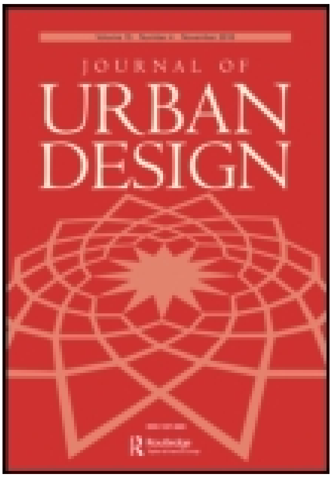

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The Influence of Urban Morphology on the Resilience of Cities Following an Earthquake

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ABSTRACT *This paper proposes a conceptual theory of resilience in urbanism and demonstrates its application through a case study. The theory's underpinnings are the attributes of resilience that have been developed in ecological sciences, but have clear parallels in urbanism. They suggest that it may be possible to enhance the resilience of a city through the design of its urban morphology. The paper explores these ideas by examining the relationship between the community's adaptive behaviour and the spaces of the city of Concepción after its 2010 earthquake. This empirical evidence suggests that the role of the urban designer in earthquake-prone cities is perhaps more critical before an earthquake happens and that the more the idea of a resilient urban morphology is embedded as part of daily life, the more effective it is likely to be in the aftermath of a major earthquake.*

Background

In the aftermath of the chaos and destruction that follows an earthquake, a city's urban structure provides important sites for the continuing activities of the city and the start of the recovery process. Urban morphology thus plays a fundamental role in the resilience of the whole urban system. But can it make a city more resilient? Do we even know how to design for resilience? This research proposes to examine the relationship between the spatial configuration of cities and behaviour leading to recovery after an earthquake. It is part of a long-term research project which looks at the spatial conditions of a number of Pacific Rim earthquake-prone cities in the early stages of recovery.[1]

The assumption is that if the spatial form of a city positively influences a community's capacity to respond quickly and effectively to major repeated disturbance, then one would expect that the city's spatial form would come, over time, to reflect that condition. In our experience, however, while a city's urban structure will often reflect a broad range of influences—geomorphologic, economic, social, and environmental—it is rare to find a city whose urban structure responds to its earthquake-prone nature. In the vast majority of

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earthquake-prone cities, important infrastructure is still sited over major fault lines, the configuration and distribution of the open space network is driven by economic necessity, and vital connections between centres remain vulnerable to collapse. This may be because in the past the overwhelming focus on cities and earthquakes has been an engineering response related to reinforcing the status quo rather than questioning the contribution of space–form relationships to vulnerability. It might also be because, after a traumatic event like an earthquake, most people want life to return to normal as quickly as possible. Despite the sense of devastation, earthquake damage is often seen as an "opportunity" to "build back better"; in many cases this is the exception rather than the rule. What, then, can urban designers do now to facilitate recovery in the future?

Urban Resilience

Arguably, in an earthquake, the most vulnerable components of urban fabric are a city's buildings and services infrastructure, and historically the primary focus of earthquake specialists has been on the reinforcement of those structures. After an earthquake, the city is the engineers' domain. They assess buildings, determining which are safe to inhabit and which should be demolished. But while every effort is made to repair built fabric and life-lines as quickly as possible, in the immediate aftermath of a major earthquake the function of a city tends to *shift* its locus from "figure" to "ground" and many everyday urban activities such as shelter, health care, the distribution of goods and services, the disposal of waste, and even commerce are managed in a city's urban landscape: its streets, parks, and squares (McGregor 1998; Middleton 2007).

This *shift* to maintain function in the face of disturbance is the behaviour found in descriptions of open systems and resilience theory. The theory of ecological resilience describes this disturbance-response relationship in some detail and suggests that people and ecosystems exist together in an interdependent relationship.[2] Resilience theorists describe that relationship as a social-ecological system or SES.

The idea of an SES is important because it suggests that people can positively influence resilience. Ecologists have used these ideas to develop strategies associated with the adaptive management of ecosystems. They describe, for example, how to map systems and their field of influence as well as when and how to intervene to achieve maximum benefit. Adaptive management is very similar to the design process, and it has important implications for designers of urban systems because it provides detailed information about the design of and for open systems in ways that include form as well as process.

Although we acknowledge that in the urban context resilient systems are always multidimensional and will depend, for their resilience, on a wide range of influences (political, social, environmental, economic, etc.), for the purposes of this research project we have focused primarily on the interrelationship between social and spatial systems, between communities and the physical environment,[3] in the belief that attention to the physical domain of a city can reduce vulnerability and enhance social resilience. We refer to this relationship throughout the remainder of this essay as socio-spatial resilience.

Resilience and Urbanism

The idea of the inter-relationship between people and the spatial environment has a long history in the theory of urban design, most obviously in the strong strand of systems thinking that has influenced everyone from Geddes (1885) to Jacobs (1993).

However, in the 1970s and 1980s a number of urbanists were explicitly influenced by theories of ecological resilience (Holling 1973). For example, in his preface to *On Streets* (1978), Sanford Anderson elaborates a theory of social ecology, describing how urban space is appropriated by different social groups for various ends. This is the essay where he develops his theories of "tight" and "loose" space, robustness and latency. And in her typo-morphological analysis of Alamo Park in San Francisco, Anne Vernez Moudon (1989) specifically refers to neighbourhood resilience. She shows how the neighbourhood maintained its identity, structure, and function over time with a "hard edge and soft centre" dynamic where relative stability at the scale of the urban grid was balanced by constant change and response to economic pressure at the scale of the lot.

However, these kinds of specific references to the spatial dimension of urban resilience are relatively rare. More common is a focus on open systems or resilience and process. For example, Landscape Urbanism investigates the potential relationship between ecology, ecological theory, and urbanism as a way of addressing the postmodern conundrum of designing in and for a constantly shifting, complex, and contingent environment (Waldheim 2006). These theories typically favour process over space and form making in cities (Corner 1999; Wall 1999). Infrastructure is often co-opted as a framework for future development, and ecology or "nature" is usually incorporated as a fool-proof way of embodying process and encouraging "flow" (Waldheim 2007). There is also a growing body of theory about the "resilient city" (Vale and Campanella 2005; Tierney 1995; Geis 2000) which, in a similar way, tends to focus on process rather than space and form. Some of the "resilient city" ideas are extremely specific, suggesting quantitative strategies that employ a range of complex resilience parametrics (Miles and Chang 2006). Others are frustratingly general (Godschalk 2006).

