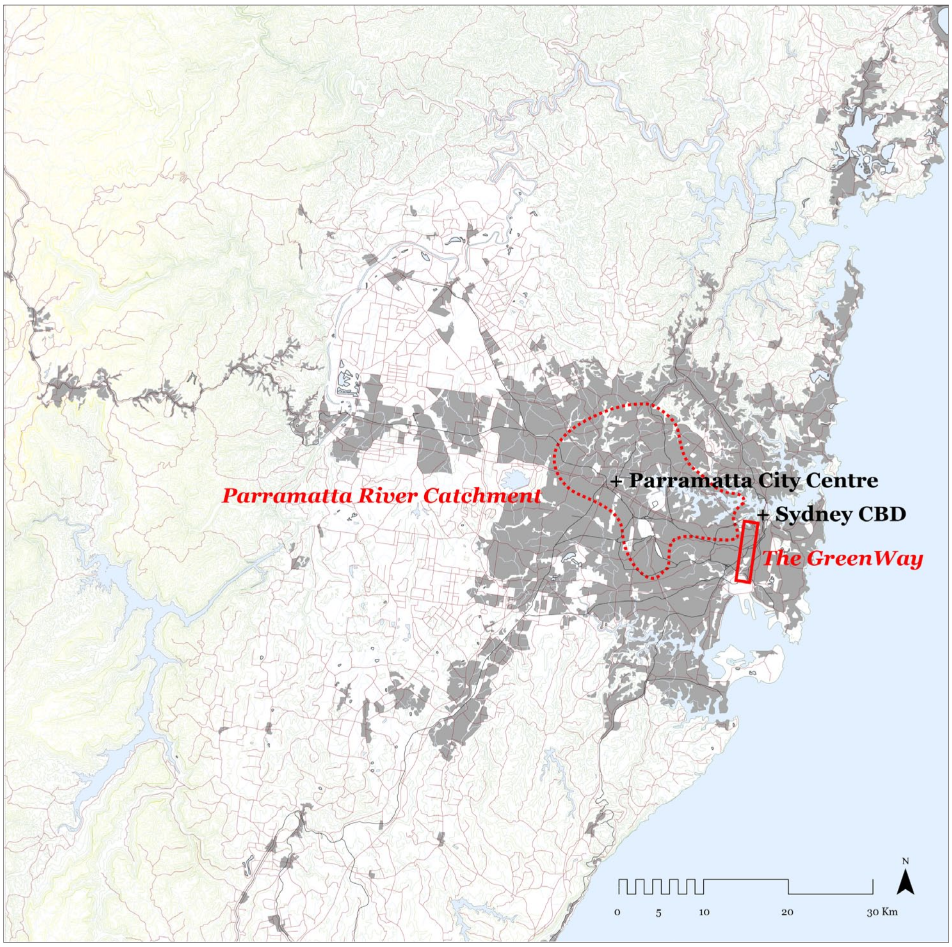


Figure 1: Location map of The GreenWay *and the Parramatta River catchment. (Image: Geoscience Australia. 2007.* Geodata topo 250K. Series 3 for Google Earth, 1:250,000 scale vector map data *(DVD). Geoscience Australia, Canberra.)*

and each student sought to illustrate the complexity of both. This exercise posed three challenges to the students:

1. evaluating the fundamental principles of landscape infrastructure based on literature;
2. translating principles to an existing site within Sydney;[6] and
3. successfully distilling and communicating landscape infrastructure outside of the discipline of landscape architecture to a lay audience through an exhibition.[7]

Because their work had to be suitable for a lay audience, students needed to both distil and apply principles in this phase. As a result, this phase addressed both aims of this research.

Phase two: New Parramatta design proposals

The second site chosen for investigation, Parramatta, is located above a weir that separates the Parramatta River from the Parramatta Estuary and Sydney Harbour. Containing several World Heritage listed and significant archaeological sites associated with indigenous, convict and colonial heritage, this growing area is Sydney's second most important centre for business, employment, health and justice. Key projects already under way include *Parramatta Square*, which is surrounded by a new campus for Western Sydney University, and new residential construction including a river foreshore tower over 50 storeys high.

In the Parramatta design phase, students considered how the application of landscape infrastructure principles could create new types of landscapes in Sydney. This involved investigating and developing ways to apply a landscape infrastructure framework in a propositional capacity. This work was underpinned by site visits and detailed briefings from local expert stakeholders, including the Parramatta City Council[8] and the Parramatta River Catchment Group.[9] They outlined issues facing the region, explained planning responses and offered two clear additional design agendas:

1. to improve water quality in the Parramatta River to achieve a safe level for swimming; and
2. to decrease urban heat in and around the centre of Parramatta.

The project site was defined at two scales. The first comprised the entire Parramatta River catchment and the second was a specific design site where students could develop their own focus and study as detailed landscape infrastructure strategy. Any systems that could be described as *infrastructural* were open for consideration as a topic of study. Strategies had to address a challenge for the region by including in greater detail a *catalyst* or an *exemplar* to enable further positive change staged over 30 years (to 2045).

Phase One: *The GreenWay*

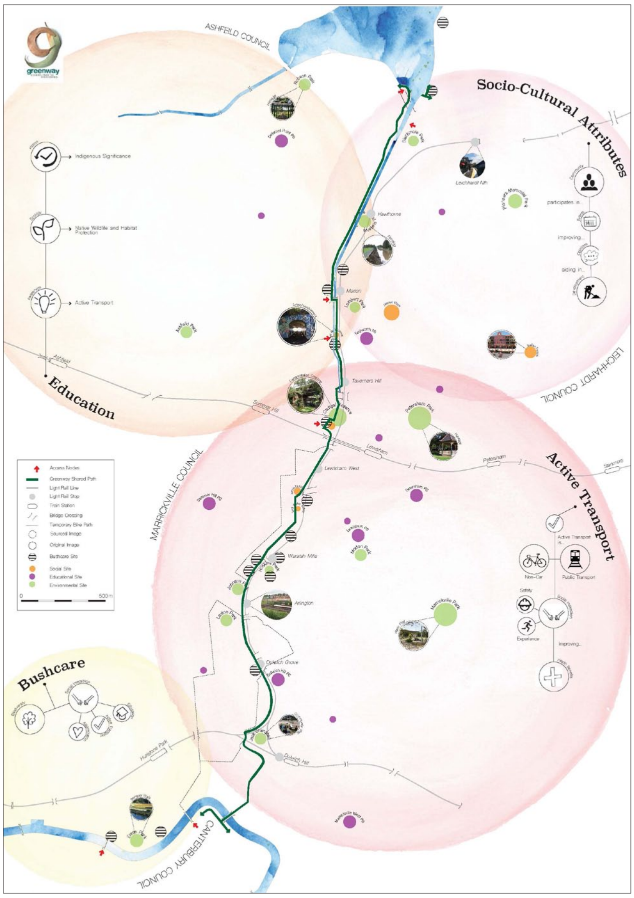
Results

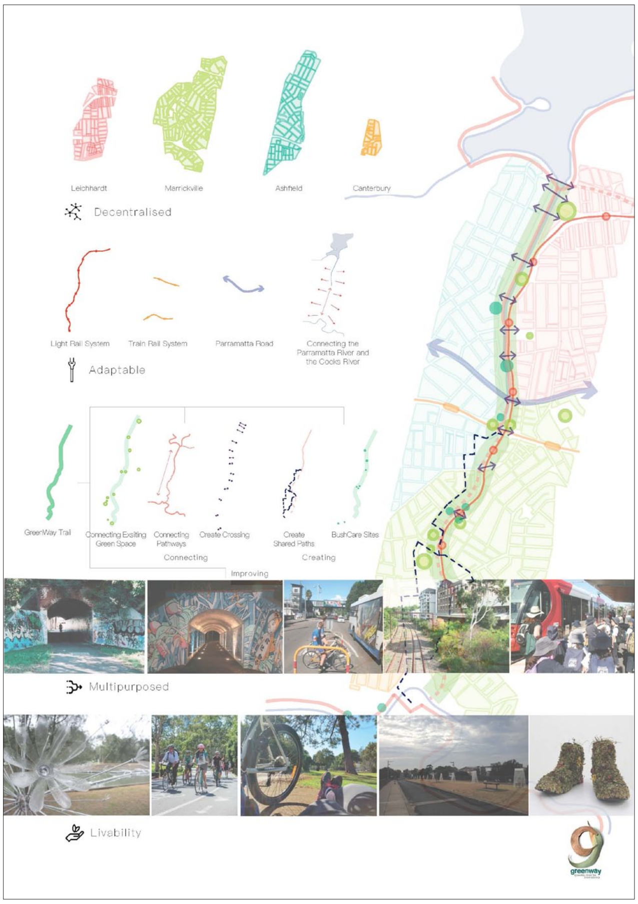
This exercise addressed both aims of this research, identifying and testing the 'generalised' principles of landscape infrastructure and investigating their application to a site in Sydney. Three posters (from a total of 15) will be discussed.

In the first poster, McCarthy simultaneously represented four categories of systems and outcomes as identified by the four neighbouring local government authorities: education, active transport, social–cultural attributes and bushcare (see figure 2). In the case of transport, a combination of public transport (light-rail) and 'non-car' movement (cycling and walking) was linked to outcomes. Through a diagram of transport systems and positive health outcomes (namely increased safety and an enhanced, more closely connected experience of place), McCarthy's work effectively communicated how synergistic and multifunctional systems enabled a spectrum of social, health and environmental benefits as interlinked, high-quality public spaces to engender social interaction: an exemplar for new forms of open space, where a drainage and rail corridor also becomes an opportunity for greater social engagement. This implied that *The GreenWay* was indeed an example of the three principles of landscape infrastructure identified by Hung (2013): 'flexibility and adaptability', 'localised management' and 'multi-functionalism'.

Shing revealed the corridor's 'decentralised' quality, placing surrounding councils – Leichhardt, Marrickville, Ashfield and Canterbury – at the top of a hierarchical diagram (see figure 3). This approach demonstrated the corridor's history, beginning with life as a canal connecting Cooks River to the harbour, and leading to the repurposing of the rail corridor for light-rail in 1997. Further adaptation, incorporating additional cycling and walking trail connections to existing parks along with bushcare sites, highlighted *The GreenWay*'s function as a spine for ecological connectivity as well as incorporating transport,

Figures 2 and 3: (left) The GreenWay *poster by McCarthy and (right)* The GreenWay *poster by Shing*





recreation and drainage. Through a photographic exploration of 'multipurpose' and 'liveability', this work skilfully communicated correlations between *The GreenWay*, landscape infrastructure principles and the capacity of landscape. By implication, Shing's work demonstrated how site operated as an example of landscape infrastructure in an Australian context.

Considering the existing and the 'reimaged/reimagined', Hardy-Clements revealed *The GreenWay*'s current operation by engaging with its 'mundane' elements, including light fixtures, to explain how incremental change could provide synergistic outcomes (see figure 4). This was achieved by overlaying graphic discussion threads on a map of the broader region and was further illustrated with photography. In one thread, road crossing improvements were linked to improving lighting to enhance overlooking from adjacent housing for greater safety. These improvements identified 'lost pockets associated with train

Figure 4: The GreenWay *poster by Hardy-Clements*

and tram lines for new urban green spaces'. This in turn was linked to improved water-quality outcomes, such as a proposed upgrade to the canal 'foreshore', currently a concrete channel. To complete this thread, the canal was reimagined as a vital, new and synergistic infrastructure with enhanced connectivity (through road crossings), safety (via lighting and visual permeability) and improved water quality. Because Hardy-Clements' work was less evident in achieving the first aim of stating particular principles, it was more successful in the second aim of discussing how this site could operate as landscape infrastructure.

Discussion

The GreenWay poster exercise required students to distil and successfully communicate the complexity of infrastructural systems located in the corridor. The best examples combined diagrams with mapping and photography, using a hierarchy of graphical layout to relate elements on the page. McCarthy (figure 2) linked health with safety and experience of place, while Shing (figure 3) explored multifunctionality and adaptation. The difficulty in communicating how landscape infrastructure operates without a single, fixed end-point but rather with inherent flexibility – as explored by Hardy-Clements (figure 4) – was an important finding. In reality, *The GreenWay* functions through a mix of grassroots activism and response to external pressures, including adjacent housing infill development. Funds for improvements to the multi-use trail and maintenance of bushcare sites are limited; and uncertainty and risk must be embraced to ensure their continuing development.

The students' work begins a successful translation of the framework of landscape infrastructure where *The GreenWay* could be understood as a site shaped to achieve 'facilitation of program' (Carlson, 2011). *The GreenWay* 'program' has become more diverse over time, shifting between drainage corridor, goods transportation and now light-rail, and increasingly reflects the principles of 'flexibility and adaptability', 'localised management' and 'multi-functionalism' espoused by Hung (2013) and demonstrated by the students' work. This project could therefore be seen as the beginning of establishing *The GreenWay* as a Sydney-based, Australian example of landscape infrastructure.

Table 2 summarises the results from this phase.

Phase Two: New Parramatta design proposals

Results

The studio then shifted its gaze to Parramatta, with detailed briefings from local experts and a group exercise to research and define this complex 'site' across three scales: the *central business district*, the *local government authority* and the *whole of Parramatta River catchment*. This exercise challenged students to expand the scope of 'infrastructure' by including systems such as patterns of consumption and distribution, waste management, energy, land use, heritage, culture and geology across multiple scales. It encouraged students to consider how infrastructure might be carried by landscape in the region already, but above all it required them to develop catalytic design insertions or exemplar design elements that would illustrate the overall strength and potential of their strategies.

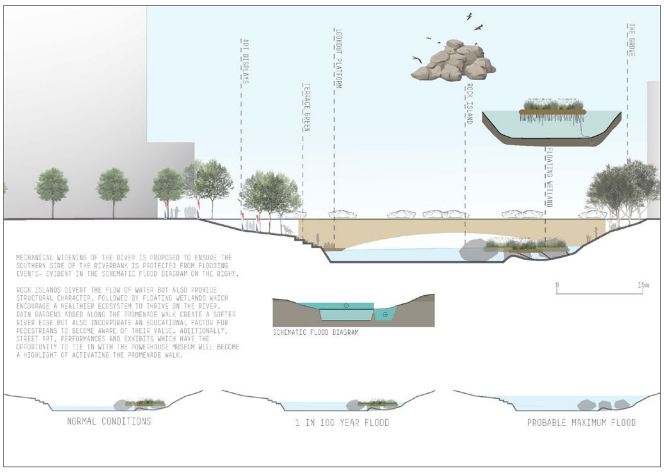
Table 2: Summary of achieving research aims through The GreenWay *poster exercise*

	Aim 1: Identify and test landscape infrastructure principles	**Aim 2: Conduct a detailed investigation and application in an Australian context**
Student	Proposed principles: 1. Landscape Infrastructure is **flexible and adaptable**. 2. Landscape Infrastructure considers **decentralised** and locally managed solutions. 3. Landscape Infrastructure is **multifunctional** such that 'the city and its infrastructure are one and the same'.	Methods for application: Communicate how an existing site operates as landscape infrastructure. Propose new forms of open space – landscape as infrastructure, infrastructure as landscape.
McCarthy	Four systems carried by landscape: education, active transport, social–cultural attributes and bushcare **(flexible, multifunctional)**. Managed by four local authorities **(decentralised)**.	Transport systems increased safety and experience of place **(infrastructure as open space)**. Positive health outcomes for the surrounding community through linking infrastructural systems to create high-quality public spaces **(example of landscape infrastructure)**.
Shing	'**Decentralised**' quality highlighted. Adaptive historical infrastructure characterises the corridor: canal, the goods line, light-rail and finally shared pedestrian and cycle path **(adaptive and multifunctional)**. Ecological connectivity incorporated with transport, recreation and drainage **(multifunctional)**.	'Multipurpose' linked to 'liveability' **(illustrates the potential role of landscapes as infrastructure)**.
Hardy-Clements	Links road crossing improvements with improving lighting and making overlooking from housing more transparent, which increased perception of safety **(multifunctional)**.	Projective in nature, communicating both what *The GreenWay* corridor is and what it could be; an open-ended proposition for how *The GreenWay* could operate **(example of landscape infrastructure, a proposal for a new type of open space and use of open-ended strategic design approaches)**. Engages with 'mundane' elements, such as light fixtures, to explain how incremental changes across a whole-of-corridor scale would provide synergistic outcomes from greater connectivity to improved safety and water quality **(example of landscape infrastructure)**.

Both Leite and Wang produced projects that addressed the Parramatta River directly. Leite's strategy returned swimming to the river foreshore by designing a swimming pool at the city centre that would clean the water with ecologically engineered systems (see figure 5). Wang's project proposed deliberately displacing the flood waters that regularly inundate the river foreshore, distancing these from the river bank adjacent to a proposed new 'civic link' back to the civic centre of Parramatta, *Parramatta Square* (see figure 6). This project showed the potential for activating the river frontage through a new form of river infrastructure.

These projects both advocated for infrastructural systems to generate new types of public spaces. Specifically, both projects demonstrated how the river corridor could catalyse active public space and alter the public perception of the Parramatta River as safer and more accessible through proposed infrastructural systems that were integrated into and made visible by landscape. Leite's project achieved this by a water treatment process that made the mechanics of drainage and wastewater management visible and landscape-based. This directly aligned the project to the principles of landscape infrastructure as *adaptive, decentralised* and *multifunctional*, illustrating that when meaningfully applied these principles provided one designed response to the first aim of this research. Similarly, Wang's project proposed a new form of infrastructure to manage the river's flow and change the perception of the river's edge, demonstrating that it can be an accessible, public open space during floods.

The specialised knowledge required to consider how these projects might operate in detail made it difficult for both of these students to develop projections into the future and to move away from a 'master plan' approach towards a wider strategy. These projects also showed the importance of multidisciplinary approaches to achieve the outcomes of the framework, as students had to make significant assumptions in communicating the possible futures their projects proposed. This work points to a recurring theme in all the students' work: applying landscape infrastructure is too complex for landscape architects to 'do it alone'. This finding highlighted a weakness in the second aim of the research. Achieving design proposals that met the aim's requirement for *strategy, open-endedness* and *uncertainty* was not possible where a student also needed to apply highly specialised knowledge outside of landscape architecture.



Figures 5 and 6: (left) Parramatta Pool: a proposal for river swimming by Leite (Extract, Panel 3) and (right) Fixing the flood: realising a reconnection to the Parramatta River through flood mitigation by Wang (Extract, Panel 4)

Two more students, Gowers and Shing, focused on the Parramatta city centre. Gowers sought the catalytic potential of improving central business district streetscapes via hydrological systems and vegetation (see figure 7). Shing repurposed a street and heritage bridge into a pedestrian space with park-like insertions (see figure 8). These two strategies clearly demonstrated the principles of *multifunction* and *decentralisation*. Gowers detailed water-sensitive treatment of stormwater through tree planting, simultaneously providing a range of benefits such as giving individual streets a stronger identity. Shing's work focused on Church Street – otherwise known as 'Eat Street', an area with a high concentration of restaurants and cafés –and dedicated the road to pedestrians and outdoor dining. This treatment extended to the river where the historic colonial Lennox Bridge was redesigned as a park over the river. Through redesign Shing also proposed undertaking local stormwater treatment and mitigating urban heat by increasing the amount of vegetation and changing ground surfaces. Shing and Gower both proposed engineered ecological processes to improve the quality of the city environment. In this way they provided examples of how landscape infrastructure harnesses a culturally mediated approach to ecology: its purpose was to increase the use of public space through improving quality.

While successful in many respects, the projects by both Shing and Gowers highlighted a problem for landscape infrastructure and the second aim of this research: the need to develop communication techniques that legibly demonstrate the full complexity of a design proposal. Projects that effectively illustrated the difficulty of considering open-ended approaches to infrastructure had that difficulty compounded by the need to design without a fixed end-point when showing landscape design details. Shing's work also emphasised the difficulty of expressing change over time in a drawing format, yet she verbally expressed credible transformations to the region into the future as a result of her design. Developing techniques of communication outside of contemporary conventional drawing, even for an advanced student, was a barrier to achieving the second aim of this research. Gowers addressed this challenge through a text-based timeline

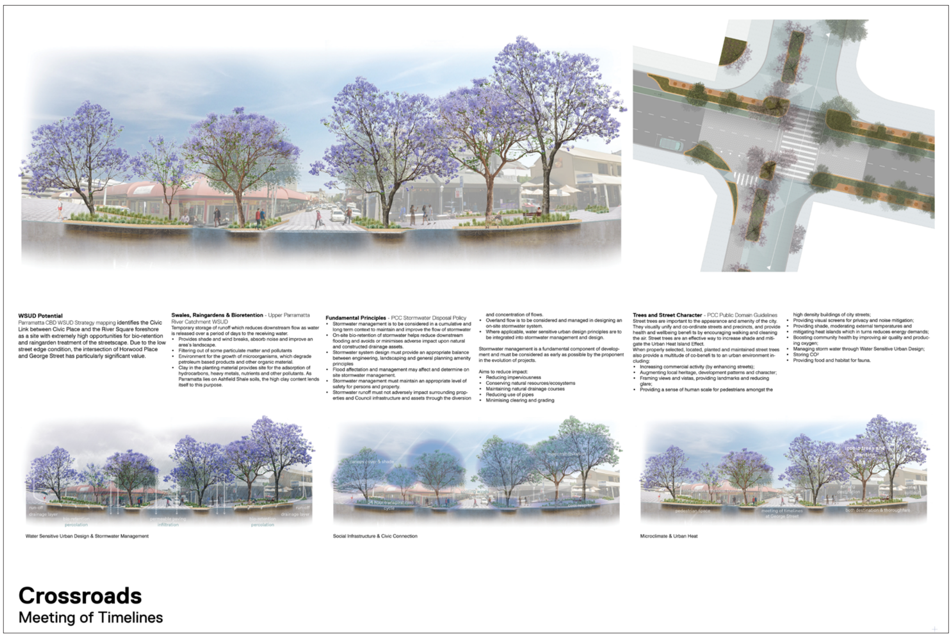


Figure 7: Shaping street identity: combining street character with water-sensitive urban design by Gowers (Extract, Panel 3)

that demonstrated a flexible approach to the catchment condition over 50 years. He also explored his proposal through changes in scale, demonstrating evidence of working across local and wider contexts, thereby aligning with the principle of decentralisation.

In two further projects, which were the most complex, Murphy and Edwards defined strategies to connect the river and the city centre. Murphy's work challenged dominant 'master plan' approaches to site, using an alternative method, including diagrams and a supporting document, to attempt an integrative strategy across the scale from site to region. Murphy investigated the region around the Westmead Hospital and considered food production, water-quality improvements via a renovated Parramatta River tributary, and new ways of living in a health precinct. These included a series of proposals ranging from future planning work on a section scaled from deep below ground to air space over head (see figure 9). Murphy's work was an example of all the principles of the framework with an emphasis on synergistic outcomes and his selection of a large and multilayered site proved beneficial in demonstrating landscape infrastructure, but a weakness when trying to resolve design elements.

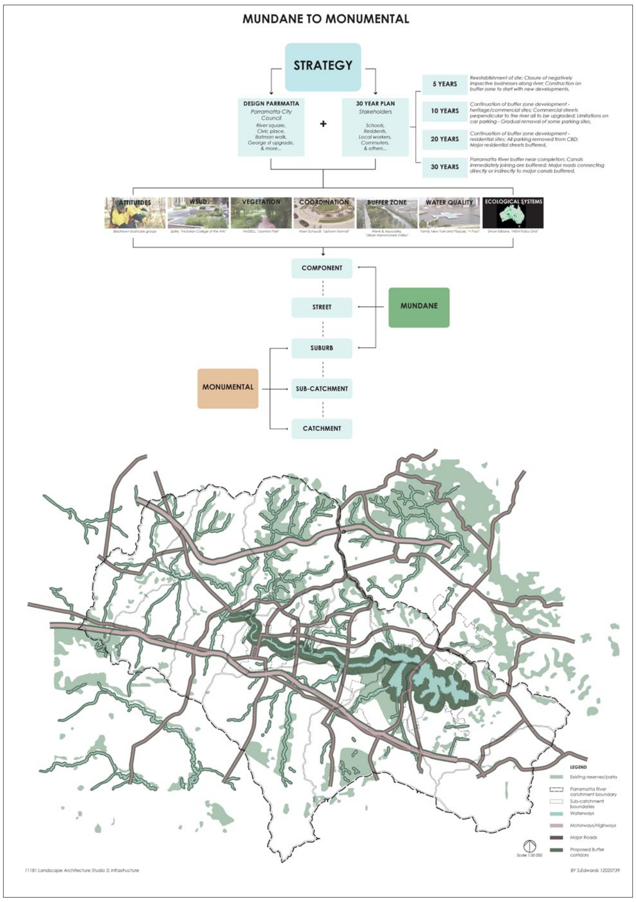
Figure 8: Reclaiming infrastructure: a proposal for an icon infrastructural landscape in Parramatta's 'Eat Street' by Shing (Extract, Panel 3)

Edwards similarly applied a breadth of landscape infrastructural principles as a framework and as an adaptive approach that allowed for continuing change over time. Through proposing seemingly banal changes incrementally over a suite of sites, Edwards cumulatively created what had the potential to become 'monumental' change (see figure 10). The project sites included easily replicable solutions for roundabouts and treatments to 'ordinary' residential streets. Edwards also identified a potentially crucial but forgotten site related to the Parramatta train station.

Murphy's use of diagrams and documents to demonstrate a strategy made it difficult for the student to 'pin down' any one idea and explain its full implications on site. Murphy instead provided the beginnings for a range of potential projects. The work was intended to be a strategy for the whole Westmead precinct, therefore achieving the second aim of the research with some success. By demonstrating resolved proposals for the chosen project sites, including changes over time, and then expressing how these sites cumulatively presented a strategy that was potentially open-ended, Edwards successfully put forward a project that met the second aim of the research. As with Murphy, Edwards was able to do this because her work embraced complexity and considered a range of sites across the region. Edwards' selection of sites allowed her to also present the work in more detail.

Discussion

Contemporary Parramatta was established during Australia's European colonisation, immediately hosting successful agricultural pursuits and the seat of government, which demonstrated the area's position as essential infrastructure for the early New South Wales colony. Parramatta is once again a focus for essential infrastructure for Sydney and over the next 20 years the population of greater Sydney – and Parramatta with it – is expected to double. Coupled with this growth, future projections suggest the number of jobs in Parramatta will increase by 100,000 within two decades (Department of Planning and Environment, 2016). These projections show the urgency of resilient and flexible development to meet future needs.



The students' work generally followed one of three main themes: strategies that addressed the river corridor directly; strategies that focused on the Parramatta city centre; and strategies that were located across larger scales outside both these regions, but that remained linked to both. Defining the site at the catchment scale inherently gave preference to hydrological systems and made water infrastructure an essential consideration for every student. It is interesting that none of the students' work considered infrastructural systems such as energy generation (despite its inclusion in the material-gathering group exercise), possibly because it is harder to translate energy to a 'landscape as infrastructure' viewpoint. By explicitly biasing the project towards water infrastructure (in line with the local stakeholders' desires), the first aim of the research – identifying and applying the principles of landscape infrastructure – was assured. This was because it was not possible to consider the health of the river without considering a localised solution to stormwater – an approach typically solved through re-creating streets as corridors for ecologically engineered water management. From this outcome, it might be observed that certain infrastructural systems are more likely to lend themselves to a landscape infrastructural framework, especially the systems that are hydrological. This is reflected in the SWA Group's case studies, many of which link hydrological infrastructure with ecological systems and new types of public space.

Figures 9 and 10: (left) Open and closed systems: reconnecting landscape and infrastructure within Westmead by Murphy (Panel 4) and (right) Mundane to monumental: a proposal for small-scale intervention to achieve large-scale realisation of landscape as infrastructure by Edwards (Extract, Panel 1)

Students were required to design a strategy or proposal instead of a master plan. This became a significant challenge in their work and limited the extent to which they could achieve the second aim of this research. This requirement was set based on the practice of landscape infrastructure, which begins by departing from design processes that aspire to a single fixed end-point. The rejection of Euclidean, fixed end-point design processes comes from landscape urbanism, which Corner (2006) describes as 'a kind of urbanism that anticipates change, open-endedness and negotiation' (p 31). In the context of landscape infrastructure, Bélanger (2012) criticises fixed end-point approaches to urbanism as 'outmoded patterns of land development upheld by the spread of standardised, end-of-pipe engineering' (p 276). Departing from a designed 'plan' and instead developing a strategy, proposal or vision was a barrier to progressing work for students in the Parramatta studio. A requirement for students' work to include a catalyst or exemplar site to demonstrate how their strategy might be applied was intended to assist with this. However, the impact this requirement had on their ability to achieve the second aim of this research later became apparent.

The student work that attempted more detailed resolutions to strategies with a smaller-scaled focus was most strongly confronted by the shift away from the master plan. These projects highlighted the importance of using creative communication techniques to demonstrate the potential for continuing change over time, with the greatest success achieved by students who focused on strategy proven through detail. To do this, successful students needed to use drawing techniques that were 'representational', rather than only traditional features such as plans and sections across scales. In developing a comprehensive vision of how a detailed proposal would meet the principle of flexibility, they had to produce sophisticated representations of possible futures to comprehensively apply the framework. This work limited their ability to achieve the second aim of this research because students were rarely successful in demonstrating open-ended, strategic and uncertain outcomes, doing so only when they experimented with methods of communication and presented a range of proposals across different scales.

The proposals that considered larger-scale, regional strategies were the strongest examples of the framework's application and, as a result, the most successful in achieving the second aim of this research. They also represented the best attempts at communicating 'design' in the spirit of landscape infrastructure as flexible, contingent and without a single, optimal end. The work demonstrates that the best examples of applying landscape infrastructure were also the most complex. This may be a barrier to using the framework more broadly, and perhaps even is the reason for its lack of application outside an academic environment. It also demonstrates that tackling this framework at an undergraduate level creates significant challenges. One of these was the need to depart from master plan, fixed end-point approaches and instead communicate flexibility and change over time. Other challenges were identified difficulties in working at a high level of complexity and working individually on projects that should be supported by multidisciplinary teams.

Table 3 summarises the results from this phase.

Table 3: Summary of achieving research aims through the New Parramatta projects and generalisable principles (as evidenced by student work)

Student	Aim 1: Identify and test landscape infrastructure principles	Aim 2: Conduct a detailed investigation and application in an Australian context	Assessment of research
Leite	Achieved	Partially achieved	Flaw in research; demonstrating open-ended, strategic, uncertain outcomes over time is restricted when specialised knowledge is required.
Wang	Achieved	Partially achieved	
Shing	Achieved	Partially achieved	Problem for landscape infrastructure and the second aim of this research; developing communication techniques that legibly demonstrate complexity
Gowers	Achieved	Partially achieved	
Murphy	Achieved	Achieved	Examples of proposals that experimented with methods of communication and presented a range of proposals across different scales
Edwards	Achieved	Achieved	

Conclusion: Meeting the research aims

Identifying and testing landscape infrastructure principles

Based on the results generated for both *The GreenWay* and the New Parramatta design strategies, it is reasonable to propose that landscapes demonstrating 'generalisable' principles of landscape infrastructure in Sydney actively exist. Numerous challenges, including communicating how landscapes can function as and carry other systems of infrastructure without a fixed end-point, raise new questions about both this emergent 'theory' and its application. As such, this research highlights the need to demonstrate landscape infrastructure's benefits in order to justify the difficulty associated with applying it.

Establishing principles from literature, supported by published case studies described as landscape infrastructure, was critical for this work to be considered research. This is especially important considering the research is based on hypothetical design strategies developed in an academic environment. Such a strategy, according to Deming and Swaffield (2011), represents 'an autonomous research strategy when it produces new "generalisable" knowledge about the world through its purposes, protocols and outcomes' (pp 205–206).[10] Identifying a resolute list of principles that can reasonably be defined as the essentials of landscape infrastructure was therefore necessary to fulfilling the first aim of this work. Testing these principles in the first of the projects undertaken, the reimagining of *The GreenWay*, was successful.

The students' work for *The GreenWay* also partially met the second aim of the research where the site could be understood as landscape infrastructure retrospectively. The work they developed as part of the New Parramatta projects was found to inadvertently bias hydrological or blue infrastructure. Landscape-based proposals for hydrological systems required solutions that were multifunctional, localised and flexible. As a result, achieving the first aim of the project, to identify and meaningfully test 'generalisable' principles, was assured in the proposals.

New explorations and applications of landscape as infrastructure in Sydney, Australia

In the work on *The GreenWay*, the research successfully demonstrated the inherently infrastructural nature of landscape. The New Parramatta projects, however, showed the difficulty in achieving the research's second aim when proposing new design. Here two barriers were identified. The first was the difficulty in applying specialised knowledge, especially where a multidisciplinary approach would realistically be needed. The second barrier was in relation to the limits of communication techniques where complex ideas over time needed to be articulated for designs that gave detailed, localised solutions to infrastructure. The projects that best achieved the second aim shifted scale across the region and offered multiple proposals. Such projects were able to demonstrate strategic and open-ended outcomes.

Among the work students proposed for Parramatta are some examples that go beyond the integration of infrastructure within landscape, potentially confirming landscape infrastructure's claim that landscape itself is infrastructural. The New Parramatta projects may also have wider implications for landscape infrastructure. Their observed bias towards blue or water infrastructure, and therefore their success in meeting the first aim of this research, suggests that the framework most readily applies to hydrological infrastructural systems. Central to landscape infrastructure is the acceptance of uncertainty and recognition of positive outcomes from embracing risk. This research has tempered this outlook by highlighting the need for multidisciplinary approaches to design in ways that address complexity. It is questionable whether a landscape architect, and in particular a student of the discipline, can embrace risk and uncertainty while also addressing complexity unless they involve other disciplines.

Although two key theoretical contributors, Weller and Mossop, are of Australian origin, much of the supporting landscape infrastructure literature comes from North America and an Australian context for landscape infrastructure has not yet been established. By investigating the framework of landscape infrastructure and applying it to locations in Sydney, first through exploring an existing site as an example of the principles (as in *The GreenWay*) and then through propositional design exercises (as in New Parramatta), this research represents a first, if brief, exploration of landscape infrastructure in Australia.

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Leite, Camila
Edwards, Stacey
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Johnston, Brittany
Ma, Yue (Matthew)
McCarthy, Caitlin
Murphy, Brendan
Pinheiro Bezerra, Camile
Shing, Sze King (Simone)
Wang, Michelle
Zhou, Ao (Anita)

NOTES

1 This was not based on region alone and can be attributed to the decline of the master plan as *modus operandi* in landscape architecture.

2 *The GreenWay* is a recreation, drainage and transport corridor in Sydney's Inner West. It includes the Light Rail Corridor from Central Station to Dulwich Hill. The corridor trail began construction as part of the Inner West Light Rail Extension and connects Cooks River to Iron Cove in Sydney Harbour. A master plan for *The GreenWay* was accepted by the four local councils that surround the corridor in 2009. *The GreenWay* is supported by the *Friends of The GreenWay* community action group and has also received numerous state government grants.

3 Parramatta Road is incidentally one of Australia's first transport infrastructure corridors. It extends approximately 20 kilometres from the centre of Sydney to the historical seat of government at Parramatta.

4 'Bushcare' sites are specific zones of focus for environmental restoration efforts, as recognised by local governance structures and funding.

5 The research is indebted to Nick Chapman, place manager for the Inner West Council, for his time and energy.

6 No site in Sydney is currently presented in any published material as an example of landscape infrastructure, making this project a research first.

7 The students' posters were designed to be viewed by the general public and were displayed at *The GreenWay* Art Exhibition from 10–20 November 2016.

8 Leanne Niblock represented the Parramatta City Council. The council is working towards achieving a liveable urban realm into the future as Parramatta increases in density and becomes the region's second central business district. Other particular concerns for the council include the Urban Heat Island effect, the potential for an improved pedestrian realm, and the activation of the Parramatta River within the central business district.

9 Sarah Clift represented the Parramatta River Catchment Group. The group crosses 13 local government boundaries and works with local authorities and the community to implement its plan *Our Living River: Our Progress to a World Class River* (Parramatta River Catchment Group, 2014).

10 Deming and Swaffield's (2011) text *Landscape Architecture Research: Inquiry, Strategy and Design* is arguably the first and most comprehensive source of research strategies for the discipline.