But there appears to be very little literature that links resilience with urban form. Where it does exist, while the concept is often not addressed directly, the behaviours associated with the disturbance-response mechanism are quite clearly central. For example, Manuel de Sola Morales (1999) has developed his theory of "urban acupuncture", a targeted urban intervention which includes form *and* process and encourages urban systems to reorganize over time in response to disturbance. Others have engaged with these ideas by investigating how communities under economic and political pressure in underdeveloped countries reorganize and adapt by appropriating and manipulating urban form and space (Ramirez-Lovering 2008; Dovey and Polakit 2006).

These discussions about spatial or formal design and resilience are not typically part of the discourse associated with earthquakes and cities. Recovery planning and emergency management documents typically refer to the urban environment as a place that should be recovered rather than one that might support recovery (MCDEM 2005). Research tends to focus on optimum spatial environments, which specify the quantity of open space required for recovery (Wang, n.d.). While this kind of information is critical, the provision of quantity without quality can be problematic. Without qualitative information, the temptation is to provide large amounts of undifferentiated open space, which can result in dispersed and rather bland cities. This was a criticism of the relatively recent reconstruction of Tangshan in China, where its wide streets, low-rise buildings and lack of an identifiable centre resulted in a noticeable lack of "urbane refinements" (Mitchell 2004).

This focus on the quantitative at the expense of qualitative solutions has begun to shift, as urban designers turn their attention to the many catastrophic events that have affected urban communities, particularly coastal ones, in the last decade (Godschalk 2003; Beatley 2009), and this research is a development of that direction. However, while many designers engaged with this work refer to the idea of resilience, its meaning in these contexts is not always clear, nor are the strategies associated with *designing* for resilience always clearly defined. Often, the concept is conflated or confused (in meaning and in strategy) with sustainability (MCDEM 2005; Beatley 2009). This is understandable, because the two are clearly related, but it is not particularly helpful. This research is concerned, then, with articulating, as clearly as possible, what designing in the context of open systems and resilience means, what the associated design strategies might be, and how to design space and form as well as process in this environment.

One way to do this is to look closely at what happens when communities are disturbed, and document the influence of urban space and form on community response and recovery in the aftermath of a major earthquake. Of equal importance is a close understanding of the mechanics of resilience and open systems as an operation or a concept distinct from sustainability.

Socio-Spatial Resilience: The Attributes

Kristina Hill (2005) has described the importance of metaphor as a way of understanding concepts when they are relatively new. The use of metaphor, she argues, allows us to develop new models that explain the way the world works. In their newness and malleability, they generate a degree of interdisciplinary mixing that becomes more difficult to achieve once the concept and its associated metaphors have "hardened". In their book *Resilience Thinking*, Brian Walker and David Salt (2006) use metaphors such as "redundancy", "latency", and "room to move" to explain the concept of resilience. They also describe in detail a number of "resilience attributes": diversity, modularity, tight feedbacks, innovation, overlap in governance, ecosystem services, social capital, and allowing for variability. These metaphors are powerful because they help us understand how resilience operates. They are evocative and transdisciplinary, and they are significant for the research in at least two ways: first, they bridge the gap between resilience theory and urbanism, and second, they act as a bridge between the general and the particular.

The attributes connect resilience with urbanism because they help to explain the spatial dimensions of urban resilience. Rather like Moudon's description of the "hard edge and soft centre" of San Francisco's urban grid, they give clues to designers about how resilient cities might operate. For example, while modern cities are built to be efficient, resilience requires a degree of redundancy as insurance against unpredictable future events. Spatial or functional *diversity* and the spatial integration of *ecosystem services* within a city's urban plan can create that redundancy. When a city has built-in spatial and functional redundancy, it is in a better position to absorb environmental *variability* (floods, sea level rise, earthquake, tsunami).[4] It has "room to move". And a city repeatedly exposed to variability, rather than protected against it, develops learned adaptive behaviours, further enhancing resilience.

Modular systems have a built-in redundancy, and *modularity* is another attribute with distinct spatial dimensions. In a modular system, individual modules are "safe to fail" (Lister 2007, 46) in that they can fail without affecting the structure and function of the whole. For example, small, modular communities with a clear identity and defined boundaries have been found to exhibit a relatively high degree of *social capital* (Oliver 2000). The presence of social capital tightens *feedbacks* and further enhances the adaptive response (Walker and Salt 2006). Using the attributes in this way helps us to look deeply at the relationship between urban space and form and resilience.

The attributes are also a useful lens or framework for the analysis of data, because they act as a bridge between the general and the particular. For example, our research involved the analysis of a city's urban structure at a number of scales and then a search for evidence of a causal relationship between structure and community response; a detailed analysis of that relationship using the resilience attributes helped us make sense of what had happened. It allowed us to understand the relationship between structure and response as it related to that specific instance; it also suggested how that information might be used in the future. It told us what worked and what didn't, but it also told us why and how.[5] This point will be discussed in more detail and with respect to the case studies later in the essay.

Using the attributes as a framework allows for a more nuanced, qualitative approach to the evaluation and design of earthquake-prone cities. There are no absolute, quantitative resilience strategies. While there may be specific forms that "work" after a major disturbance, and others that don't, these are likely to be embedded in a matrix of city-specific parameters that need to be negotiated as part of everyday urbanism.

This makes recovery planning an urban design issue, and the timing of urban interventions a significant challenge. The benefit of the attributes is that many of them are already an accepted part of the vocabulary of urban design. Their lineage can be traced through a series of key concepts in urban theory over the last 50 years (Table 1). In this way, they have the potential to suggest how urban designers might contribute to the design of earthquake-prone cities now, to create urban environments that are resilient to everyday as well as extraordinary disturbance.

Methodology

This study is part of a much larger research project which investigates the relationship between spatial structure and urban resilience in a number of Pacific Rim earthquake-prone cities, including the 1906 earthquake in San Francisco, USA, the 1996 earthquake in Kobe, Japan, the 2010 earthquake in Concepción, Chile, and the 2011 earthquakes in Christchurch, New Zealand. This essay uses one case study, Concepción, to describe our approach. It also discusses some preliminary conclusions.

In each case study, we began by examining the city's morphological history and the influences that resulted in its distinctive urban pattern. The data gathered

Table 1. The resilience attributes as they appear in urban design theory.

Attribute	Resilience definition	Evidence of attributes in urban theory
Diversity	A major source of future options.... The more diversity, the better the capacity for a system to adapt to a wide range of different and sometimes unpredictable circumstances (Walker and Salt 2006, 145)	Mixed use, short blocks, variety of building age and density (Jacobs 1993), spatial heterogeneity (McGrath *et al.*, 2007), functional diversity (Mathur 1999; Dovey and Polakit 2006; Ramirez-Lovering 2008; Anderson 1978)
Modularity	Allows individual modules to keep functioning when loosely linked modules fail, and the system as a whole has a chance to self-organise (Walker and Salt 2006, 146)	Polycentric urban form (Batty 2001; Kloosterman and Musterd 2001), flexibility of the grid (Ramirez-Lovering 2008; Moudon 1989), architecture and cities (Sadler 2005)
Innovation	An emphasis on learning, experimentation, locally developed rules and embracing change (Walker and Salt 2006, 147)	As a strategic intervention (Dodds 2008; de Sola-Morales 1999; Descombes 1999)
Tight feedbacks	Social networks play key roles in determining tightness of feedbacks. Centralized governance and globalization can weaken feedbacks (Walker and Salt 2006, 146)	Traffic (Jacobs 1993), diversity (Jacobs 1993), polycentric urban form (Batty 2001), the capacity of a system to self-organize (de Sola-Morales 1999; Descombes 1999) bottom-up civil action (Dodds 2008)
Overlap in governance	Institutions that include redundancy in their governance structures (Walker and Salt 2006, 148)	Creating diversity (Healey 1997), community and urban development (Moudon 1989)
Ecosystem services	Include ... unpriced ecosystem services in development proposals and assessments (Walker and Salt 2006, 148)	Ecological urbanism (Mostafavi and Doherty 2010), urban density and sprawl (Bolund and Hunhammar 1999)
Social capital	The capacity of people to respond together ... to change any disturbance ... depends on social capital (Walker and Salt 2006, 147)	Small places with definite boundaries (Oliver 2000; Onyx and Bullen 2000; Putnam 1995), public sidewalk life, diversity and settings for casual public contact (Jacobs 1993), encouraged by lack of state control (Dodds 2008), heterogeneous neighbourhoods (Jacobs 1993; Oliver 2001; Putnam 1995), institutional infrastructure (Temkin and Rohe 1998)
Variability	Embrace variability rather than attempting to control or reduce it (Walker and Salt 2006, 146)	Ecological engineering (Bergen, Bolton, and Fridley 2001), redundancy (Graham and Marvin 2001)

at this stage suggest various patterns of disturbance and response over time. These are the patterns that helped shape urban morphology and that are likely to influence community response to disturbance in the future.

Then we looked at the way people responded to the impacts of the earthquake during the emergency stage of recovery, before the external influences of city or state began to take effect. This is when communities need to rely on what is to hand in order to survive, and when the relationship between morphology and the adaptive response is most clear. Once we had gathered the data, we analyzed them through the lens of resilience, to make connections between morphology and recovery. We then suggested potential urban interventions or strategies that might influence urban resilience. The research documents evidence of community response using these four cities as case studies and then analyzes that evidence using resilience as a framework or lens to arrive at conclusions, which are intended as guides for urban designers in earthquake-prone cities.

The Case Study: Concepción

The following section applies the theoretical framework of socio-spatial resilience to a case study of one Pacific Rim city, Concepción, Chile, after the 2010 earthquake. First, the urban structure of Concepción's greater metropolitan region, the Área Metropolitana de Concepción (AMC), which includes the cities of Concepción, Hualpén, Talcahuano, San Pedro de la Paz, and Coronel, was mapped (Figure 1). Then three tools were used to assess the way this urban structure supported recovery after the 2010 Maule earthquake: (1) a review of formal and informal communications including newspapers, Web pages, Facebook, Twitter, blogs, etc.; (2) collection of information through social networks; and (3) approximately 50 interviews (between August and November 2010) with regional civil defence and emergency managers and urban planners, local government emergency managers, and representatives of neighbourhood associations. Finally, these data were evaluated using four qualitative resilience attributes: modularity, diversity, ecosystem services, and variability. The final section discusses the implications of our findings.

History

When La Perouse arrived in the Bay of Concepción during his exploration of the South American coastline in 1786, he encountered a coastal outcrop of mountains linked to the mainland by a low-lying isthmus of marshlands, lagoons (or lakes), rivers, streams, and low hills (Figure 2). The small coastal port villages of Talcahuana and Port St Vincent nestled into the base of the hills above the marshlands where the Laws of the Indies precluded settlement. Upstream, on the Bio Bio River, lay the village of La Mocha, and across the river to the south was Fort St Pierre, established as the *fronterra* between Native American settlement and Spanish colonization. The coastal town of Penco, ruined after repeated tsunami, had relocated to La Mocha, which was renamed Concepción. The AMC has subsequently grown to become the second-largest city in Chile, with a population of 1 million.

The City Today

In much of modern Chile there is an extreme disparity in living standards. An urban country (88% of its 16,750,000 people live in cities), Chile ranks 40th in the world in gross domestic product and has a 95.7% adult literacy rate. Chile plummets to 164th, however, on the Gini index of income inequality, ahead of just 18 other ranked countries (UNDP 2009). In the AMC, the well-off tend to physically occupy the high ground, which is in short supply, while the urban poor have settled on the less valuable marshland and coastal plains.