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Net Environmental Benefit in Urban Centres

STEPHEN KNIGHT-LENIHAN

A theoretical model is proposed to assess whether activities associated with urban development create net positive environmental benefits. The rationale is that the application of *no net loss and preferably a net gain* goals for biodiversity values associated with offsetting development impacts requires a shift away from the usual regulatory pursuit of minimising harm toward requiring benefit. A catchment-based decision-making framework is used to demonstrate the process. Limitations include outcome uncertainty and deciding on baselines related to cumulative effects, and dealing with transaction costs.

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KEY WORDS

Ecosystem values

Biodiversity offsets

Urban development

Managing ecosystem impacts from urbanisation requires avoidance, remediation or mitigation (Resource Management Act 1991, section 5(2)(c)) and, commonly, ecological compensation (Brown et al, 2013). Ecological benefits may result from these actions, though this is not required (Knight-Lenihan, 2013; 2014).

This minimising harm and making occasional gains is inadequate, evidenced by continuing ecological decline globally (eg, WWF, 2016) and locally (eg, Gluckman, 2017; PCE, 2017). This has led to an argument that all human activity, including urban development, needs to contribute to a *net ecological benefit* (Birkeland and Knight-Lenihan, 2016; Knight-Lenihan, 2015).

This paper proposes an assessment framework as a step towards operationalising the concept of net benefit. A net gain needs to be demonstrated at the place where urban development occurs (such as creating a subdivision) as well as net gains or losses across supply chains supporting urban systems. Assessments include various environmental dimensions, such as atmospheric carbon emissions, water quality and waste, as well as ecosystem functioning, leading to the adoption of the term *net environmental benefit*.

The first part of this paper describes the concept and application of net gain. The challenge of auditing is then discussed, with possible approaches suggested for further research. A catchment-based decision-making framework is proposed. The difficulty of establishing baselines against which to measure progress, and where transaction costs fall, is also discussed.

Net environmental gain assessment framework

The prospect of *net ecological benefit* evolved with the use of ecological compensation and biodiversity offsets as applied in New Zealand (Brown et al, 2013; New Zealand Government, 2014) and internationally (BBoP, 2012b; Pilgrim et al, 2013). Offsets are measurable conservation outcomes compensating for significant residual adverse biodiversity impacts occurring from development,

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after appropriate prevention and mitigation measures have been taken (Brown et al, 2013; New Zealand Government, 2014).

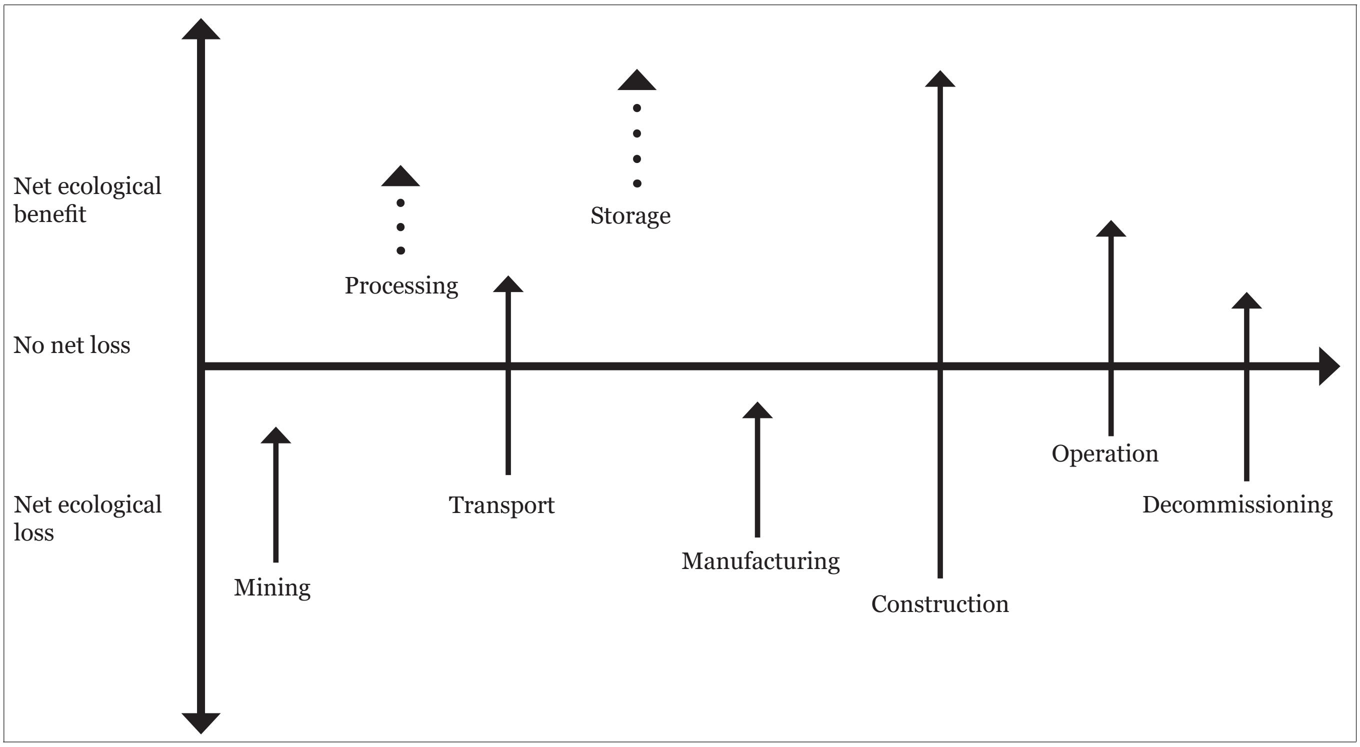
Offsets promote a *no net loss (NNL)* and *preferably a net gain* in biodiversity.[1] This, in effect, creates a preference for a net ecological benefit, given that biodiversity is a measure of, and helps define, ecosystem functionality.

Net benefit goals may help reverse cumulative ecological losses over time and space associated with economic development. The normalisation of ecological losses associated with development (Knight-Lenihan, 2015; Pitcher, 2001) – for example, freshwater degradation seen as a price paid for economic development (Gluckman, 2017) – means economies evolve on the explicit or implicit assumption of continuing ecological decline. To be sustainable, development must address cumulative losses by enhancing ecological health and integrity (sensu Park, 2000) and social and natural capital (Birkeland, 2008; Birkeland and Knight-Lenihan, 2016). This places net gain as the preferred outcome rather than one to be pursued after prevention and mitigation.

Assessing a particular system's ability to work within local biophysical limits should also include assessing the impact such systems have elsewhere. This is because the 'elsewheres' also need to work within their own biophysical limits.

The concept of NNL in biodiversity (ecosystem) values, and preferably a net gain, is used to illustrate the model (see figure 1). There is a sliding scale from negative (net ecological loss) to remedial (eg, removing pest species) to net positive (increasing ecological values by, for example, increasing the number of species, and the number of individuals in particular targeted species, in a given habitat; and/or improving habitat condition). A position below or above the line indicates the extent to which an activity is or is not achieving net benefit (NB). Solid lines indicate the potential improvement due to current planned activities. Dotted lines indicate any existing 'credit' level of an activity, proportional to the distance above the NNL axis.

Figure 1: Framework for assessing the biodiversity and ecosystem net losses and net benefits of activities associated with urban development



Applying the concept of net gain

Figure 1 represents an imaginary example of an urban brownfields (ex-industrial) site being converted to a residential subdivision. Towards the bottom of the *y*-axis is where an increasing net ecological loss occurs. Ecological loss includes the loss of biodiversity and ecosystem functioning, such as declines in soil condition or contributions to maintaining water quality. The *x*-axis, half-way up the diagram, indicates the point where no net ecological loss occurs. Above the line is where an activity has resulted in a net improvement in ecosystem values: that is, improvements that exceed impacts and that would not have happened had the activity not occurred.

The *x*-axis is also the timeline where moving left to right indicates the stage of securing and formulating the materials required to build the infrastructure and housing associated with the subdivision. These raw materials are processed, transported, stored and manufactured into products used for construction.

Impacts occur at each of these stages. Some are unavoidable and will always require compensation: for example, a quarry removes top soils, sub soils and habitat. Other impacts can be avoided, remedied or mitigated to a point where they have little or no significant effect: for example, storage systems in energy-neutral buildings using solar power.

The model can be broadened to consider various environmental impacts to be compensated for. At each stage, an independent audit would be made assessing the extent to which net environmental losses occur and what (if any) steps have been made to compensate for them. Therefore, it would be possible to create versions of figure 1 relating to various environmental dimensions, such as biodiversity and ecosystems, energy, atmospheric carbon emissions, water quality or waste. Each dimension could be assessed independently, and the dimensions would be identified by a strategic environmental assessment prioritising issues to be addressed.

The *NNL* and *net ecological benefit* terms would be modified accordingly. For carbon emissions, it would be the point where reducing emissions and/or offsetting emissions reaches and exceeds a carbon neutral point. For waste, it is the point where no waste is landfilled, and above the line is where material is repurposed for other uses. Water is more problematic, but the 'NNL' point could be where the activity no longer pollutes or abstracts water, with above the line being where actions contribute to improving water quality and/or help in recovering natural flow regimes.

Using the ecological benefit example in figure 1, the audit generates an estimate of the extent to which net ecological loss has been compensated for. The objective is to achieve NNL and preferably an NB. Aiming for NB in effect ensures at least NNL is achieved, given the high degree of uncertainty in estimating unwanted ecological impacts and compensation actions. Compensation is for cumulative losses over time and space, creating baseline and assessment challenges, as discussed below.

At some points along the *x*-axis, activities will have a net environmental benefit. For example, a mined materials processing plant might use co-generated electricity and heat from waste incineration, thereby diverting waste from landfill and reducing demand for electricity from coal-fired plants. This reduces atmospheric carbon emissions. In a separate assessment, the owners of the plant also contributed to a biodiversity offset during construction that has resulted in an ecological benefit in addition to what would have happened had the plant not existed.

Similarly, the storage facility is designed for passive lighting and heating, and uses solar power. Excess power is stored in batteries and used by the electricity supply utility to contribute to morning and evening peak demand from domestic consumers, at a time when the storage facility demand is low. This reduces the need to use a stand-by coal-fired electricity plant to meet growing peak demand, thereby contributing to avoided emissions.

In addition, when applying for its resource consent in this hypothetical example, the storage facility agreed to contribute to a biodiversity offset brokering scheme being run in the water catchment it is operating in. As with the processing plant, this is anticipated to have a benefit in addition to what would have occurred if the storage facility did not exist. The benefit can only be potential because offset success can only be confirmed over time.

Taking these actions into account, the independent auditors assess the processing and storage facilities as having existing and potential net environmental benefits in dimensions relating to carbon emission, ecosystem values and waste. Other prioritised dimensions would be similarly assessed. Therefore, for some environmental dimensions, credits would be generated (indicated by the dotted lines) proportional to the estimated NB. An NB is represented by the distance each facility is above the NNL line, in terms of biodiversity values, or a similar neutral line for each of the other dimensions.

The distance above or below the line is expressed proportionally. For example, an assessment could rate an activity as having achieved 20 per cent of the required action for emissions neutrality and 50 per cent towards the ecological compensation goal. Thus, while mining may have a far greater real environmental impact across various dimensions than say construction, both can be compared in terms of the distance they are from their own neutral and NB goals.

Incentives for achieving an NB would be from generating credits that could be used to earn developer rights elsewhere, or for trading. This, of course, relies on there being markets, which may exist for carbon emissions (see, for example, the New Zealand Emissions Trading Scheme)[2] and nutrient management for reducing impacts on waterways (Duhon et al, 2015), but are problematic for biodiversity and ecosystem values. This is discussed further below.

As noted, the solid lines in figure 1 indicate the potential benefit of current and planned actions by each of the components in a net ecological loss situation. Some may not achieve NB or even NNL, due to financial and technical limitations.

It is important to note that the assessment of progress combines quantitative and qualitative measures. This is because the complexity of achieving environmental 'progress' requires professional opinion as well as measurement.

In summary, the idea is that activities along a supply chain can be rated according to:

- whether they are audited
- the extent to which the auditing can be verified as independent and effective

- the results of the audit in terms of percentage progress towards, or the degree to which it exceeds, NNL or the equivalent, and whether this can be estimated
- the clarity of the methodology used and its reliability.

This includes the extent to which the urban development project itself is addressing on-site cumulative ecological impacts.

The focus (at least initially) would be on large-scale projects and large-scale suppliers. In some circumstances, it may not be useful to estimate percentage achievements due to technical issues associated with evolving methodologies. Instead, it may only be possible to note whether and how an activity is addressing an identified issue. The caveat of methodological limits would have to be attached to the estimate.

Given jurisdictional limits, it is not always possible to directly influence suppliers. However, ratings will contribute to behaviour change. This is partly because suppliers already reducing their ecological impacts, or creating positive benefits, gain profile and possibly market share from promoting this fact. Those currently not doing so may be motivated to start. Those further up the supply chain can then refer to components of their product or service as contributing to ecological value, in addition to any action they may be taking.

It is tempting to allow those up the supply chain to incorporate credits from suppliers to offset their own impacts. This would not be advisable, however, given the likely scope for manipulating data and avoiding taking action locally. Equally, making users liable for supplier ecological debts would be an administrative burden that would outweigh any benefit in terms of encouraging behaviour change.

All of this rests ultimately on consumers and regulators responding to evidence of environmental impacts. That is, consumers in their desire to favour developers demonstrating both supply chain and local net environmental benefit efforts, and regulators in terms of putting in systems rewarding such action. Underpinning this is having confidence in the auditing process and a decision-making framework. These ideas are explored in the following sections.

Auditing

Auditing the movement toward or away from NNL or its equivalent is the biggest challenge of this proposal. Research in this area is incomplete. Existing assessment systems do exist, however, that in part address this need. Three are looked at below:

- ecological footprints
- built environment material and resource flow assessments
- expanded product verification systems.

None of the above has been subjected to rigorous analysis for this paper. The objective is to outline three mechanisms that could be developed for an auditing process.

Ecological footprints

The premise behind ecological footprinting is calculating the biophysical carrying capacity required to support a given human population. It accounts for the ability to use international trade to "relieve local ecological constraints" (Rees and Wackernagel, 1994, p 363), addressing a need to calculate impacts on distant ecosystems to complement estimates of local impacts. It includes resource consumption and waste production and has evolved into a tool claiming to measure the natural environment's capacity to support human activity.[3]

This is a rather narrower goal than that discussed for this paper. That is, essentially, it draws attention to the value of ecosystem services for human welfare (Shackleton et al, 2017), which, while potentially allowing for the broadening out of natural capital measures (see, for example, Guerry et al, 2015), is not the same as measuring total ecological health and integrity. It does, however, set up a database that can be both contributed to and interrogated independently,[4] a valuable attribute for auditing.

Also contributing to the evolution of ecological footprints is restoration ecology, which may broaden the scope of what is included when valuing ecosystem services, and, hence, payment for those services (Bullock et al, 2011). For example, the contribution of New Zealand urban ecosystems to biodiversity goals (Clarkson and Kirby, 2016) extends observations that incorporating 'working environments' (that is, economically developed landscapes not in the conservation estate) is vital to achieving net improvements in biodiversity values (Green and Clarkson, 2006). This requires measuring progress towards protecting and enhancing indigenous biodiversity, which could be included in an ecosystem footprint account.

Built environment material and resource flow assessments

Initiatives such as the Leadership in Energy and Environmental Design credit system demonstrate it is technically possible to assess on- and off-site impacts of (and associated compensation by) buildings and precincts or city blocks.[5] Compliance can be regulated for, or incentivised by, preferential investment in rated buildings and policy evolved to (for example) reduce the environmental impact of buildings (Nejat et al, 2015). Commercial and residential neighbourhoods can also be assessed.

Models are also being developed to calculate and characterise present and future energy use, carbon emissions and associated costs for the built environment, including transport (Webster et al, 2011). Such modelling could form the basis for the energy component of the auditing required to calculate existing and future impacts of the built environment.

However, code compliance aims to mitigate impacts (Nejat et al, 2015) rather than result in an NB (Birkeland, 2014, Birkeland and Knight-Lenihan, 2016). Alternative code requirements would be needed to create buildings that, for example, absorb more carbon than they emit over their lifetime through integrating vegetation and micro-ecosystems, renewable energy and passive solar design (Renger et al, 2015). Such 'green scaffolding' also supports functions such as heating, cooling, on-site water treatment, food production and ecosystem functioning (Birkeland, 2014).

Attaching these initiatives to such things as attempts to increase urban biodiversity (Ignatieva et al, 2011) and ecosystem functioning (Clarkson and Kirby, 2016) would generate credits according to the extent to which a development (in this case, a building) contributed to ecological restoration and carbon sequestration and storage goals.

Product verification systems

Another issue is the need to verify the assessment of progress against the priority impacts. Results would answer the following.

- Is it clear what the priorities are? Has there been an assessment against broader national, regional and local medium- to long-term goals? Gaps in such a process need to be noted.
- How has progress towards goals been measured and reported? Any independent audit would need to generate an estimate of the reliability of the data, as well as establishing what progress has been made towards individual goals.

The technical challenges are significant, particularly when considering how to generate 'credits'. Using the example of biodiversity offsets, issues occur over how to assess the condition of a particular habitat, whether and how to compare different types of habitat and/or species for offsetting and whether there can be a valid acceptable 'currency' for doing so, challenges over how to measure additionality (that is, whether there is an additional benefit over what would have occurred anyway), the difference between applying an offsetting process and the time it takes to prove it worked, and the overall ethics of trading in biodiversity and estimating the risk of poor outcomes.[6]

Another issue is transaction costs. Requirements to comply with auditing of impacts will add costs at each stage, resulting in resistance from those in the supply chain. However, this problem already exists for any region or country attempting to address environmental externalities. It is accepted that, in some situations, the legal and regulatory systems will not be adequate to ensure externalities are accounted for, while in contrast some companies may well respond to consumer pressure to improve the environmental management despite the regulatory regime.

An additional cost comes from capturing information for those further up the chain. So, for an urban subdivision, a developer addressing the two bullet points above will need collated data from suppliers. This would add a transaction cost for the developer and suppliers. The drivers would be consumer pressure to demonstrate knowledge about the environmental status of suppliers, and any regulatory requirement to do so.

As a result, taxpayers or ratepayers should meet a share of the costs. This is because developers and suppliers make investment decisions within an economic system that not only allows for but incentivises ecological capital cross-subsidising. All of society benefits from this drawing down of natural capital, and all of society should be equally responsible for repaying the debt.