Urban functions are divided across the AMC. It depends on the port of Talcahuano and its surrounding industries for economic growth, the central business district for government functions, the city of Concepción for universities

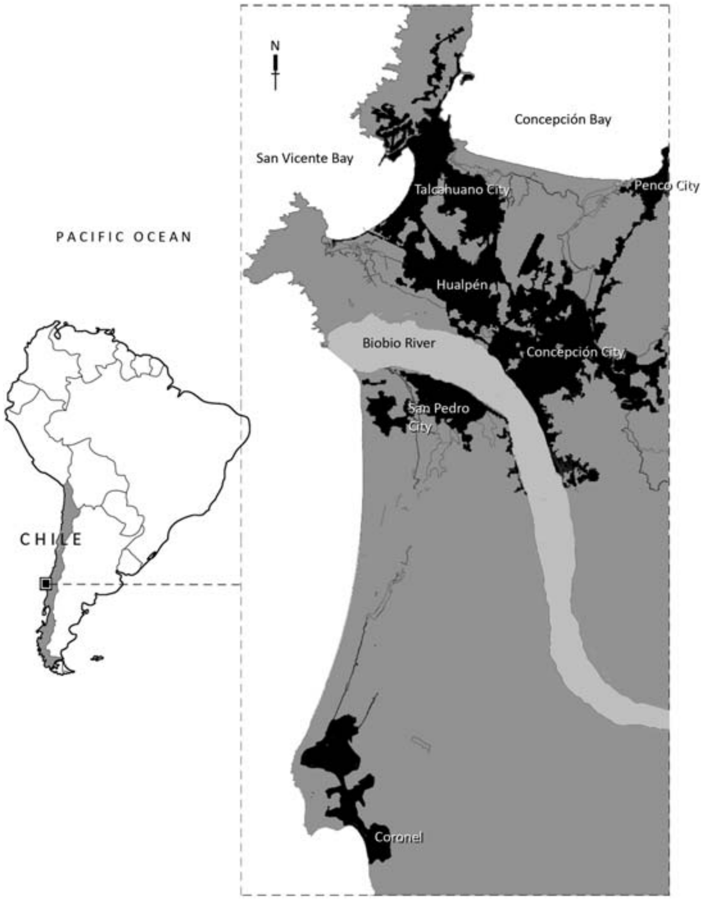

Figure 1. The Area Metropolitana de Concepción (new image drawn by Winston Dewhirst, VUW).

and hospitals, and the dormitory suburbs of San Pedro la Paz and Coronel for residential accommodation and secondary schools. Three bridges span the river, and a series of roads and a railway line cross the marshy landscape connecting the port to the central business district.

Concepción, often called the City of Lagoons, is defined by the many and diverse landscapes associated with water (Figure 3). The AMC has sprawled over this landscape, constrained by its geomorphology and divided in two by the Bio Bio River. This has resulted in a polycentric conurbation of loosely connected cities and towns (Figure 4). Talcahuano, Hualpén, and Concepción are located to the north, and San Pedro de la Paz and Coronel to the south.

The region's geomorphology and urban structure have resulted in a variety of residual or left-over spaces, sometimes referred to as "urban voids"—large tracts of public space unfit for development (riverbanks, lake and wetland edges), with permeable edges and integrated within or adjacent to the urban fabric (Figure 5). Many of these spaces have no particular function or are very loosely programmed, making them essentially redundant to the everyday operations of the city. This particular urban typology, extensive throughout the AMC, was an important factor in the recovery of the city.

Figure 2. La Perouse's plan showing Concepción Bay, the low-lying peninsula, and the town of La Mocha, soon to become Concepción on the Bio Bio River. *Source*: National Library of Chile.

Disaster

On 27 February 2010, at 03:34, a magnitude 8.8 earthquake, one of the strongest in modern history, struck the coast of Chile. Its epicentre was 100 km north of Concepción. The earthquake was followed by up to four tsunami waves that hit the coast near the city over the course of the early morning, beginning at 03.48. A period of extreme civic unrest followed, which local police were powerless to suppress, as the population fought for access to food, water, and safe refuge on high ground. Looting was widespread. The region was without water and power for at least four days, in some areas for much longer, and communication with the rest of the country was restricted.

After the earthquake and tsunami, the AMC's open space network—its squares, streets, parks, vacant lots, and undeveloped spaces—were rapidly occupied by the affected population, first as safe spaces and then as temporary habitable spaces, supporting a diversity of functions such as shelter, emergency services, and the distribution of aid.

Figure 3. Concepción the City of Lagoons. Photo by Penny Alan.

Figure 4. The AMC showing the polycentric nature of the conurbation. *Source*: Michael Davis, Victoria University of Wellington (VUW).

Figure 5. Typical view of the AMC's 'urban voids' as seen from one of its raised highways. Photo by Penny Allan.

Post-Disaster Impacts

The cities and suburbs within the AMC were affected by the disaster in different ways.

Talcahuano (Figure 6), sited partly on the coast and partly in the foothills, was devastated by the tsunami. It also suffered significant earthquake damage. The combination of impacts from both events resulted in a large number of displaced people requiring temporary shelter.

Hualpén and Concepción, sited further from the coast, were not affected by the tsunami. In both cities, earthquake damage varied according to urban form and density as well as other factors such as subsoil conditions. The greatest damage occurred in the more established areas of each district. Concepción, for example, suffered significant damage to its heritage and tall buildings in the central business district; however, there was no significant loss of low-rise, recently built housing. In Coronel there was significant damage to uncontrolled occupier-built housing.

Although there was no tsunami on the AMC's south coast, there was a tsunami warning, which resulted in mass evacuations from the cities of San Pedro de la Paz and Coronel (Figure 7). The subsequent displacement of homeless people required the establishment of a large number of emergency housing camps (Figure 8).

In the following section we discuss how the qualities of the region's urban morphology created a set of opportunities for recovery with respect to two aspects of recovery: occupation and shelter, and access and evacuation.

Occupation and shelter. In the emergency period, although there were "official" sites for gathering and recovery, many displaced people made ad hoc decisions about where to establish temporary shelter. Campsites were occupied for days, weeks, and sometimes months after the event.[6] In residential areas outside urban centres, people camped in streets and front gardens for the first two or three days

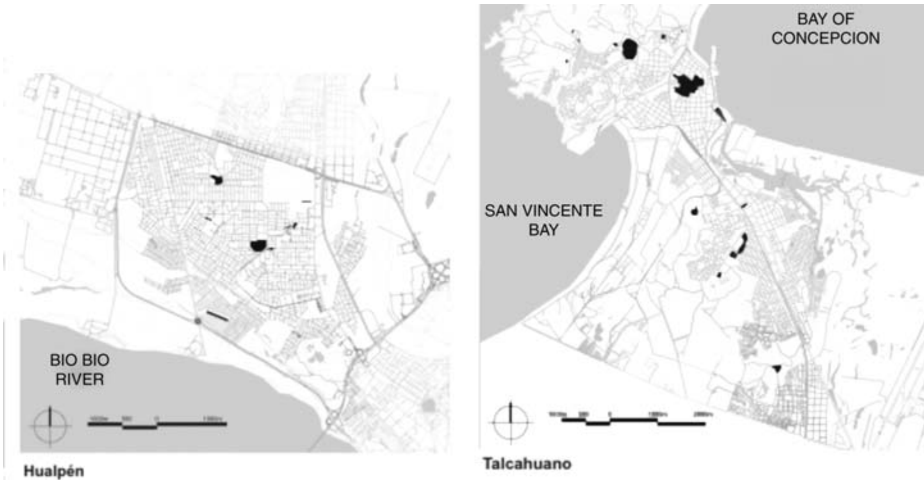

Figure 6. The cities to the north of the River Bio Bio: Talcahuano, Hualpén, and Concepción. *Source*: Camila Wirsching and Daniela Garcia.

until they felt safe enough to return to their homes (Figure 9). In some cases, because of the threat of tsunami and the fear of aftershocks, common areas were used as campsites at night but people returned to their houses during the day.[7] In all cases, sites were chosen for diverse reasons. These included the type of disturbance (tsunami or earthquake); proximity to home, family and services; the site's history of occupation after previous earthquakes and tsunamis; safety and visual access; availability of ecosystem services such as water for drinking and cleaning; and the opportunities for response and recovery offered by the diversity of spatial types available (for example, clear flat ground and shelter).

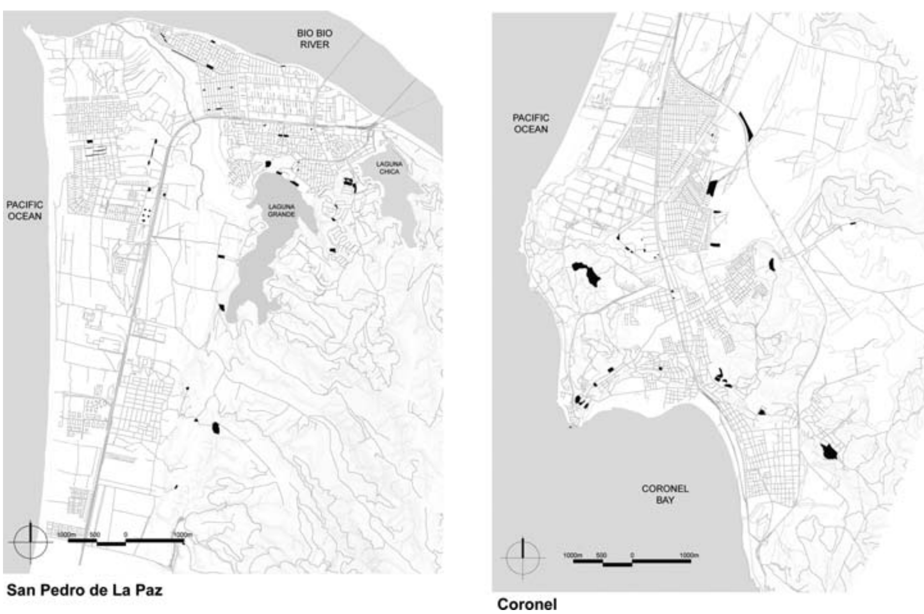

Figure 7. The cities to the south of the River Bio Bio: San Pedro La Paz and Coronel.

Figure 8. Emergency housing camps on Santa Elena Hill in Coronel, from the air. *Source*: Municipalidad de Coronel, Concepción, Chile.

Sites selected in response to the threat of tsunami shared a number of characteristics. They were typically elevated sites, away from the coast, peripheral to the city and with a capacity to support large numbers of people.[8] Their size facilitated the installation and management of temporary settlements for an extended period. Many of them seemed to have no apparent owner.

Sites selected in response to earthquake impacts tended to be located near or adjacent to residences and urban infrastructure, and were of medium size, with defined and permeable boundaries and clear sight lines to adjacent areas. In cases where the built fabric was completely demolished, temporary camps were established at some distance from the destroyed urban fabric, on institutional sites and in green areas (local parks and sports fields). These were usually located next to housing or large tracts of land. Sites were typically flat and adjacent to a street, and were able to accommodate large numbers of people.

The region's diverse and dispersed sources of water played a critical role in the selection of sites for recovery. The region was without centralized water services for at least three days following the earthquake. During this time, watercourses and lagoons provided safe environments and a plentiful supply of water for washing and, when treated, drinking (Figure 10). In the towns of Talcahuano, Hualpén, and Coronel, the local government installed pumps to

Figure 9. Camping in public space: the streets of Concepción. *Source*: Personal file of Juan Garay.

Figure 10. Sourcing water at Laguna Grande, San Pedro de la Paz. *Source:* Jose Luis Saavedra, Reuters.

access groundwater. In Concepción and San Pedro de la Paz, water was sourced from the district's many lagoons (Three Pascualas, Laguna Redonda, and Laguna Grande) and the rivers Andalién and Bio Bio. The urban parks along these rivers, which are well connected to primary roads and interdistrict highways, were all heavily occupied after the disaster.

In the old city of Concepción, public spaces, particularly urban parks close to fresh-water resources (streams, springs, and lagoons, and even fountains and swimming pools) and adjacent to a primary route of communication (connecting routes between sub-centres), were key sites for recovery. In the port cities of Talcahuano and Coronel, because of their history of rapid growth and shortage of public space, the most readily available and appropriate places for temporary settlement were private spaces such as defence lands (typically unoccupied headlands) and undeveloped natural areas.

The most occupied sites in the suburbs of San Pedro de la Paz and Hualpén were parks, vacant lots and communal space situated close to homes. Many inhabitants of four- or five-storey apartment blocks were displaced to their communal open space area for temporary shelter (Figure 11). In the outlying suburbs of San Pedro de la Paz and Coronel, parks, empty lots, and open space associated with infrastructure (freeways and railway corridors) were the most commonly occupied. Many fled to higher ground, which was in short supply and mostly privately owned. The displacement of disadvantaged communities from the coastal plains to the relatively exclusive middle-class suburbs in the hills of San Pedro la Paz and Coronel created an overcrowded, dangerous, and volatile siege situation, which required the intervention of the military.