Of course, other ways exist of pursuing positive outcomes, community support for ecological restoration being an obvious one (Clarkson and Kirby, 2016).

The point of this paper, however, is to address a need to generate net gains in environmental values by helping to embed changes in the economic system and go beyond relying on voluntary action.

The product verification system could be similar in structure to the auditing done by organisations such as Trade Aid. For example, all components of coffee sold under the Trade Aid banner have to be individually audited and confirmed at source.[7] This then generates a compliance assessment.

The overall objective is to estimate the extent to which urban activities are achieving net environmental gains locally and to which goods (such as raw materials) and services (such as energy generation) in the supply chain are achieving their own goals. This would be incorporated into a rating for parts of the built environment. The following section shows how this might evolve within the New Zealand planning system.

Decision-making framework

For each criterion at each stage of the lifecycle analysis, it is necessary to have a goal-setting process. This will of course vary, depending on in which country and region the lifecycle stage occurs. For the urban development stage, the 2014 New Zealand National Policy Statement for Freshwater Management (NPS-FM) shows how this process might work.

The NPS-FM sets objectives and limits for freshwater quality and quantity standards to be achieved by managing land use at a catchment level through freshwater management units. The NPS-FM sets environmental bottom lines that regional councils and unitary authorities must comply with but have the discretion to go beyond. This is where the potential for both net positive ecological benefits and broader environmental benefits arises.

New Zealand has examples where biophysical improvements can be achieved by setting limits on such things as total anthropogenic nitrogen catchment loads or water allocation within a catchment, and allowing permit holders to trade within the cap (see, for example, Duhon et al, 2015). The overall cap is then reduced (or, if it were applied to biodiversity, increased) to help achieve collective goals. This establishes a condition for achieving net ecological benefit.

Hence, the country does have a catchment-based freshwater unit capable of including NB goals, if desired. Three questions then arise. What is an acceptable level of net benefit; what is the baseline; and can this relate more broadly to issues beyond water quality? The third question has been answered. Initiatives generating co-benefits relating to water quality, flood control, biodiversity, sediment control and atmospheric carbon sequestration already exist (Clarkson and Kirby, 2016; Ignatieva et al, 2011). The former two questions are addressed by looking at the example of managing Auckland's coastal wetlands.

Globally, coastal wetlands are known to reduce the risk of climate change (CC) through carbon sequestration and storage (CS&S) (which reduces the probability of CC happening), as well as providing coastal protection (which reduces the scale of CC impacts).[8] A lot of uncertainty exists around, in particular, CS&S estimates. However, by using climate zone delineation, species and habitat comparability, and making conservative estimates of the past and current extent of Auckland's coastal wetlands, inferences can be drawn (Khodabakhshi, 2017).

Using a social cost of carbon[9] estimate of US$220 per tonne (around NZ$300) (Moore and Diaz, 2015), Khodabakhshi (2017) concludes CS&S services of mangrove forests and saltmarshes in the Auckland region are worth about US$9.6 million (around NZ$13.2 million) per year. Equally, recent losses in the aerial extent of Auckland wetlands are worth about US$4.4 million (around NZ$6.0 million) per year. Consequently, per hectare CS&S benefits associated with individual parts of the Auckland coastline could be calculated. Notably, this would not include any co-benefits of adaptation, such as to coastal and marine biodiversity or water quality; these values could be assessed separately.

The benefits of wetlands for coastal protection are highly site specific. Wetland restoration may require removing coastal development, with associated direct costs, or, alternatively, rule out certain development, with associated opportunity costs. The value of protection will depend on the value of existing infrastructure.

If a development in a particular catchment could demonstrate benefits to coastal wetland protection or enhancement through either avoided reclamation or direct protection, this could contribute to compensating for emission impacts of the development. CS&S benefits could be calculated relative to the whole of the Auckland coastline, while protection (adaptation) benefits would be linked to the specific infrastructure being protected.

These actions could be done within the freshwater management units generated as part of the NPS-FM. The legal impetus comes from councils needing to give effect to an NPS (Resource Management Act 1991, section 55(2)), which includes having regard to the connection between freshwater bodies and coastal water (NPS-FM, Policy A1(iii)). Coastal wetland protection and enhancement help address this connection while generating co-benefit improvements in CC security.

Baselines

The example above raises an important point about baselines. For emissions, exceeding the 'carbon neutral' point earns credits that can either be used by the developer elsewhere or sold to another developer. Contributing to adaptation capability does not require passing through a neutral point, because all additions are beneficial. In this case, all developer contributions are positive and earn credits.

Estimating ecological baselines (in this case as a co-benefit) is far more problematic given arguments over how far back to go to reach an 'un-impacted' level. This may be unnecessary for coastal wetland protection and rehabilitation, however, given the benefits accrue immediately and the debate is not over returning the coast to what it was originally but, instead, creating new ecosystems that have climate, biodiversity and recreational values. What remains is the difficulty in estimating the scale of improvements and deciding what is fair and reasonable. These issues are not resolved here.

However, while technical difficulties are substantial, ultimately, the objective is to clearly connect urban development to prioritised catchment-level ecosystem protection and rehabilitation projects. If this is not done, net ecological decline will continue.

Conclusion

A net environmental benefit concept has been developed in this paper. A lifecycle analysis approach has been taken, arguing that assessments of every stage of the securing and formulating of materials, and provision of energy, should be audited against various prioritised environmental issues. Estimates of progress would translate to proportions: so a mining company might be assessed as offsetting its ecological impacts by 50 per cent while offsetting its atmospheric carbon emissions by 20 per cent. The objective is to ensure all activities associated with development generate a net environmental benefit.

A decision-making framework based on the National Policy Statement provisions of the Resource Management Act 1991 demonstrates how the process might be implemented. Baselines are a major challenge. That is, what determines a point of no net loss (NNL) for such things as biodiversity or ecosystem values? This was not resolved in the paper. It was proposed that creating a credit trading system might help incentivise developers to keep adding benefits beyond the point of NNL, that is, beyond a baseline.

Transaction costs already occur at each stage of the supply chain, depending on the regulatory environment in place. Additional transaction costs occur in collating and providing information to those further up the supply chain. Given the socialised benefits, consideration will have to be given to taxpayer or ratepayer payment for some or all of the transaction costs. What is fair and reasonable will be set locally, resulting from negotiations between communities and regulatory authorities.

Two further aspects of pursuing net environmental benefit arise: is there a process in place to measure it? And could it work?

The first aspect requires an independent auditing system to be established, and one acceptable both within the region and country where the activity occurs and to those receiving the goods and services. The second aspect asks whether and how it is possible to assess if it works. A fundamental challenge with environmental compensation is being able to wait long enough to see whether what is established in fact delivers.

Neither challenge has been resolved in this theoretical paper. However, these challenges are not new. Difficulties in audit reliability have always existed, and outcomes related to biophysical phenomena are by definition uncertain. Equally, these challenges are already being addressed. The added dimension argued in this paper is to apply process improvements to the goal of requiring development activity to demonstrate net environmental benefits. While the example provided is urban, the principle applies to any development initiative.

There is also a question of the complexity of process. If a process is too complex, it will not be implemented. The proposal here is to compartmentalise parts of the life cycle so different regions and countries may pursue net benefit at their own pace. It will be consumer pressure that generates work towards resolving the technical and management issues, and incentivises progress toward achieving net environmental benefits.

NOTES

1 Based on the Business and Biodiversity Offsets Programme definition (BBoP, 2012a; 2012b and http://bbop.forest-trends.org; accessed October 2016).

2 See www.mfe.govt.nz/climate-change/reducing-greenhouse-gas-emissions/new-zealand-emissions-trading-scheme; accessed June 2017.

3 See, for example, the Global Footprint Network www.footprintnetwork.org/our-work/ecological-footprint; accessed November 2016.

4 See http://data.footprintnetwork.org/#; accessed May 2017.

5 See www.usgbc.org/credits; accessed November 2016.

6 See, for example, BBoP, 2012a; 2012b; Birkeland and Knight-Lenihan 2016; Curran et al, 2014; Gardner et al, 2013; Knight-Lenihan, 2013; 2014; May et al, 2017; Overton et al, 2013; Pilgrim et al, 2013; Quétier and Lavorel, 2011; Walker et al, 2009.

7 See www.tradeaid.org.nz/our-story/made-fair; accessed November 2016.

8 Material in this section is summarised from a submitted doctoral thesis (Khodabakhshi, 2017).

9 The social cost of carbon is the estimated price of the economic or social costs or damages caused by each additional tonne of carbon dioxide emitted and has been commonly used to assess the benefits of CC mitigation policies (Nordhaus, 2014).

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Avon–Ōtākaro Network Vision for Regeneration of the Avon–Ōtākaro Corridor Red Zone

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The 2010/11 earthquakes in Canterbury, New Zealand caused considerable damage to residential development along the Avon–Ōtākaro River Corridor, which is land prone to liquefaction. An area was identified post-quakes by government as uneconomic for immediate redevelopment of housing because of the cost of remediation – what is referred to as the 'residential red zone'.

The Avon–Ōtākaro Network was formed by members of the greater Christchurch community. Their vision is for an ecological and recreational reserve for the residential red zone land in the Avon–Ōtākaro River Corridor from the Christchurch central business district to the Avon Heathcote Estuary Ihutai (from the city to the sea). The objective is to create a multi-purpose river park with a broad continuous corridor of indigenous habitat with specific regard to enhancing water quality and biodiversity. The reserve would incorporate cultural values and provide a network of paths and cycleways with interconnections to the greater Christchurch area. The goal is to create a long-term asset for the Christchurch community.

This paper describes the research projects undertaken over the past five years and still in progress that include: (1) compiling and integrating community project initiatives and seeking feedback on their support; (2) community group and student investigations of the corridor environment and conceptual design of heritage, ecological and recreational elements; (3) commissioned research on the economic value of the ecological and recreational reserve; (4) the Mahinga Kai Exemplar Project in partnership with Ngāi Tahu and government agencies at Lake Kate Sheppard as an example of river corridor restoration for ecological and Māori values; (5) research into the implications of sea level rise for conservation planning in the corridor; and (6) the opportunities for improved water quality management of stormwater and sewage overflows, and improved flood plain management that could be incorporated in a reforested corridor.

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Community research
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Conservation planning

Christchurch City (population of about 370,000) suffered extensive damage from a series of earthquakes and aftershocks in 2010 and 2011. This included 185 deaths mainly associated with the failure of two large office buildings in the central business district. Many homes (about 150,000) were affected by shaking and liquefaction of the alluvial sediments. Underground infrastructure (such as water supply, sewage and stormwater) was damaged throughout the city. The capital cost of the earthquake damage is estimated to be around NZ$40 billion (Potter et al, 2015).

Residential areas that were damaged and considered uneconomic for redevelopment as housing were declared 'red zones', and the New Zealand Government made offers to purchase the properties. About 400 hectares along the Avon–Ōtākaro River Corridor between the Christchurch central business

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district and the Avon Heathcote Estuary Ihutai outlet to the sea were designated as a residential red zone (see figure 1).

The Avon–Ōtākaro Network (AvON) comprises individuals and organisations dedicated to creating an ecological reserve and multi-purpose river park in the Avon–Ōtākaro River residential red zone. AvON's approach is to develop a community-driven and science-informed strategy for the red zone regeneration (Avon-Ōtākaro Network, 2016).

This paper outlines the research that AvON has led to inform the regeneration strategy. One component has been research into community aspirations for the Avon–Ōtākaro River Corridor red zone land. This has involved combining community forums, negotiated agreements between interest groups, and a detailed analysis of community feedback on proposals to define the corridor concept and possible project elements. The research strategy's second component involved undertaking investigations through student projects, professional research funded by community grants, trial plantings by community groups with professional assistance, and compilation of findings from government agencies to provide a scientific basis for delivering on community aspirations.

Research projects

The research projects undertaken can be considered in the categories discussed below.

- Community-driven regeneration research

  This work involved compiling and integrating community initiatives (Kennedy, 2014), creating a geographic information system database (Ward, 2013) and then an interactive map on the AvON website (Avon-Ōtākaro Network, 2016). A major community engagement – EVO::SPACE – was undertaken to get community reaction to various community initiatives (Smith, 2015).

- Community design research

  Through a series of community group and university student projects, the conceptual designs for heritage, ecological and recreational elements have been defined.

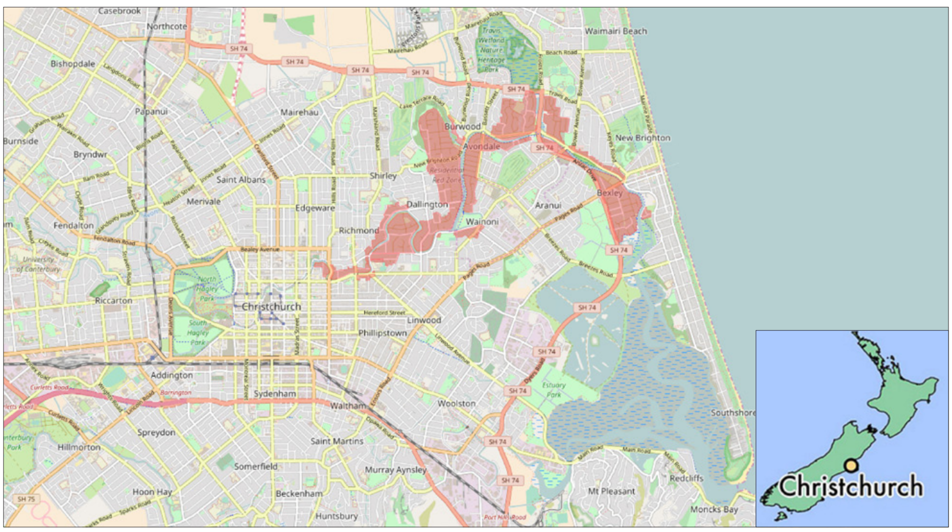

Figure 1: Residential red zone on the Avon–Ōtākaro River Corridor (Source: Smith, pers comm.)

- Economic value of ecological and recreational reserve

  A choice modelling survey, coupled with literature estimates for public health, water quality and flood mitigation benefits, was undertaken to estimate the economic benefits of the proposed river park concept (Vallance and Tait, 2013).

- Mahinga Kai Exemplar Project

  This project concerns Lake Kate Sheppard, a stormwater lake tidally connected to the Avon–Ōtākaro River, and adjacent land within the Anzac Drive Reserve. It is a partnership between Ngāi Tahu, the three levels of government (national, regional and city), University of Canterbury and the community (through AvON). Many research initiatives are being progressed as an example of restoration of Māori and ecological values.[1]

- Research on the implications of sea level rise

  The Avon–Ōtākaro River Corridor settled about 0.5 metres as a result of the earthquakes. This has provided a unique opportunity to research the implications of projected sea level rise on conservation planning. The research includes a collaboration with the National Institute of Water and Atmospheric Research to develop salinity modelling capability for the Avon–Ōtākaro River. The current research focuses in particular on determining salinity effects on inanga[2] spawning habitat, which occurs in the vicinity of the saltwater–freshwater interface (Orchard, 2016).

- Green rather than grey infrastructure

  The next significant piece of research, which is at the proposal stage, is examining the cost-effective implementation of reforestation of the red zone. This will include the comparative economic performance of green infrastructure for water-quality treatment and management of flood and earthquake risk (Smith, 2016).

The main findings of the research programme are discussed below.

EVO::SPACE online spatial planning application for community engagement

The EVO::SPACE website is designed to provide community feedback on guiding principles for the regeneration strategy and on suggested proposals for the red zone and surrounding areas. A map and description of 27 proposals were included in the initial website and the option of providing further proposals was available. A further 17 proposals were added by community interests. The main outputs from the community response were a ranking of guiding principles and the level of community support for suggested proposals.

Table 1 shows the average ranking of guiding principles from those who provided feedback. The community preference is for keeping the community safe from natural hazards, a green sustainable rebuild and building strong connected communities. Redevelopment and a return to residential use were the lowest priorities.

Figure 2 shows the level of community support for the 44 proposals. Highest support was for a cycleway and walkway network and a city-to-sea river park. The nature of the projects reflects the community preferences noted in table 1.[3]

Table 1: Ranking of guiding principles on EVO::SPACE

Guiding principle	Average priority
Keep communities safe from natural hazards	2.6
Build back clean, green and sustainable	3.3
Build strong connected communities	3.3
Support healthy lifestyles	4.0
Rebuild schools	5.0
Promote economic recovery of the east	6.0
Provide good affordable housing	6.1
Reclaim red zone land for residential use	7.6
Keep any redevelopment cost neutral	7.8

(Source: Smith, 2015.)

Community design research

AvON worked with university student groups to refine several community concepts for the Avon–Ōtākaro residential red zone as research topics for course projects. Lincoln University landscape architecture students designed a heritage trail (Madgin et al, 2012). University of Canterbury students investigated cycle trails (Goslin et al, 2013) and refined designs for integration with existing cycleways in the city (van Looy, 2013, see figure 3). Investigations were also done on remnant vegetation in the corridor and soil types suitable for community gardens (Cox et al, 2012).

Economic value of ecological and recreational reserve

AvON commissioned the Lincoln University economics research unit to estimate the value of a recreation reserve or river park in the Avon–Ōtākaro residential red zone (Vallance and Tait, 2013). Choice modelling surveys were undertaken to estimate the value of different purposes of the park for households and aggregated as annual benefits for the park. The attributes and their estimated annual value are shown in table 2 and total NZ$36.3 million per year.

Using New Zealand Transport Agency criteria, additional benefits from savings in public health costs were estimated to be NZ$50.3 million per year. Based on secondary data, ecosystem services were estimated to be around US$6,923 (NZ$9,623) per hectare per year for flood mitigation, US$3,389 (NZ$4,711) per hectare per year for water improvement and US$5,700 (NZ$7,923) per hectare per year for nutrient recycling. This equates to NZ$8.8 million per annum. The total benefits were estimated to be NZ$95.4 million per annum (table 3).