Beyond the suburbs, in the AMC's peri-urban neighbourhoods, orchards and vegetable gardens provided food for people who had fled the coast and were temporarily camped in the hills. One survivor described how she collected food from backyard gardens during the trips she took between the coast and the hills to check on the safety and well-being of her family while she waited for the threat of earthquake and tsunami to subside.

One of the most dramatic, spontaneous, and widespread adaptive responses to the earthquake was the construction of barricades to create small neighbourhoods with distinct boundaries. These were usually located at street corners, with a fire at night to improve visibility. The size of these neighbourhoods encouraged efficient communication, and first-hand accounts give evidence of the strong bonds that

Figure 11. Collective space: tents in the parking lot of buildings, San Pedro de la Paz. *Source:* Personal file of Soledad Garay, University of San Sebastian, Concepción.

developed between members of these small communities and the way they adapted to facilitate recovery. For example, in a neighbourhood with a local park, the community elected a leader and gathered twice a day in the park to discuss survival strategies. In another neighbourhood of gridded streets with no park, the street and front yards together acted as a public square for the exchange of information. In both cases the existing urban structure afforded a degree of privacy and a degree of interaction; people could choose to withdraw or congregate without leaving their neighbourhood. It allowed people to retain a degree of dignity and privacy as they recovered (Figure 12). The opportunity to control space in this way was not available in larger urban parks or the communal space of apartment blocks, where space was claimed on a first-come-first-served basis and there was no possibility of privacy.

Access and evacuation. The geomorphology and associated urban structure of the AMC influenced the effectiveness of evacuation associated with both the tsunami and the earthquake. One of the AMC's greatest vulnerabilities, and arguably the greatest barrier to long-term recovery, is its geomorphology and the resulting urban infrastructure of access. Single-highway connections are built like levees above the marsh, and earthquake- and tsunami-related damage seriously affect

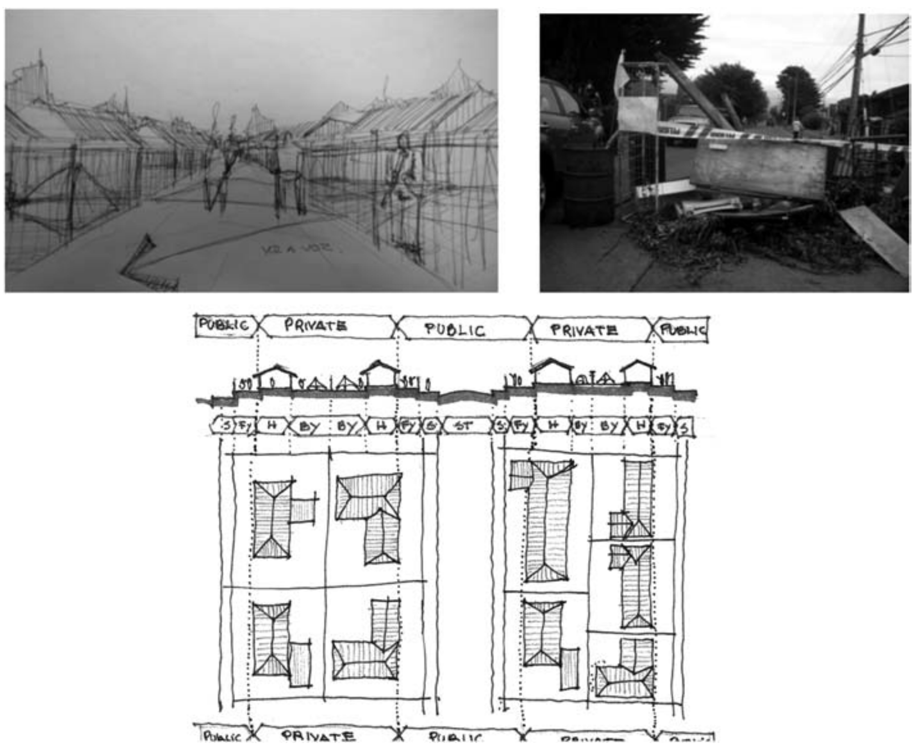

Figure 12. The renegotiation of public and private space for recovery after the earthquake in Concepción. Top left: drawing by student Diego Ramirez, showing how his community managed space to recover in the first week after the earthquake. Top right: an example of the makeshift barricades constructed by communities to protect themselves from looters. *Source*: Personal file of Paula Villagra. Below: plan view showing same (St: sidewalk; Fy: front yard; H: house; By: back yard). *Source*: Emilio Garcia, VUW.

connectivity. Damage to the bridges that span the Bio Bio River had even greater implications for recovery. Of the three bridges that span the river, two collapsed. This affected access to medical treatment and waste disposal sites, stemming the exchange of goods and services across the river and seriously hampering the long-term recovery process.

Despite the connective capacity of Highway 160, the urban fabric south of the Bio Bio River is relatively fragmented; each centre has its own idiosyncratic internal structure, which made it difficult to move quickly through the region. North of the river, access is less constrained, and highways were used for evacuation between centres, away from the coastline, while secondary streets were effective as evacuation routes through centres to highways because of their width and legibility.

The elevated areas in the region were important sites for temporary emergency shelter in the first few days following the disaster. The Cordillera de la Costa rises steeply to the east of the AMC, at some distance from the coast, but remnant small hills and slopes rise intermittently above the relatively flat urban fabric of Talcahuano and Coronel. San Pedro de la Paz, a relatively new settlement high in the hills, is further from the coast and more difficult to access because of the lagoon and waterway that separate it from the coastal settlement of Coronel. Despite these difficulties, and the issues associated with public access, the hills were critical for the recovery of coastal communities in the first few days after the disaster.

But there were access problems inherent in the urban structure south of the river. For example, in response to the tsunami warnings, thousands fled from the extensive coastal plains to higher ground. While evacuees easily navigated the permeable street network on the plains, poor connectivity, the small number of narrow, winding roads, and the junction between the plains and the hills created a bottleneck which seriously restricted the speed and effectiveness of escape (Figure 13).