Mahinga Kai Exemplar Project

Lake Kate Sheppard and its surrounding area, Anzac Drive Reserve, have been a major research focus for AvON. The area is a Christchurch City Council reserve connected to the Avon–Ōtākaro River, with residential red zone land on both sides. With community access to the residential red zone denied by central government, the Anzac Drive Reserve around Lake Kate Sheppard has been used as an exemplar for restoration for mahinga kai[4] values. The aim is to restore and redevelop mahinga kai in greater Christchurch to include recognition of cultural

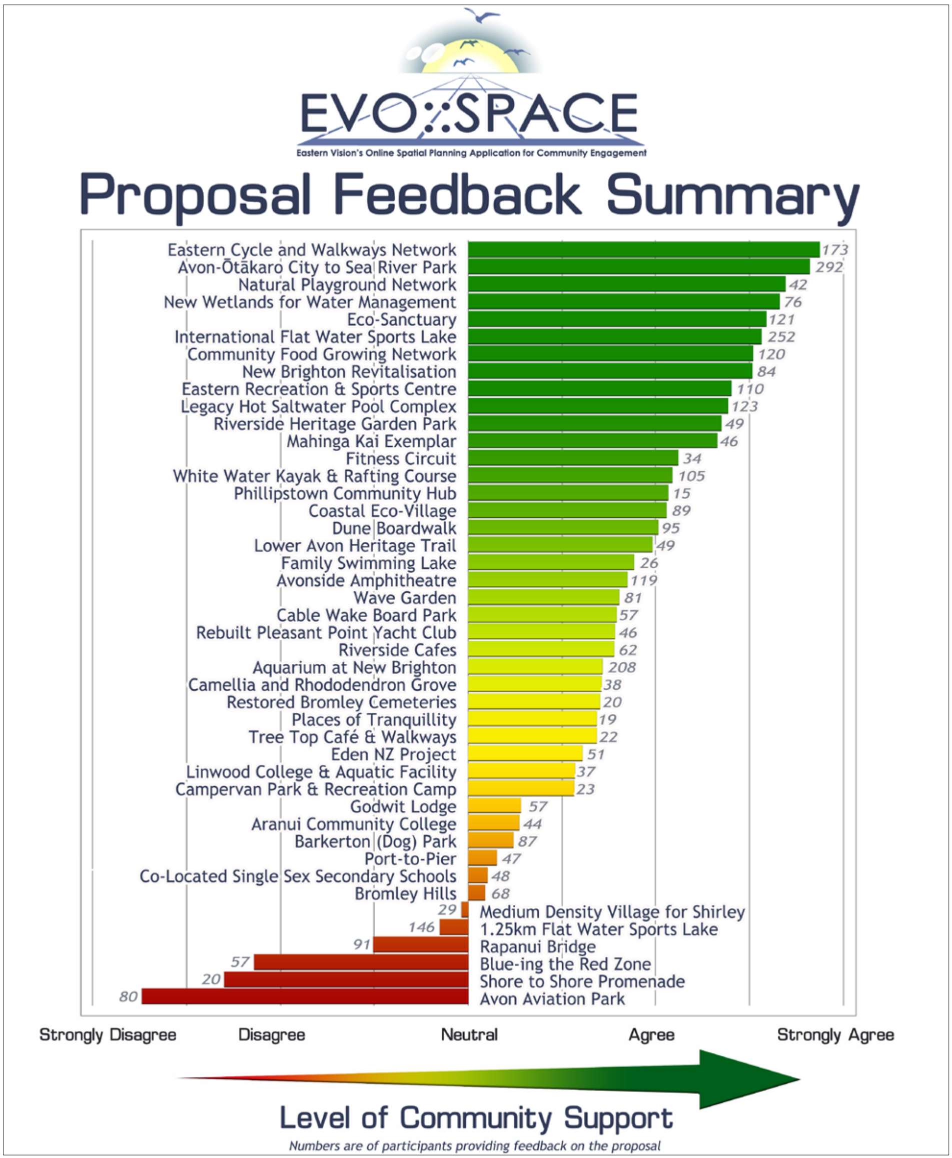

Figure 2: Level of community support for proposals from EVO::SPACE. (Source: Smith, 2015.)

and heritage values, restoration and enhancement of ecosystems, natural habitat, biodiversity, inanga spawning, pathway connections, stormwater treatment, land drainage, food production, and active and passive recreation (MKE Partners, 2016).

The area has been a focal point for many days of restoration plantings by community volunteers with support from government agencies (for example, Christchurch City Council, Department of Conservation and Environment Canterbury). This work has benefited from a biodiversity baseline survey involving environmental professionals and community members organised by AvON (Orchard, 2015). An example of the vegetation mapping is shown in figure 4.

A significant component of the restoration is the relationship between lake level and salinity with respect to tidal incursion from the lower Avon–Ōtākaro River and Avon Heathcote Estuary Ihutai and freshwater inflow to the lake. The lake level and salinity are significant for riparian planting design as well as the maintenance and enhancement of inanga spawning habitat. A major contributor has been the GEOG 309 course at the University of Canterbury run by Professors Eric Pawson and Simon Kingham. Successive student research projects (Baker et al, 2016) and a Waterways Centre for Freshwater Management summer

Table 2: Estimated value of river park use based on choice modelling

Attribute	NZ$m per year
Cycle/walking/jogging paths	5.1
Water-based opportunities	2.3
Improved river and habitat quality	3.0
Mostly native plants and habitat	5.7
Restoration of wetlands	2.2
Preservation of heritage gardens	4.9
Paths connecting central business district to Brighton and beyond	2.8
Cafes	1.8
100% residential red zone in park	3.1
Regular festivals and markets	3.6
Community food gardens	1.8
TOTAL	**36.3**

(Source: Vallance and Tait, 2013.)

scholarship (Keenan, 2015) have measured levels and salinity with increasing refinement to improve our understanding of this important relationship. Initial work on modelling the levels and salinity in the lake has also started through Engineers Without Borders New Zealand (Throssell, 2015).

Research on the implications of sea level rise on conservation planning

Sea level at Lyttelton (the port of Christchurch) has increased at a rate of 1.9 millimetres per year between 1925 and 2010 (Hannah and Bell, 2012). Christchurch City is considering a future sea level rise projection of 1.0 metres by

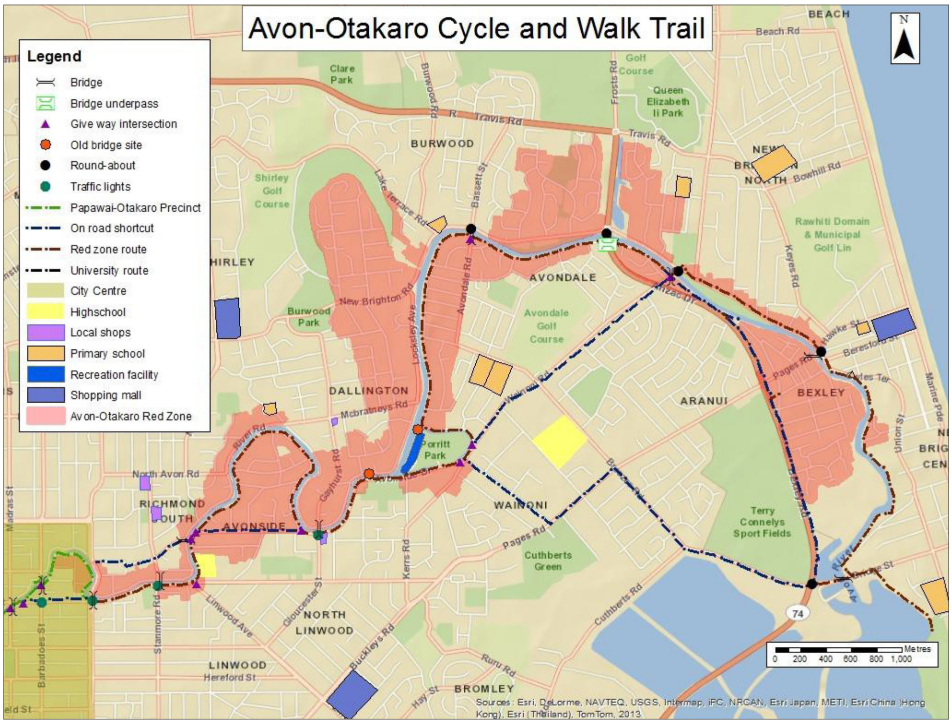

Figure 3: Avon–Ōtākaro cycle and walk trail. (Source: van Looy, 2013.)

Table 3: Estimated economic benefits resulting from river park

Attribute	**NZ$m per year**
Ecological and recreational reserve	36.3
Public health benefits	50.3
Water quality improvements	8.8
TOTAL	**95.4**

(Source: Vallance and Tait, 2013.)

2115 as a planning guideline (Tonkin & Taylor 2013). The impact of the 2010/11 earthquakes resulted in floodplain subsidence in excess of 0.5 to 1.0 metre in the lower reaches of the Avon–Ōtākaro River Corridor (Hughes et al, 2015), leading to an effect equivalent to sea level rise in relation to tidal effects on the river.

Inanga spawning occurs in suitable riparian habitat inundated at spring tide levels at the freshwater–saltwater interface. The location of inanga spawning habitat is expected to move upstream (subject to habitat availability) with sea level rise (or river corridor subsidence). Inanga egg surveys have been undertaken in the Avon–Ōtākaro and Heathcote–Ōpāwaho rivers in Christchurch and compared with historical results. Straw bales were also used as a further detection tool to test potential habitat both at sites in gaps in the distribution of known sites and at sites that represent potential habitat upstream and downstream of all known sites (Orchard, 2016).

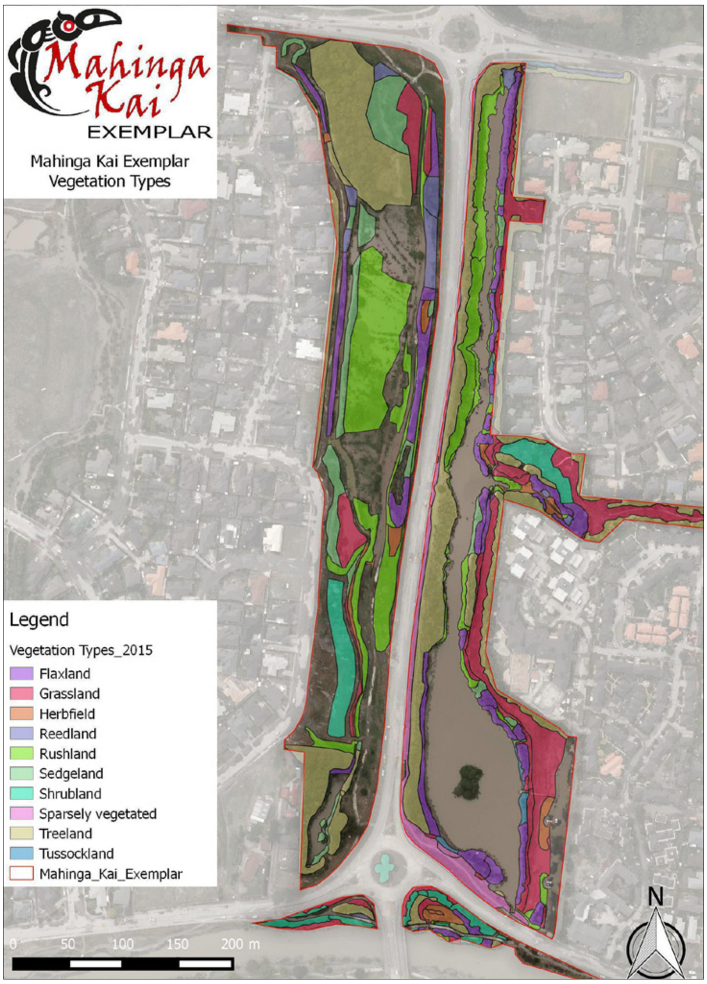

Figure 4: Vegetation types of Mahinga Kai Exemplar site. (Source: Orchard, 2015.)

The results to date indicate that the inanga spawning distribution has expanded since the river corridor subsidence resulting from the earthquakes (figure 5). Evidence from the straw bales also identifies degraded sites that could be restored to increase the area of habitat available. This is important because spawning habitat can be affected by riparian margin vegetation management, flood management works and bank stabilisation, all of which occur within the post-quake spawning reach (Orchard and Hickford, 2016). The effects of sea level rise and riparian management have implications for conservation planning for the ecological corridor envisioned for the Avon–Ōtākaro River Park. In particular, the flooding frequency is expected to increase and the salinity from tidal incursion will reach further inland, which will influence vegetation suitability and inanga spawning locations.

Green rather than grey infrastructure

The next main research tasks will involve: (1) investigating the options for enhancing indigenous vegetation recovery and implementing reforestation of the Avon–Ōtākaro residential red zone; (2) undertaking a cost-effectiveness analysis of a forested corridor as a green alternative to grey infrastructure for flood management and water-quality management; and (3) considering the opportunity costs of urban development uses in relation to earthquake risk management. A proposal to undertake this research has been prepared (Smith, 2016).

The natural ecological zones before urban development have been identified (Lucas, 2011). However, for reforestation, the effects of river corridor subsidence and sea level rise need to be considered to be able to identify vegetation communities compatible with the current hydrological and salinity regime as well as projected future changes. An ecological corridor needs to be established for species migration and climate change adaptation.

The appropriate reforestation also depends on the approach taken to flood plain management. The residential red zone is not only subject to significant earthquake risk (based on the damage sustained in the 2010/11 earthquakes and

Figure 5: Comparison of inanga spawning sites before and after earthquakes. (Source: Orchard, 2016.)

liquefaction risk assessments) but also to significant flooding. A forested flood plain has the potential for being a more cost-effective land use option for managing earthquake and flooding risk. Also, with less constrained land elsewhere in the city (ie, not subject to liquefaction or flooding risk), the opportunity costs for traditional urban development in the residential red zone are significant because of cost premiums for earthquake and flooding hazard management.

Furthermore, the available land in the residential red zone provides an opportunity to establish constructed wetlands, sewage overflow storage and riparian plantings to improve water quality. Current river quality is graded 'very poor' in relation to recreational use (Environment Canterbury, 2016). One of the student projects identified sites for stormwater treatment in the red zone area (Apelu et al, 2013). The Christchurch City stormwater management plan has also identified potential stormwater treatment device locations in the red zone (Christchurch City Council, 2015). Green rather than grey infrastructure has the potential to be a more economic approach.

Conclusions

AvON is developing a community vision for the residential red zone. It is community driven and science informed. Research is an important element to this approach, with community interests working with interested professionals and tertiary students. The goal is to create a long-term asset that serves multiple needs and improves sustainability. The recovery strategy for the red zone provides an opportunity to: (1) establish an ecological and recreational corridor; (2) reduce flood risk and create more resilient river margins; (3) incorporate stormwater management and sewage overflow capture; (4) improve water quality to improve water-related recreation opportunities; and (5) integrate multiple community uses, cultural heritage, community gardens, recreational and cycling corridors, a biodiversity corridor and earthquake memorials. The Avon–Ōtākaro River Park incorporates all of these opportunities.

NOTES

1 The Mahinga Kai Exemplar Project is an exploratory project to show how it is possible to progressively restore and enhance mahinga kai resources as part of the Natural Environment Recovery Programme (Environment Canterbury, 2013).

2 Inanga – common galaxias, a small silvery-white diadromous species of freshwater fish. Juveniles migrate upstream from the sea and are caught as 'whitebait', which is an important food species for Māori. Adults mature at one year and migrate downstream to spawn when spring tides flood marginal vegetation.

3 The importance of green spaces was also evident in community responses in the Christchurch City's 'Share an Idea', which was a conversation with the Christchurch community to gather ideas on how the community wanted the central city redeveloped following the devastating February 2011 earthquake. Greening the city was an overarching theme for redevelopment, based on the analysis of community responses through website entries, community surveys and Post-it notes from a community expo (Christchurch City Council, 2011).

4 Mahinga kai describes the natural resources that mana whenua (indigenous people with traditional authority over the land) gather throughout their takiwā (territory) and the places and practices that they use in doing so. It includes the direct and indirect use of those resources for ceremonies, medicines and sustenance (MKE Partners, 2016).

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Between Grey and Green: Ecological Resilience in Urban Landscapes

EMILIO GARCIA

This paper analyses the city of Christchurch, New Zealand, which has been through dramatic changes since it was struck by a series of earthquakes of different intensities between 2010 and 2011. The objective is to develop a deeper understanding of resilience by looking at changes in green and grey infrastructures. The study can be helpful to reveal a way of doing comparative analysis using resilience as a theoretical framework. In this way, it might be possible to assess the blueprint of future master plans by considering how important the interplay between green and grey infrastructure is for the resilience capacity of cities.

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RESEARCH

Brenda and Robert Vale (2009) wisely affirmed that land sets the ultimate resource limit. We use land resources to build our habitat, to provide ecosystem services, to produce food and to sustain our lifestyles, usually forgetting that land is a finite resource. Population growth and changes to more sophisticated lifestyles have produced the need for more services and more complex infrastructures that demand more space and consume more land resources (Millennium Ecosystem Assessment, 2005). The infrastructure design of the built environment, what might be considered the grey areas, impacts on the availability of other land surfaces, like green areas (for growing) and brown areas (open areas with permeable surfaces that could be easily converted to green areas), that are necessary for the sustainability and persistence of our species.

Despite or perhaps because of the many approaches to defining green and grey infrastructure, it is hard to find consensus among scholars (Mell, 2013). The terms sometimes refer to technologies and sometimes exclusively to land surfaces. In any case, what is clear is that cities need both. According to the Natural Economy Northwest Programme (2009), green infrastructure refers to all the natural assets that occupy land – for example, parks, sports facilities, agricultural land and private gardens – and that are important for regulating microclimates, absorbing carbon dioxide emissions and reducing the risk of flooding. Brown areas are not brownfields. In the United Kingdom and the United States of America, brownfields are usually related to industrial sites or contaminated areas (Alker et al, 2000). In this paper, brown areas have a broader meaning related to the reversibility of land cover infrastructure into green areas. For this reason they are included as a subcategory of the green infrastructure. Brown areas could be decks, permeable surfaces like synthetic grass or abandoned areas in between buildings with no grass or pavement.

Grey infrastructure refers to all the constructed assets that occupy land: namely, transport infrastructure (motorways, roads, car parks), commercial infrastructure (factories, offices, retail), services and social infrastructure (schools, housing and buildings in general). Grey areas are essential to keep the city functioning. However, the uncontrolled proliferation of grey infrastructure through sprawling, bigger buildings, more car parks and plot infilling occurs to the detriment of green areas, helping to intensify the heat island effect (IPCC [Intergovernmental Panel on Climate Change], 2014). This situation is critical in cities, where urban growth tends to increase the competition for space by reducing the quantity of green areas. The problem is that the benefits provided by these green areas are less tangible than the perceived economic benefits from the development of new motorways, buildings and businesses. The issue is highlighted when it comes to developing new master plans for cities that have suffered natural disasters. On the one hand, the city needs businesses to keep on running and therefore attracting new investments seems the way to put the city back on track, particularly through the development of a compact built environment with mixed-use buildings. On the other hand, the enthusiasm for attracting new businesses could result in the depletion of green areas and standardisation of the urban landscape, which could in turn impact on the city's resilience capacity to adapt to future natural hazards.