The method and urgency of escape from earthquake damage depended largely on the urban structure of the affected area. In affluent suburban areas, the wide avenues and large open spaces around buildings encouraged recovery "in place". Despite building damage, there was plenty of open space adjacent to residential areas with easy and legible access to streets connected to main highways. However, in older cities like Concepción, with dense centres and relatively little available open space, it was necessary to evacuate to safer territory.

Figure 13. A trial evacuation some months after the earthquake and tsunami. The vulnerabilities of narrow access and lack of public space in the hills of San Pedro la Paz were evident. *El Sur* newspaper, Hualpén.

Evacuation proceeded via secondary streets, which were well known as direct access routes to highways leading out of the city and wide enough to remain passable despite building damage and rubble.

Discussion

Analysis of the activity of individuals and communities in the days and weeks following the earthquake reveals some important relationships between urban structure, recovery, and resilience.

Spatial and Functional Diversity: Quantity vs. Quality

While it is difficult to draw universal conclusions from one case study, the case study suggests a relationship between a city's spatial and functional diversity and the capacity of communities to manage their own recovery.

Although most earthquake-prone cities designate official sites for gathering and recovery, displaced people tend to make ad hoc decisions about where to shelter, particularly in the first few days, before the government can coordinate recovery and relief operations. The spatial and functional diversity of the AMC's open space network allowed individuals and communities to actively choose sites based on their particular needs for temporary shelter and recovery. The shortage of easily accessible public open space on elevated land seriously affected the recovery process in those communities escaping from the threat of tsunami south of the river. Where this was not the case, however, permeable but defined boundaries, clear sight lines, and easily accessible connection to evacuation routes were important factors in the choice of sites for shelter. Other important factors included proximity to home (many people slept in parks but spent the day at home) and the provision of essential services (water and sewer). Collective memory was also a significant factor: a number of key parks in the city (e.g. Parc Ecuador, at the base of the hills on the outskirts of the old city) had a history of occupation after earthquakes, and communities naturally gravitated to these sites immediately after the 2010 earthquake.

Communities that recovered "in place" manipulated the physical fabric of their surroundings to help them survive. This was most apparent in the practice of barricading, which, while ostensibly a technique to protect against looting, also created communities small enough for quick and efficient responses to day-to-day needs. In some cases the boundaries between public and private space were also redefined to facilitate the recovery process. For example, in a typical gridded street, barricaded at each intersection, the street, verge, and front gardens of houses were treated as communal space. The community would gather each day to discuss when the water truck was coming, who was ill, or how to get food. Behind houses, in back yards, space was private. This is where tents were set up for sleeping and people could withdraw during the day if they needed privacy. This choice of public or private was a luxury not available to apartment dwellers, who had to set up tents in the undifferentiated space of the communal garden at the foot of their apartment block.

The provision of spatial and functional diversity in the urban plan of vulnerable cities can offer important choices to displaced people and positively influence the recovery process. Just how much diversity, and how that should be provided, is a city-specific issue. It is likely, though, that small, evenly distributed spaces as well as large ones are likely to be important, and that access to alternative supplies of critical services, clear sightlines, defined boundaries, and relative ease of access to evacuation routes are all important considerations.[9]

The flexibility and adaptability of urban space is critically important where urban space is at a premium. In these situations, it is not necessarily the quantity of space that is important, but its potential for different, unplanned uses—in other words, its capacity to be adapted. This question of quantity vs. quality is an important area of research in urban design and has implications for the design of vulnerable cities. Too much space can create dispersed and potentially unsustainable cities, while too little restricts the potential of displaced communities to recover. Undifferentiated space may seem to be the most adaptable, but in fact it can offer reduced opportunities for adaptation, as seen in the case of the apartment dwellers' lack of privacy in Concepción. An important area of research in light of these issues is how people appropriate space for different ends (Dovey 2006; Ramirez-Lovering 2010) and what designers can do to encourage it.

Modularity vs. Connectivity

The inherent tension between modularity and connectivity certainly influenced the AMC's capacity to respond and recover. The region can be described as "thinly polycentric" (Kloosterman and Musterd 2001) in that the function of the region as a whole relies on the differentiated function of its parts. The urban structure is modular, but not modular enough. Each centre within the conurbation has a degree of internal cohesion and connectivity, but connectivity between centres is relatively poor. If the city were resilient, each centre would display a high degree of autonomy and be "safe to fail", to compensate for poor connectivity between its sub-centres.

The urban grid characteristic of much of the study area exacerbates this situation. Although its permeability and the redundancy of connections encourage traffic flow, a conflict occurs when the large volumes of vehicular and/or pedestrian traffic meet a pinch point. These tend to occur at the junction between urban structure and geomorphology or two spatial or urban typologies (e.g. city to highway, city to suburb, and plains to hills) and can create dangerous bottlenecks, particularly when large numbers of people are attempting to evacuate quickly. In the panic that ensues after an event, with large numbers of people evacuating from dangerous areas, people need to be able to escape through the urban fabric to safety quickly and efficiently, almost without thinking.

The delicate balance between modularity and connectivity is a challenge for the urban designer. Solutions will vary from city to city and from scale to scale. Connectivity in the AMC is problematic because of its low-lying geomorphology. While it is important to reinforce existing connections from centre to centre, it is perhaps even more important to develop strategies to increase each centre's relative level of autonomy. In other cities, it might be easier and cheaper to focus on improving connectivity. At the neighbourhood scale, the actions of communities in response to looting highlight the importance of modularity or the capacity to reinforce it. Small modular neighbourhoods with clearly defined boundaries were critical for the development of social capital and the subsequent generation of effective survival strategies.

Variability: Redundancy and Efficiency

Resilient systems "embrace variability rather than attempting to control or reduce it" (Walker and Salt 2006, 148). The AMC's urban voids are remnants of the overlay of urban structure and geomorphology, by-products of urban infrastructure, and the result of the city's shifting economic fortunes. These urban voids played an important role in the recovery process. They are "redundant" but not superfluous and an integral part of the overall structure and function of the region. Redundant spaces can absorb a variety of urban functions if necessary. Because of their relative ambiguity and lack of defined structure, they played an important role in the AMC after the earthquake and tsunami. Although some suffered a degree of liquefaction, most were relatively safe, and they supported thousands of displaced people after the disaster, particularly those evacuated from coastal areas, while the city recovered.