Because the organisation and distribution of green and grey infrastructures are evidence of human behaviour in terms of the historical choices made regarding land use, the study of changes in the use of land cover might help to better understand how to create conditions for the persistence of urban life in a context of change. This paper, therefore, analyses the city of Christchurch, New Zealand, which has been through dramatic changes after it was struck by a series of earthquakes of different intensities between September 2010 and December 2011. In this context, a resilience approach will involve observing changes in green and grey infrastructures. The challenge is to develop a deeper understanding of resilience (Vale and Garcia, 2016) that helps to narrow down how change can be usefully analysed. The study can be helpful to reveal a way of doing comparative analysis using resilience. In this way it might be possible to assess the blueprint of future master plans by considering how important the interplay between green and grey infrastructure is for the resilience capacity of cities. Therefore, the question that this paper investigates is: how can designers assess the impact of master plans on the resilience capacity of urban landscapes?

Theoretical background – green infrastructure, grey infrastructure and resilience

Early research about green and grey infrastructure (Norton et al, 2015) focused on the management of stormwater systems for the purpose of reducing the impact on aquifers, erosion and water pollution. Currently, the green and grey debate is closely related to the resilience of cities (McPhearson et al, 2015). Green and grey infrastructure approaches have also been used to forecast alternative ways of designing urban infrastructure that would mitigate the impact of natural hazards in a more natural and less costly manner (Sutton-Grier et al, 2015). The green infrastructure approach has also been used to understand the role that common gardens could play in periods of food shortage (Barthel and Isendahl, 2013) and in the development of cultural diversity (Colding and Barthel, 2013). In landscape architecture, green and grey infrastructures have been related to the resilience of cities by highlighting the role that open green areas play in providing shelter during and after earthquakes (Allan and Bryant, 2010). Moreover, research has shown that vacant areas are an important part of generating a 'temporary city' (urban spaces where activities happen while the city is reorganising) so that a community can keep on functioning while experiencing stressful situations (Wesener, 2015).

Another urban approach to the use of green infrastructure has been developed by Garcia (2013). This approach analyses the role of open green areas in the resilience of urban landscapes when a city undergoes changes that are produced by its own developmental processes rather than by extraordinary events like earthquakes or flooding. Recently, Garcia and Vale (2017) have questioned how much compact built environments really contribute to the sustainability and resilience of cities. According to the authors, compact cities are not necessarily more sustainable because the ecological footprint largely depends on the behavioural choices of the people living there rather than on the population density. Moreover, they argue that where built environments have been made more compact by replacing small domestic buildings with bigger and fewer mixed-use buildings, they become more rigid and standardised, making future changes potentially more expensive and less frequent. This is a factor that limits the capacity of the built environment to change. Furthermore, referring to Christchurch specifically, Richardson (2013) has challenged the future of the city's current urban interventions, alleging that rather than creating a more inclusive city, it could increase gentrification processes.

The idea that the compaction of a built environment will create better cities is thus in question. In the case of Christchurch, the urban landscape generated by the earthquakes can be understood as an opportunity for evaluating the resilience of loose landscapes through looking at the relationship between grey and green areas.

Understanding resilience

If cities are to survive any transition towards a more sustainable future, they need to harness the idea of designing cities to adapt to unpredictable changes produced by stressed ecosystems and the human societies within them (IPCC, 2014). Enhancing urban resilience is a helpful way of understanding how cities can use change to adapt and persist (Garcia and Vale, 2016). The first tests of applying resilience to urban landscapes came in studies of vulnerability, risk, mitigation, robustness and adaptation of cities in relation to climate change and natural hazards. Originally, resilience appeared as a concept in engineering and was later developed in psychology and ecology simultaneously but with different implications. In engineering, resilience refers to the elasticity of materials and was used to measure the quantity of energy that materials can stand without breaking or deforming permanently (Tredgold, 1818). The key point in the engineering definition is that resilience is about coming back or recovering from undesirable changes to a previous state of stability. In contrast, in ecology Holling (1973) refers to resilience as 'the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist'. He notes that keeping systems stable is of little use if they do not survive. Therefore, the management of ecosystems should focus on creating the appropriate environment for survival instead of only on avoiding disturbance.

Holling further shows that change is inherent in complex systems and that some disturbances, like fires in the savannah, are part of the life cycle of an ecosystem and a key element of its persistence. On this basis, resilience is not a state; it is a property of a system that is relative and temporal. Resilience depends on the capital that is measured and on the moment of its assessment. Moreover, resilience is not a status that can be held forever; therefore, a continuous assessment of the system is needed. In this paper, the understanding of resilience emphasises the relationship between persistence and change and, in addition, is about how to create stability by acknowledging change.

In relation to Christchurch, the concept of resilience discussed is linked with the persistence of the diversity of the urban landscape and, more specifically, with the diversity generated by the interrelationship between green and grey infrastructures and their role in making the city resilient to future natural hazards. The assumption is that the diversity of the urban landscape, in this case provided by the green and grey infrastructure, contributes to the heterogeneity and resilience of the city.

Heterogeneity, diversity and relative resilience

In landscape ecology, the analysis of the heterogeneity of landscapes has helped to create a better understanding of change. Forman and Godron (1986) propose that the heterogeneity of a landscape depends on three factors: function, structure and change. Structure is linked with the relationship between species and resources in the landscape. The structure of an ecosystem describes how resources and materials are distributed by number, geometry and kind of species. Function refers to the interrelationship between elements through the flow of energy and materials. Change is an alteration in the structure of the landscape – namely in its configuration, composition and distribution. For example, if a tree changes, it does not necessarily mean that the forest has changed; however, if all the trees belonging to one species are removed from the landscape, there will be a change in the composition and diversity of the forest, and in this way a change in its structure. Therefore, the heterogeneity of a landscape forms a useful concept for understanding changes that are not easy to predict and that are happening at multiple scales.

The concept of heterogeneity has also been used to understand resilience in ecosystems. The textural discontinuities hypothesis (Holling, 1992) uses the concept of heterogeneity to understand the link between different textures in a landscape and different resilience capacities. Gunderson and Holling (2002) argue the heterogeneity of a landscape is linked with its complexity and resilience. More complex, diverse and heterogeneous landscapes will have higher resilience capacities. Gunderson and Holling also affirm that the link between heterogeneity and resilience could be applied to the study of other complex adaptive systems, such as cities. This is very important for designers because the analysis of the texture of a landscape is closely related to our field of study and can be used to develop new hypotheses and advance the research into how cities cope with change.

Relative resilience (Allen et al, 2005) is a method used in ecology to assess and compare the distribution of species and resources in a landscape. The method Allen and colleagues developed uses a diversity index to assess the variety of species, as well as their number and distribution in a landscape. The relative resilience can be used to measure how much a system has changed after a disturbance by comparing changes in the diversity of the structure of two or more landscapes. According to Allen et al, a system will show resilience when changes in the population and in the distribution of elements and functions in a landscape fail to affect the structure of the system critically.

For example, if a system like the built environment of a city suffers an earthquake and many buildings are destroyed, the relative resilience of the system could be seen in its response to the quantity of change produced by the loss of buildings. If all the people leave because the city has nowhere to house them, the population structure of the city has changed; conversely if the remaining buildings have enough redundancy to house those displaced in the population, the structure has not changed. If the built environment has become less diverse after an earthquake (due to loss of people and their skills), it will mean that the resilience was at some point surpassed and the system could not maintain the same functions, structure and feedback while undergoing a disturbance. In contrast, if the diversity of a built environment has persisted after the earthquake, the system in question has buffered the changes produced by the disturbance and the buildings lost have not affected its structure. Relative resilience has previously been used in urban studies in a comparative analysis between the urban landscapes of Auckland in New Zealand and Nezu in Japan, as well as to understand the contribution of green and brown areas to the development of the urban landscape of Auckland (Garcia, 2013).

The importance of change and diversity to the urban landscape is known to designers. In cities, new buildings are constructed and old ones destroyed every year while others remain in place. Morphologists have devoted their studies to observing change in urban landscapes and its importance in developing cities and the communities living in them. Conzen (1960) suggests that the urban landscape is a palimpsest on which the history and culture of a city have been imprinted. For her part, Jacobs (1961) has discussed the importance of diversity by analysing the impact of modernism on the loss of street life. Jacobs was meticulous in observing that the size of plot and buildings affects the quantity and diversity of the street life. Another to discuss the importance of diversity to the built environment and its identity is Relph (1976), in analysing the negative effects of fast and big changes on the sense of belonging to a place. The analysis of the changes happening in the built coverage of plots, as well as in the number and size of buildings, and the related street systems, could be used to explore and understand the texture of the landscape and its contribution to the understanding of change in cities.

What the resilience framework offers to urban studies is the possibility of understanding diversity as a variable that is linked with a system's opportunities to adapt and persist. Moreover, the analysis of the heterogeneity of an urban landscape produced by the diverse distribution of its elements, like the distribution of green and grey areas in Christchurch, could provide some insight into the complexity and potential resilience of its urban landscape.

Methodology

The paper analyses how the diversity of grey and green infrastructures in the central business district (CBD) of Christchurch could contribute to the resilience of the built environment. To measure changes in the diversity of the urban landscape, a comparative analysis is made between three hypothetical scenarios after the earthquakes. The scenarios chosen are: 1) the urban landscape after the earthquakes; 2) the Blueprint for the CBD produced by the Canterbury Earthquake Recovery Authority (CERA); and 3) a hypothetical landscape where all the buildings targeted for demolition are replaced by open green space. By using different scenarios, it becomes possible to observe different stages in the equilibrium of the CBD of Christchurch. The objective is to try to understand what different plans mean for the diversity and future resilience of the city.

The methodology has three steps: data collection; analysis of the relative resilience; and finally a comparative analysis of the three scenarios proposed using a diversity index. The following sections explain each step of the methodology.

Data collection

The materials used for this research were mainly maps and satellite pictures of the urban landscape of Christchurch after the earthquake. Complete digitised maps (in shapefiles or other digital formats suitable for opening in geographic information software like ArcMap or QGIS) containing plots, building footprints, streets and green areas were not found in a single source. Therefore, when information was not available it was inserted using satellite pictures as a reference. The key data sources available for producing the maps were: a satellite picture of the CBD of Christchurch; a digitised version of the cadastral map of the CBD containing the plot system (extracted from Koordinates website); and digitised information containing all the building footprints along with CERA's projected demolition work. The impervious and permeable surfaces were mapped using satellite pictures provided by Google Maps, Google Earth, OpenStreetMap and Land Information New Zealand.

Relative resilience

To calculate the relative resilience of each scenario, a cluster analysis was performed to find the size classes contained in the green and grey infrastructures and also to produce a diversity index based on the range of sizes found in each group. The cluster analysis is used to find the number of groups of variables in a data set. It is useful for managing and comparing large data sets. The analysis grouped the different sizes of each feature into clusters. A feature is every single building footprint or green, grey or brown area mapped. A layer contains all the features of one category. Each cluster represents a class size. The quantity of clusters differs from layer to layer according to the quantity (number) and size (square metres) of the features in each category (building footprints, brown areas, green areas and grey areas).

The cluster analysis was performed separately for each category, using WEKA, free software developed by the University of Waikato. WEKA produces a 'model' that describes the number of clusters and features contained in each group. The results of the cluster analysis WEKA produces can also be attached as a third column to the initial data set imported from QGIS. In this way it is possible to identify what elements belong to which cluster. If needed, the new data set can be exported to QGIS and the information used to map the results.

Diversity index

The diversity index was created using the Shannon-Wiener diversity formula. The index was used to measure the distribution of features across the group sizes found in the cluster analysis. According to the ecological theory of resilience (Allen et al, 2005), elements with more clusters will tend to have a richer structure and probably a higher resilience. The number of clusters represents the size classes that can be found in one category (building footprints, brown areas, green areas and grey areas). The number of clusters can be used to measure the richness and complexity of each layer analysed. More clusters mean greater richness and therefore, more complexity.

The relative distribution refers to the relationship between the number of features in one class against all the features distributed in all the clusters. It thus represents the proportion of elements in a class compared with the whole, and can be expressed as a percentage.

The pi value is the natural logarithm and explains how evenly features are distributed across classes. It is measured from 0 to 1, where 0 represents all the features being equally distributed and 1 represents all the features belonging to one group. Therefore the closer to 1 the pi value is, the more uneven the distribution.

The diversity value refers to the possibilities that two elements of a group belong to the same class. It is measured from 0 to 1. The closer a result is to 1, the higher the possibility for two randomly picked elements to be different. The closer the diversity value is to 0, the less diverse the cluster.

The final or total diversity in one category is defined by the sum of the diversities found in every cluster (see the total in table 1). The diversity is always a negative number, and for that reason is multiplied by –1 to make it positive.

The area of study: Christchurch CBD

In February 2011, Christchurch suffered an earthquake of magnitude 6.3 on the Richter scale, costing the lives of 185 people, as well as causing severe injuries to 6,600 people and the destruction of more than 1,500 buildings. It followed on from a previous quake in September 2010 and was part of a sequence of earthquakes and aftershocks that formed the most dramatic event in the contemporary history of New Zealand. The sequence has had an impact on the country's economy. Significantly too the natural hazards that have disrupted the everyday life of the people of Christchurch remain as threats to the stability of the city (Christchurch Central Development Unit, 2012). Therefore it is important to rethink the rebuilding of the city to deal with this uncertainty.

The city of Christchurch, located in the South Island of New Zealand, has historically been the island's most important economic and population node. The city was built on a plain terrain that is bordered to the east by the Pacific Ocean and the estuary formed by the Avon and Heathcote rivers. The city was officially recognised in the 1850s and its centre was designed using a grid, which has helped to define the identity of the city.

The central area of the city has been chosen for this study because it has become a focus of attention for planners and designers and also because it is a meaningful place for the community (Pickles, 2016). The area of analysis was red-zoned after the earthquake – meaning all members of the public, including residents were excluded from it – for safety reasons. Since then, it has become one of the referents for the reorganisation of Christchurch and the place where an important part of the demolition work is concentrated. Even though this central area is no longer red-zoned, it continues to go through massive changes that are further defining the future of the city. For this reason, it is timely to start developing methods that can help policy makers, developers, designers and the community to assess the outcomes and implications of each proposed change and, in this way, to compare alternative futures for Christchurch. Moreover, what needs to be assessed is the capacity of the proposals to create a city that will cope with future uncertainties. But how is it possible to assess the changes and plans happening in the city? The next section addresses this question.

Analysis

Object of study

In each of three scenarios (figures 1–3), the green infrastructure was divided into two groups: green areas and brown areas. Green areas were defined as open spaces with permeable surfaces that are sometimes classified as natural reserves (parks, gardens, rivers and so on). Brown areas refer to open spaces with permeable surfaces that are not necessarily green but could easily be turned into green areas (like decks or unpaved areas in backyards). Most of these areas were in spaces remaining between buildings, but some were in front yards, backyards and vacant plots.

The grey infrastructure was represented by impervious surfaces. To facilitate the mapping of the grey infrastructure, it was separated into two groups: roofs of buildings and paved surfaces. The building roofs were mapped using the building footprints in each plot as a reference. Building footprints refer to the built area of buildings at ground-floor level. All other impervious surfaces that were not related to the building roofs were assumed to be grey areas. Grey areas are thus the car parks, paved courtyards and other paved surfaces. Streets, roads and motorways, which should be included in this group, were not considered in the mapping because the information available was insufficient to provide accurate measurements.

Description of the scenarios

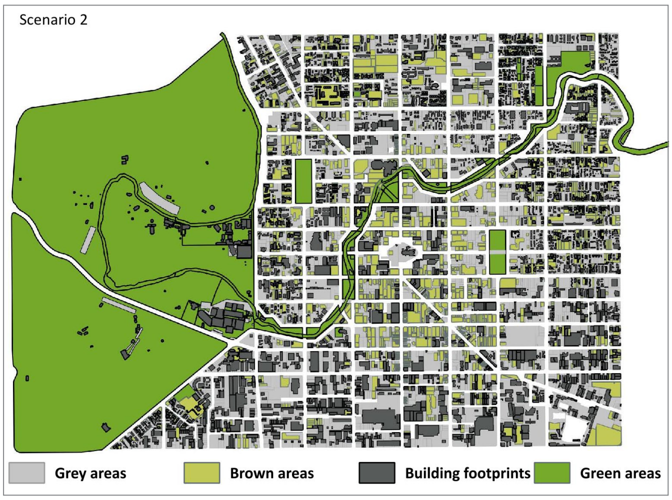
Scenario 1 refers to the urban landscape of the study area immediately after the 22 February earthquake (as at 24 February 2011). The main characteristic of this landscape is the incompleteness produced by plots with no buildings. The dominant surface in the built environment is a mixture of building footprints (dark grey in figure 1) and grey areas in between these (light grey in figure 1). The building footprints clustered around the ChristChurch Cathedral tend to be bigger than the residential building footprints found in the north and east blocks of the CBD. Building footprints and grey areas get even bigger in the blocks located in the south of the CBD, which is the area populated by warehouses. The green areas

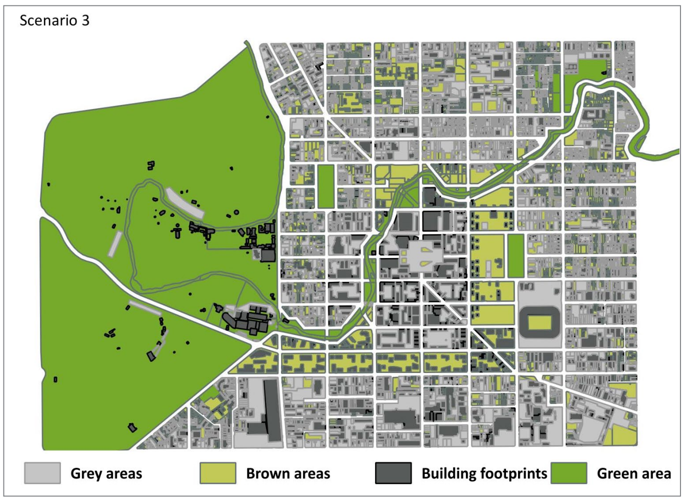
Figure 1: Scenario 1 – urban landscape post-earthquake

(light green in figure 2), as defined by the river and parks, have a strong presence in the landscape. Hagley Park occupies a third of the CBD. The rest of the green infrastructure is fragmented and dispersed within residential blocks in the north and east of the CBD. This scenario will be the reference with which to compare the alternative futures proposed in scenarios 2 and 3.

Scenario 2 presents a hypothetical landscape where demolished buildings have been turned into permeable surfaces. Behind this is the idea that the complexity of the green infrastructure of the city, and consequently its resilience, can be increased by adding new permeable open spaces to the landscape. Therefore, in this scenario, much of the core of the central area is open space (light green in figure 2). These open spaces use the plot system inherited from past landscapes to guide the layout. This provides a set of vacant spaces that look fragmented but could be linked to produce a network of green areas that would allow for temporary activities to happen. The intention behind this scenario is to increase

Figures 2 and 3: Scenario 2 – urban landscape with vacant plots now green space and scenario 3 – CERA's Blueprint for the Christchurch CBD





the complexity of the landscape without building more impervious surfaces – in other words, without adding new buildings to the city.

Scenario 3 (figure 3) is based on the Christchurch Central Recovery Plan, particularly the Blueprint for the CBD that CERA produced in partnership with public and private sector institutions. The most important element introduced in this plan is an inner green belt that embraces the surroundings of Cathedral Square and serves as a framework for the location of new buildings and amenities (figure 3). This 'green frame' divides the CBD into two sectors: the first is enclosed by the green frame and characterised by a compact arrangement of mixed-use buildings; the second is outside the green frame and is characterised by a dispersed residential periphery with neighbourhood centres. Even though the plan has an uncertain future, it is useful to evaluate it critically to see what alternative scenarios might have to offer for increasing the resilience of Christchurch. In this particular case it is important to determine whether more open green spaces will increase the complexity of the green and grey infrastructures of the landscape.

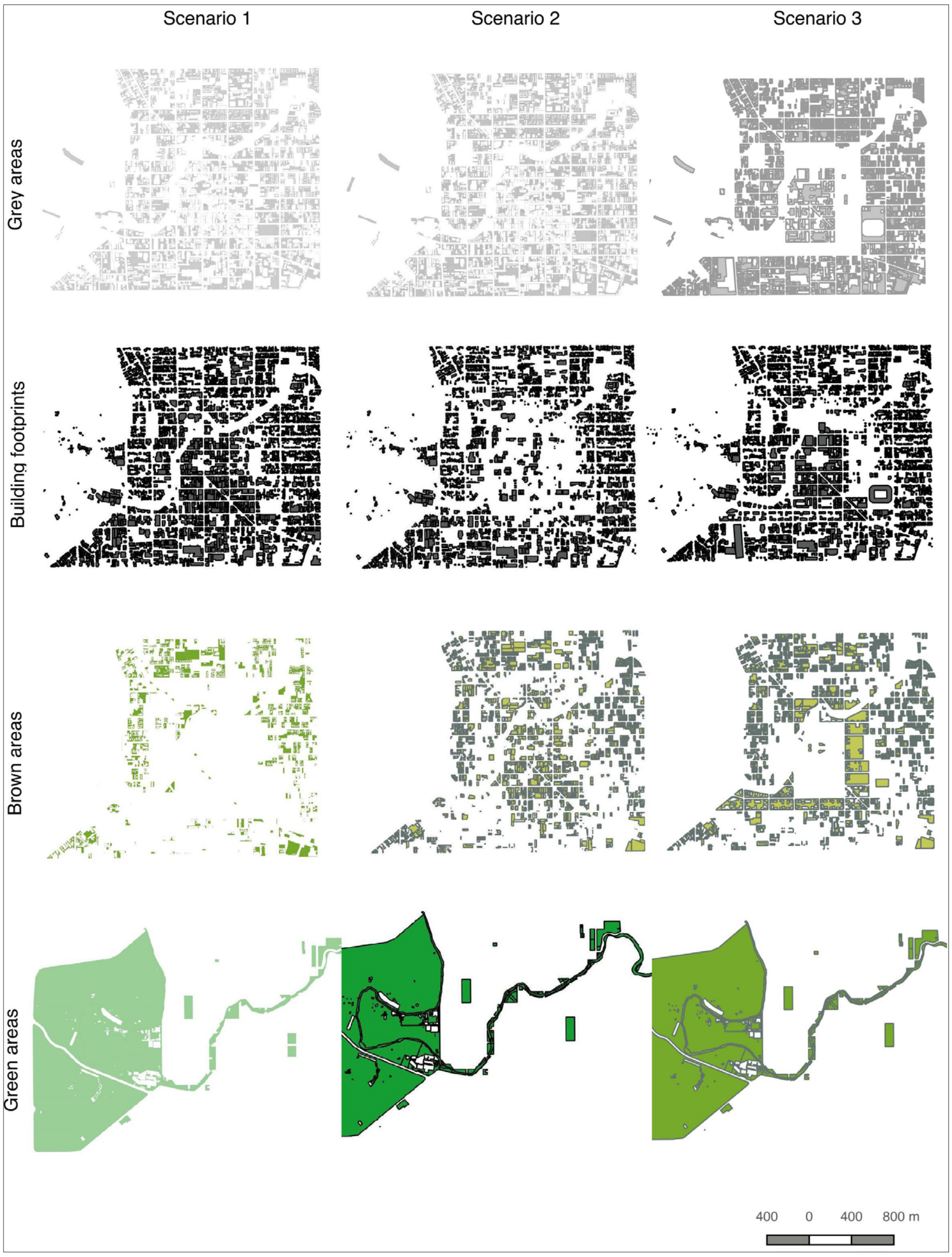


Figure 4: Visualisation of green and grey infrastructures for each scenario. Grey infrastructure is represented by grey areas and building footprints (first and second rows). Green infrastructure is represented by brown and green areas (third and fourth rows)

Organisation of the information

To produce a cluster analysis, all information was first digitised (redrawn from maps) or exported to ARCHGIS, where maps were already in a digital format. When all the information was assembled in this way, it was organised into different layers corresponding to the different elements (green and grey infrastructures). Once the information was classified and organised (figure 4), it was possible to know the area (in square metres) of every element in the map, whether it was a building footprint, or a green, grey or brown area. This information is needed for the cluster analysis.

Cluster analysis

The areas of features in each layer were imported from QGIS to WEKA as CSV format (Comma Separated Value). The data were clustered in WEKA using the 'Expected Maximization' mode. This mode was chosen because it gives the possibility of discovering the number of clusters in each category without predefining them. It is important to set the K value (number of clusters) to –1 so the algorithm finds the number of clusters. Figures 5–7 are the charts used to visualise the results of the cluster analysis for each scenario. In each chart, vertical bars represent clusters, while the colour in each bar refers to a different category – namely, building footprints, brown areas, green areas and grey areas.

In scenario 1 (figure 5), building footprint (the number of buildings in the landscape) is the most populous element with more than 2,000 counts. Grey areas are the richest element of the urban landscape with 10 clusters (light-grey bars in figure 5), while the green areas have only one cluster. This means that the various areas that constitute the total amount of green space do not differ dramatically in size. The richness of building footprints and brown areas is quite balanced with five and six clusters respectively. This is probably the result of having different land occupation ratios for building footprint and plot sizes.

In scenario 2 (figure 6), the group of brown areas is the richest element with 11 clusters. Even after the demolition process has been completed, the group of building footprints has not lost any clusters (six) but instead the structure shows a greater richness with the addition of another cluster. With 24 clusters across the different categories, this scenario is the richest urban landscape of the three proposed.

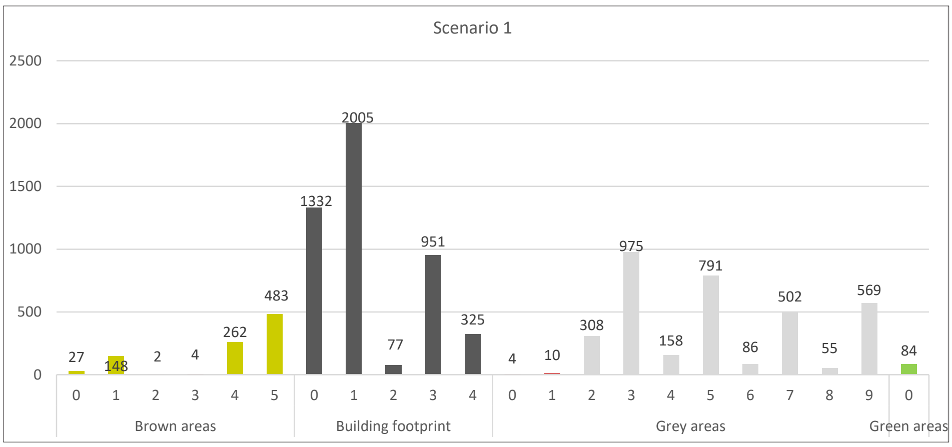


Figure 5: Clusters in scenario 1. The x-axis gives the number of clusters divided into categories. From left to right: brown areas (light green), building footprints (dark grey), grey areas (light grey) and green areas (green). The y-axis refers to the number of features contained in each cluster.

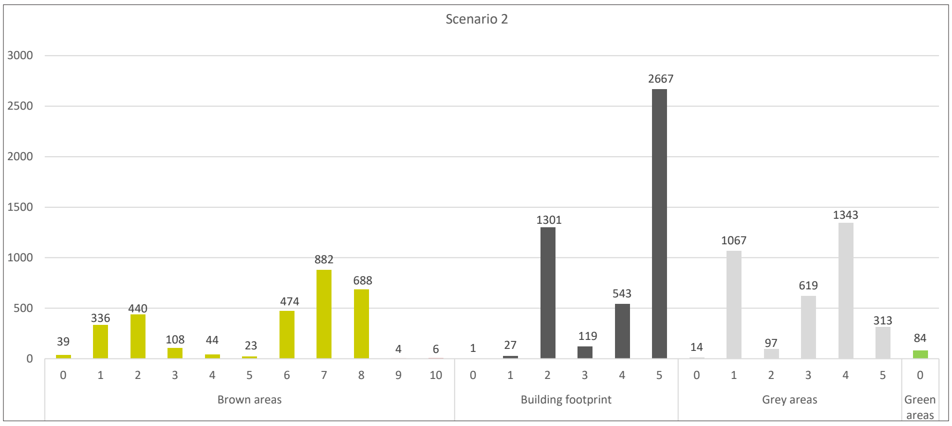


Figure 6: Clusters for scenario 2. The x-axis gives the number of clusters divided into categories. From left to right: brown areas (light green), building footprints (dark grey), grey areas (light grey) and green areas (green). The y-axis refers to the number of features contained in each cluster.

In scenario 3 (figure 7), the group of building footprints is the richest element of the urban landscape with eight clusters. This suggests building footprints are more diverse. However, because the structure of grey areas has been reduced to only two clusters, it seems that the arrangement of the new buildings in the landscape has produced standardised sizes for open spaces between buildings. These spaces are much bigger than in the other scenarios but are also more homogeneous in their sizes and shapes. Even though the green framework could introduce new green spaces to the CBD (it is the scenario with the most brown areas), it is still the landscape with the fewest clusters (16).

Results: diversity index

The diversity index was calculated in Excel by creating a table with the number of clusters analysed per layer, the quantity of features in each cluster, the relative distribution of the features across clusters, the pi value (ln pi) of the features (each area) and the diversity value of each element. Table 1 shows an example of the diversity index for brown areas in scenario 1. The same analysis was performed for all categories in each scenario.

Figure 8 sets out the results of all the calculations done for the diversity index. The chart is useful for visualising and comparing the results for the diversity index of green and grey infrastructures in every scenario. It shows that in scenario 1 grey areas are the most diverse category. The diversity in the building footprints category is probably generated by the contrast between the big size of industrial buildings and the small size of residential houses. The residential

Table 1: Example of diversity index for brown areas in scenario 1

Scenario 1	Clusters	Features	Relative distribution (pi)	Ln pi	Diversity pi (ln pi)*(−1)
Brown areas	0	27	0.029157667	−3.535037369	0.103073444
	1	148	0.159827214	−1.833661961	0.293069082
	2	2	0.002159827	−6.137727054	0.01325643
	3	4	0.004319654	−5.444579874	0.023518704
	4	262	0.282937365	−1.262529731	0.357216835
	5	483	0.521598272	−0.650857581	0.33948619
	Total	926			**1.129620685**

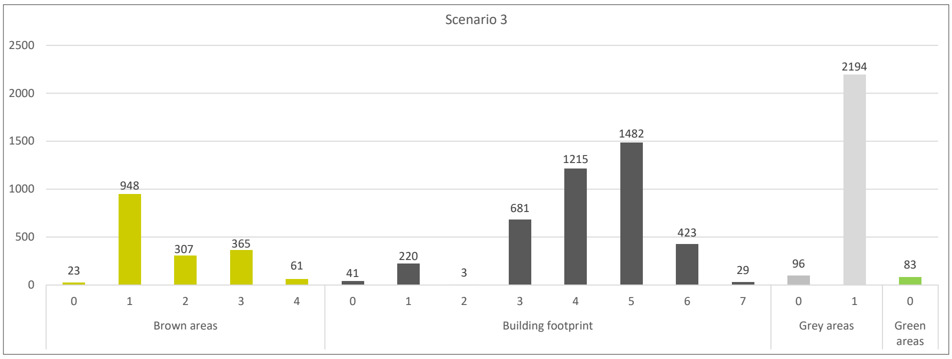


Figure 7: Clusters for scenario 3. The x-axis gives the number of clusters divided into categories. From left to right: brown areas (light green), building footprints (dark grey), grey areas (light grey) and green areas (green). The y-axis refers to the number of features contained in each cluster.

plots create a fine grain with small buildings and green backyards that contribute to the richness of building footprints, grey areas and brown areas. In scenario 2 the most diverse elements belong to brown areas (figure 8). This result supports the idea that the generation of a fragmented network of vacant spaces between buildings produces great diversity in brown areas without lessening the diversity of the built environment critically. The built environment that results from this scenario is a rich and diverse landscape that helps to maintain the complexity of scenario 1. In scenario 3 the most diverse category is building footprints (figure 8). This is probably due to the introduction of new buildings during the reorganisation process, and it is also linked with the richness found in the cluster analysis (figure 7). The results show that the diversity of each scenario has different characteristics, which in turn unravels the role that every element plays in the urban landscape.

Figure 9 compares the total diversity in each scenario (light-blue column), which is the sum of diversity values for green and grey infrastructures. The sub-total diversity of the green infrastructure (light green) is the sum of green and brown areas for each scenario, while that of the grey infrastructure is the sum of the diversities in grey and building footprint areas. Scenarios 1 and 2 are the more diverse while scenario 3 is the least diverse, particularly due to its lower values in the diversity of grey and green infrastructure areas. Based on the results illustrated in figure 9, scenarios 1 and 2 have a higher relative resilience because of their greater diversity.

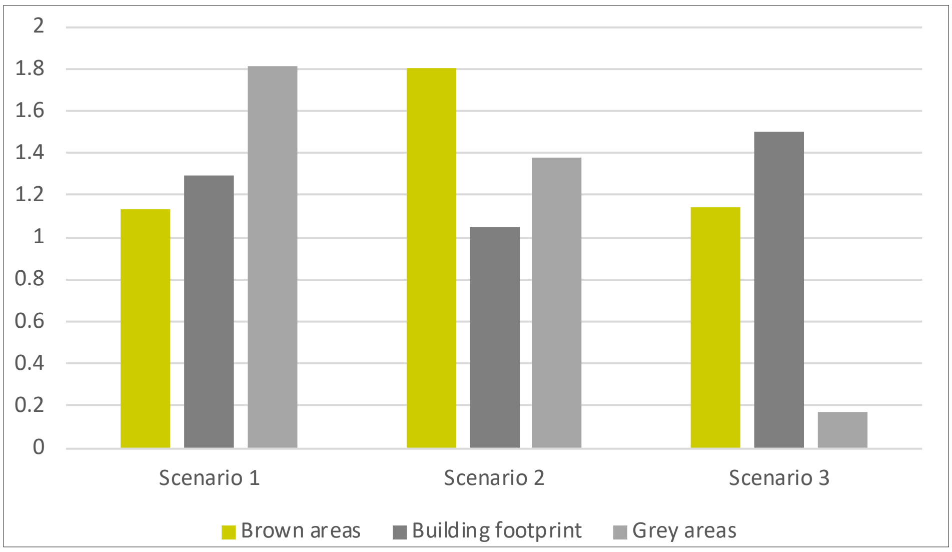


Figure 8: Diversity index for brown areas (light green), building footprints (dark grey) and grey areas (light grey) for scenarios 1–3. The value of green areas was 0, so these are omitted. The x-axis gives the categories analysed and grouped by scenario (1–3). The y-axis refers to the diversity index (total diversity) for each category.

Discussion

It is necessary to have an arrangement of elements of different sizes and shapes to produce the discontinuities that will make urban landscapes more diverse. Green and grey infrastructures are both important in defining the diversity and complexity of the urban landscape (see figure 9). The open spaces between buildings are key contributors to the richness and diversity of the urban landscape. When building footprints get richer and more diverse (scenario 3 in figure 8), brown and grey areas get more homogeneous and less rich. However, when the diversity of open spaces between buildings increases (grey areas in scenarios 1 and 2, figure 8), the diversity of the whole urban landscape increases (figure 9).

An important factor that has increased the diversity of brown and grey areas in scenarios 1 and 2 is that the grey and green areas are defined by the size and shape of the plot system. When the plot system is affected, the entire urban landscape is driven to change. In scenario 3 the plot system was more affected by the predominance of bigger buildings, some of them with a free perimeter, which were not found in the traditional plot system.

In the Christchurch CBD, the most compact scenario (scenario 3) was not the most diverse one. According to the results, the green belt around the compact centre proposed in scenario 3 will not be enough to increase the diversity of the urban landscape. The result of this research challenges the idea that a sudden compaction of the built environment will enhance the resilience of its urban landscape.