Many of these spaces support a variety of ecosystem services, which were able to sustain the functioning of communities when conventional infrastructure had failed. The abundant and dispersed lagoons in the AMC, and the presence of aquifers near the surface, were particularly important. The availability of these services in a diversity of forms empowered individuals to be self-reliant or to work with their local community to source supplies, thereby building social capital while reducing the load on centralized emergency aid services.

While the engineering response when services break in an earthquake is usually to reinforce them, and engineering "redundancy" usually means two pipes instead of one, there is a growing interest in ways to decentralize and democratize the availability of essential services (Graham and Marvin 2001). While the agenda for this shift has been largely based on issues of social equality and sustainability, further research concerned with making services visible, accessible, and redundant (and therefore resilient) will almost certainly improve the community's chances of survival in the event of a major earthquake.

Conclusions

Despite the focus in the last decade on urban resilience and the discourse around urban processes that underpins contemporary urbanism, there is relatively little information for designers about how to physically design for resilience. This may be due to a misunderstanding about the role of form and space in the dynamic of urban systems. Or it might be related to the variety of definitions of the concept of resilience. And it is potentially exacerbated by the persistent conflation of the concepts of sustainability and resilience.

The research described in this essay is an attempt to clarify these issues and in particular to understand the nature of urban resilience and the influence of urban morphology on urban resilience. By examining resilience metaphors or "attributes" that describe how open systems and in particular urban systems operate, the research expands on what urban morphologists already know: that people and place exist in a tight and dynamic interrelationship and that space and form can sometimes precipitate flow rather than hindering it (Moudon 1997).

The research is also an attempt to determine what exactly designers of urban space and form can do in cities to encourage resilience. While "urban acupuncture" proposes targeted, strategic interventions, creating disturbance to elicit a particular adaptive response, this research takes a slightly different direction. It assumes that the disturbance (e.g. an earthquake) is unmanageable and unpredictable, and thus looks to variables in the urban system that *can* be manipulated to see whether adjustments can be made that might precipitate an adaptive response. In order to do this it focuses on cities that have undergone or are undergoing a process of reorganization in response to a major disturbance such as an earthquake. It looks for a correlation between form and response, and it interprets both the forms and the responses through the lens of resilience, and in particular through a consideration of resilience "attributes".

The intention of the research is also to test the usefulness of these attributes as a framework for research. Preliminary results indicate that they help to explain how and why communities respond the way they do in order to survive. They also give clues about the design of form and space in a resilient urban system and how these contribute to the adaptive response, offering qualitative strategies for the design of earthquake-prone cities that can be (and must be) applied at a variety of scales. Their qualitative nature suggests that the attributes are likely to be most effective when calibrated, through design, with a city's existing urban structure and function in a way that negotiates, for example, relative qualities and quantities of space, modularity and connectivity, redundancy and efficiency, with the multiplicity of competing requirements in the urban environment.

This, in turn, reinforces the importance of urban designers to urban resilience and recovery planning. Recovery planning typically has relatively little to do with urban planning or urban design (MCDEM 2005). But the literature is beginning to suggest that recovery is very clearly a pre-disaster as well as post-disaster issue. In the aftermath of a major earthquake, there is an overwhelming focus on major reconstruction. History suggests that reconstruction after an earthquake is often restricted by the overwhelming variety of competing interests as well as the need to return to normal as quickly as possible (McDonald 2004). It may be more effective, then, for vulnerable cities to be retrofitted incrementally, in the relative calm of the pre-earthquake environment. To encourage this shift, design for resilience needs to seen as part of, not separate from, day-to-day decisions. The spatial strategies hinted at in this essay are useful in this regard. On the one hand, they actively enhance the capacity of a community to respond effectively to extreme disturbance. On the other, they are already an established part of urban design language and their implementation is therefore likely to enhance the quality of daily urban life.

Notes

1. Sometimes referred to as the emergency period a period when communities must fend for themselves before organized help arrives and which most clearly reveals a city's spatial vulnerability.
2. Ecological resilience is "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker *et al.*, 2004). Resilience depends on "1) the amount of disturbance a system can absorb and still remain within the same state … 2) the degree to which the system is capable of self-organization … and 3) the degree to which the system can build and increase the capacity for learning and adaptation" (Folke 2006, 259–260). It also depends on the capacity of a system to operate at a series of interconnected scales.
3. In this we have been influenced by Anne Vernez Moudon's research into urban morphology, where she refers to the city as a complex matrix of buildings, infrastructure, and open space, "constantly used and transformed over time" (1997), where individuals and communities exist in a tight and dynamic inter-relationship with that matrix.

4. Water-sensitive urban design strategies are an example of spatial designs that absorb environmental variability. Detention basins and rain gardens take up more space than traditional storm water pipe systems; from that perspective they are relatively inefficient. But the extra space can help to absorb flood peaks in wet years, insuring against environmental unpredictability or variability.
5. For example, later in this essay we talk about the widespread and spontaneous use of neighbourhood barricades to prevent looting in Concepción. While some members of our team were horrified at this evidence of a "siege mentality", a closer examination of the practice through the lens of the resilience attributes suggests that by creating smaller, more manageable neighbourhoods, communities were, perhaps unwittingly, generating social capital, making it easier for them to organize and respond quickly and effectively.
6. One first-hand account describes "a community of 50 families with 15 children, camping in the same park at Laguna Grande for three days because of the fear of aftershocks" (C. Cifuentes, Boca Sur Viejo, San Pedro de la Paz, 2010).
7. "Some of us returned the next morning [to our houses] and then we returned to the hills to sleep. Others stayed longer in more established camps" (Cecilia Munos, president of the Talcahuano community, 2010). "For about a month ... they were sleeping in tents during the night and then left during the day. This was because they had built their own houses and they were structurally unstable" (R. Pavez Hidalgo, Boca Sur Viejo, Villa Mora, Coronel, 2010).
8. "We were looking for elevated land above 20 metres. Everyone from Coronel was running to the hills" (A. Salazar Diaz, Coronel, 2010).
9. In San Francisco after the 1906 earthquake, the generous width of most of the streets allowed for a wide range of functions to be established in the recovery period, from domestic cooking to temporary rail lines and temporary commerce, and the hilly topography and widely distributed park network ensured that there were plenty of opportunities to shelter in local parks with good visual access.

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