Conclusions

Cities are changing continuously and they will be under more pressure in years to come as their human populations grow. Christchurch will not be an exception. The city will also have to deal with the challenge of continuing to reorganise in the face of the possibility that further earthquakes may occur in the future. The first step in establishing a more resilient built environment is to make appropriate kinds of decisions about the use and occupation of the urban landscape. Focusing only on making buildings more resistant to earthquakes will not be enough to increase the

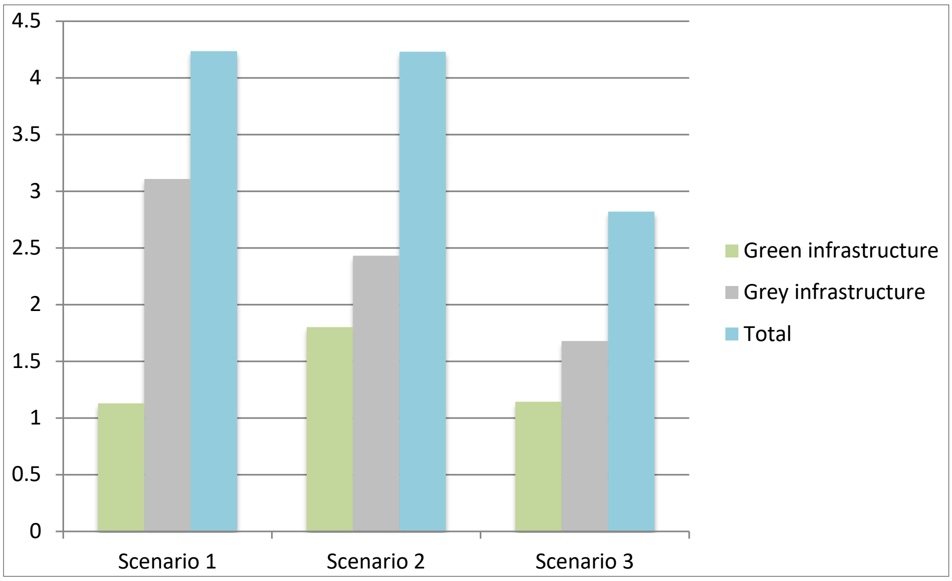


Figure 9: Total diversities per scenario (light blue) and sub-total diversities for green (light green) and grey infrastructures (light grey) in each scenario (1–3). The x-axis gives the categories per scenario. The y-axis refers to the diversity index value per category.

resilience of the built environment because it is the design of the non-built spaces in the landscape that largely defines its richness and diversity. Designing the green and grey infrastructures of urban landscapes to enhance the resilience of a city seems like a relevant consideration that deserves further research.

Some findings from this paper can be used to question the idea that having a heavily clustered and dense built environment is the best solution for the Christchurch CBD. From a resilience perspective, the challenge for the future of the urban landscape of the CBD is to create spaces that interact and catalyse more diversity. At the moment the landscape of the city has a degree of looseness that can be seen as an opportunity. Many of the vacant plots in the city, where construction is not permitted, have been occupied by car parks, an activity that allows the owners of the land to make some profit without having to rebuild. Tourists come to Christchurch to see the city but also to experience the inheritance that the earthquakes have imprinted on the city, from the destruction of buildings to the new works undertaken to reorganise the city. The walls of several buildings in the CBD are exhibiting amazing works of art that express the suffering, desires and hopes of the community. The diversity of these events is happening in between buildings, in vacant places and spaces that have emerged after the earthquake. This is an opportunity for designers to rethink a new type of CBD, where the central area could be characterised by a landscape of heterogeneous and diverse spaces. Perhaps a resilience approach to the future of Christchurch is less about what needs to be built and more about what spaces should not be built on, in order to create an urban landscape that can gradually introduce more complexity in the future. However, this is a challenging task for designers given the future of Christchurch is not only about design actions. The present study has focused solely on the morphology of the built environment yet cities are much more than buildings. Future research can use the methods explained while adding more variables that better describe the complexity and history of the city.

The analysis of the three scenarios presented in this paper has served to produce an alternative understanding of how the concepts of green and grey infrastructures can be used to compare the resilience of the urban landscape of the CBD of Christchurch. Rather than proposing a solution or silver bullet to the reshaping of the built environment in a 'resilient way', it offers an approach to acknowledging and measuring what is gained and what is lost when a particular design is imposed on the landscape; in other words, the cost of the opportunities profited from and lost.

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Net-positive Design and Development

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KEY WORDS

Green infrastructure
Design for eco-services
Ecological footprint
Eco-positive buildings
Open systems thinking

REPORT

The burgeoning interest in urban green-grey infrastructure is bringing together many disciplines, ranging from urban ecology to sociology. This convergence of views promises to direct attention toward basic sustainability issues that have fallen between professional boundaries. In the past, the built-environment design fields (urban, building and landscape design) tended to regard the others as black boxes. Despite collaborative practices, professional territories contributed to 'closed-system thinking'. For example, sometimes architects do not think outside the building envelope, landscape architects do not think outside property lines and planners do not think outside urban borders. Consequently, some green-building rating tools count indoor air quality as an 'ecological gain'. Yet an ecological gain, when the human population and consumption are growing, must increase space for nature, ecosystems and biodiversity habitats. One illustration of gaps that occur due to conceptual boundaries is where landscaping fails to offset the impacts of the structures that support it.

Designers of buildings, public spaces and infrastructure projects increasingly use green roofs or walls to help purify the air and provide other environmental amenities (Velazquez, 2008). While greenery may compensate for some ground area covered by the construction, building surfaces do not provide adequate vegetation to treat a building's harmful emissions (such as volatile organic compounds, solvents and adhesives), let alone cleanse the polluted outside air that infiltrates the building. Often industrial air-conditioning systems in green buildings expel more heat and dirty air than the on-site landscaping can internalise. In dense urban centres, little landscaping occurs other than street trees and barren public plazas. These elements cannot absorb all the pollution from transport infrastructure, let alone produce enough oxygen for inhabitants, which requires several trees per person (Villazon, 2015).[1] Therefore, urban landscaping seldom compensates for carbon emissions, pollution or 'ecological waste' – that is, the cumulative ecological damage caused during resource extraction, construction and ecosystem restoration time (Birkeland, 2007).

Consequently, urban vegetation, at each scale, falls short in oxygen production, carbon sequestration, pollution absorption and other environmental functions. Buildings draw down from the urban environment, and cities draw down from their bioregions. Positive Development (PD) aims to reverse this linear, negative relationship between humans and nature by, in part, increasing total space for the 'public estate' and 'ecological base' (Birkeland, 2008). PD theory reconceives cities as landscapes that support their bioregions like reefs support their oceans. This concept goes beyond the early definitions of sustainability, as well as subsequent watered-down versions. Sustainability initially meant achieving inter- and intra-generational equity and ecological preservation. Since then, over 50 per cent of biodiversity has been sacrificed and disparities of wealth have skyrocketed (World Wide Fund for Nature, 2014). The original ecological base can no longer meet the demands of a growing population. Therefore, ecological regeneration is not enough. A development that reduces natural or social support systems more than 'no development' closes off future options and survival prospects.

Despite inspired euphemisms like 'human–nature partnership' and 'co-evolution', nature simply cannot evolve fast enough. Therefore, humans must evolve intellectually. New forms of conceptual, physical and institutional structures must be designed to increase ecological carrying capacity and universal life quality (Birkeland, 2003). Thus far, sustainable design has aimed only to leave the environment 'better than before construction' and/or to restore landscapes to a pre-construction state (Hes and du Plessis, 2014). This focus merely reduces *relative* resource and energy flows by improving on typical buildings, site conditions and construction practices. To be sustainable, development must instead reverse the global rates of degradation and inequity (Birkeland, 2005) by increasing the 'natural' environment beyond pre-human conditions and providing more urban public space. PD is development that gives back 'more than it takes' from society and nature, ideally at each scale (Birkeland, 2008). This means that the 'positive ecological footprint of nature' must exceed humanity's negative footprint. With a new, different building and landscape design paradigm, net-positive outcomes are possible.

Almost any building cluster or urban block could be retrofitted to be eco-positive, assuming whole-system accounting that deducts perverse subsidies and externalities. By combining passive and renewable energy systems, multifunctional design, integrated ecosystem services and net-positive offsetting, a development could potentially overcompensate for unavoidable impacts and address social issues in the surrounding area. For instance, substantial building-integrated, vertical space for permanent vegetation can sequester more carbon than emitted during construction and operation, without additional floor area or 'extra' costs (Renger et al, 2015). Similarly, building-integrated 'eco-services', which include both intrinsic and instrumental values of nature, can provide select combinations of two-dozen natural systems that support building, environmental and ecosystem functions (Birkeland, 2009c). External landscaping can create micro-ecosystems and biodiversity incubators that support or re-seed their particular bioregions. Transport infrastructure combined with nature corridors could assist their bioregions, such as with roads covered with 'green scaffolding' for algae-based biofuel production, solar cells, air purification, biodiversity bridges and habitats (Pearson et al 2014).

Outmoded institutional frameworks still shape or affect design in subconscious ways. Codes that set minimum or maximum thresholds effectively authorise or legitimise negative impacts up to an 'acceptable' level of harm. Green-building rating tools reward specific negative impacts if those impacts are merely less harmful than current industry norms or 'best practice'. Even biodiversity offsetting often requires compensation only for additional negative ecological impacts (Birkeland and Knight-Lenihan, 2016). When most green buildings are still based on the old industrial template, more design guidelines, criteria and indicators have no transformative effect. While sustainable design has always aimed to regenerate the environment, community and economy (Lyle, 1994; Van de Ryn and Cowan, 1996; Wann, 1996), it has not entirely escaped the philosophical and institutional legacy of the industrial era: 'Do no harm'. For example, some projects claim to increase urban resilience and adaptability but are not designed to facilitate retrofitting to meet higher standards over time. To enable a fundamental paradigm shift, therefore, PD sets different design standards for physical and institutional structures.

The *ecological* standard in PD is a net increase in space allocated to ecosystems, nature corridors and biodiversity incubators, on both a spatial (floor area) and a temporal (life cycle) basis. Achieving this standard requires design *for* nature, as well as *with* nature (for example, permaculture) or *like* nature (for example, biomimicry) through, among other measures, 'design for eco-services' (Birkeland 2004, 2009a, 2009b). Working with nature is necessary, but it is no longer sufficient. For example, ecosystem services are typically employed only where economic benefits can be shown, such as worker productivity, human comfort and health. Eco-positive rules and standards in regulations and assessment processes might only require the addition of the adjective 'net-positive' – assuming adequate instructions are adopted to demonstrate how to meet the new criteria and measure performance. However, while the term has been frequently adopted, it is being redefined to just mean 'improvement', *not* a net increase in the ecological base beyond industrial or pre-human times.

The *social* sustainability standard in PD is a reduction in regional social inequities and an increase in universal, direct access to the means of survival, health and wellbeing, called the 'public estate'. Social sustainability requires democracy and civic engagement, which, in turn, require urban infrastructure that guarantees resource security, safety and equity. Engineering and economic efficiencies do not always ensure the distribution of essential services.[2] So-called 'sustainable' development often concentrates wealth, reduces cultural diversity and heritage, and increases disparities of equity and opportunity. 'Urban acupuncture' (targeted improvements in disadvantaged areas), such as new community centres or playgrounds, can revitalise communities. However, this does not ensure *universal* access to social-support systems, basic needs such as shelter, food, energy, clean air and water, or safe havens in civil or environmental emergencies. *Direct* access means access uninterrupted by market, electronic, transport or other central delivery systems that can make people politically or economically vulnerable.

Different planning and design methods are necessary if built environments are to become the catalyst for positive social and ecological transformation (Walker and Giard, 2014). It is necessary to rethink green-grey infrastructure from first principles. To that end, my forthcoming book *Net-positive Design and Development* (Birkeland, undergoing peer review) proposes changes to physical and institutional infrastructure. Whereas *Positive Development* (Birkeland, 2008) was a discussion between a paradigm and a sceptic, *Net-positive Design and Development* spells out the theoretical bases and specific methods to implement the reforms. PD builds on fundamental shifts from closed- to open-system frameworks (mindsets, models, methods and metrics) that increase the natural and social life-support systems and expand future options (Birkeland, 2012). Whereas closed-system models internalise negative impacts, open-system models transcend system boundaries and externalise positive impacts. Whereas decision methods compare and choose among known alternatives, design-based methods create synergistic systems that multiply benefits and options. Whereas measurement tools quantify inputs and outputs, whole-system metrics include both net-positive impacts and cumulative, remote negative impacts.

A new constitution for urban decision-making and design is needed to address fundamental sustainability issues. To that end, the new book reviews PD theory and principles, net-positive criteria and exemplars; ways that design can achieve net-positive social and ecological outcomes (not simply off-site benefits), often with a financial payback; and elaborates on two-dozen new forensic analyses for identifying and addressing deficits in regional ecological and social conditions (Byrne et al, 2014). Then the book will apply an ethics-based prism to a critique of current frameworks of development control or consent processes, guidelines and assessment methods; and propose frameworks, principles and processes for reforming urban environmental governance, with specific means to incentivise, implement and assess net-positive design. These include participatory design processes for making regional ecological and social improvements, and a unique assessment tool for measuring net-positive outcomes.

In conclusion, sustainability is a system design problem, and only by design can sustainable institutional and physical systems be created.

NOTES

1 Estimates of net oxygen production of different trees vary, but over seven trees per person may be necessary (Villazon, 2015).

2 One per cent of the world population has the combined wealth of 99 per cent of the rest, and the world's eight richest men have the same total wealth as the poorest half of the world population (Elliott, 2017).

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Unravelling Sustainability and Resilience in the Built Environment: Book Review

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Unravelling Sustainability and Resilience in the Built Environment, Emilio Jose Garcia and Brenda Vale, New York, NY, USA: Routledge, 2017, ISBN: 978–1–138–64402–1 (hardcover); 978–1–138–64404–5 (paperback); 978–1–315–62908–7 (ebook)

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Sustainability and resilience are often used interchangeably in discourses about the built environment, but, in fact, they mean very different things. This is what Emilio Jose Garcia and Brenda Vale have endeavoured to clarify in their book *Unravelling Sustainability and Resilience in the Built Environment*. They set out to investigate if sustainability and resilience are compatible, and if theories of resilience – particularly ecological resilience – can be applied to the built environment. The authors note that urban designers and architects rarely participate in institutions concerned with resilience, and they question the reasons for this mismatch while aiming to be 'the first architectural toe dipped into the cold water of resilience' (p 12).

The book is divided into three parts: (1) definitions, (2) case studies and (3) ways of measuring sustainability and resilience. It has 11 chapters and the microscale of the case studies and real-life examples kept me captivated throughout the book; however, the examples described could at times have been substituted with or supported by the use of images. Part 1 aims to define, clarify and map sustainability and resilience. Sustainability is approached from the perspective of behaviour and technology, while resilience introduces the idea of Panarchy, which entails systems 'organized through multiple scales, with key processes driving the rhythm and cycle of change at each scale … [in which] changes happen in a cyclical manner' (p 37). These cycles are called adaptive cycles and have different phases linked with processes of development and decay. Part 1 concludes with mapping sustainability and resilience based on similarities and differences between both concepts, and the idea of Panarchy permeates discussions throughout the text.

Part 2 uses case studies to investigate the topics of eco-cities, heritage and compact cities. The discussion around eco-cities focuses on two main case studies: Whitehill and Bordon (United Kingdom) and Tianjin (China). The former is a car-dominated city that demonstrates the problems of trying to insert new ideals into a well-established built environment. The latter is an Asian city with a strong western historical influence, where city planning has generated a lifeless and empty environment. Using these examples, Garcia and Vale conclude that urban renewal is more sustainable and resilient than building new towns and cities, and eco-cities seem to be just another way of 'selling' sustainability. The next topic,

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heritage, is approached as identity instead of monument and investigated in Tucumán (Argentina) and Hanoi (Vietnam), because both cities have changed over time but kept their uniqueness. The authors focus on the changes and adaptation of the Chorizo and the tube houses to demonstrate that a more adaptable urban form is a more resilient one. Compact cities are discussed from three different perspectives: density, intensity and compactness. The authors argue that density does not necessarily generate intensity and cite Le Corbusier's way of planning as a good example of an approach that generates density but not compaction or intensity. On the other hand, 'perhaps the concepts of being compact and being a liveable city are incompatible' (p 125), as the example of Melbourne shows, as a city that is sprawling but considered the most liveable in the world. Finally, place-based constraints become clear in the discussion of density and compaction, both regarding culture (they may vary between Asia and Europe, for example) and climate (compaction can prevent ventilation in hot climates and insolation in cold climates).

The case studies approach is important and engaging, but the reason for studying these specific cases, and particularly for varying them according to the subject of analysis, is unclear. Could the authors have used one case study and focused on the different aspects of that environment from eco-city, heritage and compaction perspectives? The variation of both criteria and case study makes it difficult to follow the role of each piece in the complex system that one single city represents.

Part 3 is an example of the application of the concepts discussed to measure sustainability and resilience. Regarding sustainability, while measurements are necessary, as designers our role is to provide the environment that will support people in making choices that have the least impact, but we cannot guarantee they will live like we propose. In measuring resilience, Garcia and Vale investigate ways of applying ecological resilience principles to the built environment. It then becomes clear that a gap exists between theory (in ecology) and practice (in design), and that the large number of indicators make the available frameworks unhelpful for designers. In this context, the concept of Panarchy proves its usefulness because it allows us to understand how the elements of a system (in this case, a city) change in time and space. In conclusion, the authors provide a demonstration of assessing sustainability and resilience using the Auckland central business district as a case study.

This book is an important step in clarifying the meaning of *sustainability* and understanding the meaning of *resilience*, especially when applying theories of ecological resilience to the built environment. Designers are the intended audience; however, to be more appealing to visual professions, such as architecture, landscape architecture and urban design, the book would benefit from making more extensive use of images. The Tucumán case study is the most interesting because it is well illustrated with sketches, although it lacks photographs. Regarding the other case studies, I still do not know, for instance, what some of the places mentioned look like. How do Tianjin or the tube houses of Hanoi appear?

Finally, the idea that 'to be a really resilient city, like Toronto, it seems that, like Toronto, you have to consume many more resources than your fair share of what the planet can supply on a sustained basis' (p 3) appears distinct from the examples of Tucumán and Hanoi, which showed resilience in a different way. These cities showed resilience through change over time in response to economic pressures; this perhaps means they are, at the same time, more sustainable and resilient places.

The ideas discussed in this book are timely and important, and any professional concerned with the built environment should become familiar with this publication.