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Designing public open space to support seismic resilience: A systematic review

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In the wake of major earthquakes public open spaces become hubs for both short-term disaster response efforts and support longer-term recovery needs. At present, few open spaces are actually designed to support these intermittent but critical uses. Currently, there is no consolidated body of knowledge or resource for landscape architects designing for areas of high seismic risk. This research identifies ways in which landscape architects and professionals within allied design disciplines can proactively plan and design open space to support seismic resilience. A systematic review of both grey literature and peer-reviewed academic papers was conducted. The results of the systematic review identified six key themes: Multifunctionality; networks; site location and suitability; size and function; site elements; and, social resilience. These themes contribute to developing a foundation for design disciplines to better incorporate seismic resilience into planning and design of public open spaces.

Keywords: earthquakes, disaster prevention parks, seismic resilience, landscape architecture

Research Highlights

- Need for open space design to support earthquake response/recovery is increasing
- Design disciplines must assume a larger role in seismic resilience
- Open space should be designed to meet basic human needs (water, food, sanitation)
- Programming, education and community engagement are critical components of design
- Design for seismic resilience enhances the overall quality of the urban environment

1. Introduction

Approximately 3 billion people currently reside in areas with high seismic activity, and in the last two decades an estimated 750,000 have died in earthquakes and subsequent tsunamis (UNISDR, 2016). By 2050, it is projected that populations in major cities at risk from earthquakes will double (World Bank & United Nations, 2010).

In the aftermath of a major earthquake, open spaces such as parks, plazas, sports fields and streets have high occupation rates (e.g., Allan, Bryant, Wirsching, Garcia & Rodriguez, 2013); "displaced residents will spontaneously converge on public parks and open space" (American Red Cross, 2011, p. 7). Immediate needs such as evacuation, medical assistance, communication, social gathering, shelter and distribution of food and water are often addressed in a city's open space (Allan et al., 2013; Masuda, 2014; Villagra, Rojas, Ohno, Xue & Gomez, 2014;). Indeed, public open space is critical, and conversely, lack of large open space in the urban environment can lead to an increase in injury and death following an earthquake.

Given the immense toll that building collapse can take on human life, it is perhaps unsurprising that current earthquake mitigation is largely focused on engineering structures and infrastructure in the built environment. However, there is a tendency to overlook open space as a component of the built environment. Although the built environment includes many different practices relating to "the design, development and management of buildings, spaces and places" (Griffiths, 2004, p. 711), open space is frequently treated as somehow separate. Further, while both land use rezoning and restriction of construction in hazard prone areas are effective, there is growing interest in using open space not simply as a barrier, but as an active component in supporting seismic resilience.

Geis (2000) lists "design and patterns of open space" (p. 157) as core areas to consider in disaster mitigation, and literature shows that improvements to public open space can have positive effects on seismic resilience (e.g., Bahrainy, 1998; Tumini, Villagra-Islas, & Herrmann-Lunecke, 2017).

Yet, there is little to no consolidation of research about how to design public open space to support response and recovery in the aftermath of an earthquake (e.g. Allan & Bryant, 2010; Allan et al., 2013; Jayakody, Amarathunga, & Haigh, 2016; Pizzo et al., 2014).

A limited but growing body of literature is beginning to address the use of open space in the post-disaster context (e.g., Allan & Bryant, 2011; Montejano-Castillo & Moreno-Villanueva, 2016; Villagra-Islas & Alves, 2016; Wesener, 2015). In the aftermath of an earthquake, a number of criteria are used to select suitable open spaces. One of the most critical drivers is the type of secondary disaster faced in an area (e.g., liquefaction, landslides, flooding, fires or tsunamis). In the event of a tsunami, for example, open spaces that are elevated, set back from the coast, and can support a large number of evacuees are typically sought out (Allan et al., 2013); with respect to fire, following the 1923 Great Kanto Earthquake in Japan, approximately 1.57 million residents sought shelter in parks that were surrounded by vegetation, which acted as a buffer from the fires (Masuda, 2014).

Aspects of shape, size, accessibility and connection to infrastructure (e.g., water, power, sanitation) are also key considerations (Allan et al., 2013; Montejano-Castillo & Moreno-Villanueva, 2016). Allan et al. (2013) note that a site's historic use in previous disasters can be a predictor of selection. Proximity to one's home and neighbourhood is another commonly cited reason for site selection (e.g., Allan & Bryant, 2011; Allan et al., 2013; Montejano-Castillo & Moreno-Villanueva, 2016; Villagra et al., 2014). While there are attributes that are important during the emergency response and short-term recovery phases after an earthquake, literature that addresses the use of open space and long-term recovery is scarce and tends to bleed into other disciplines, as the lines between the recovery phase and a return to normal daily activity become less defined.

Most papers that address the use of open space in the post-disaster context state that their findings are intended to be used as a guide for urban designers and allied professions, such as landscape architects, working in urban areas prone to earthquakes (Allan & Bryant, 2011; Allan et al., 2013; Villagra, Rojas, Ohno, Xue, & Gómez, 2014). However, this and other scholarship that could contribute to designing public open space to support seismic resilience, has not been consolidated.

Design disciplines can play a key role in seismic resilience, yet "spatial planners, urban designers and landscape architects are rarely involved" (Allan & Bryant, 2010, p. 34). Landscape architects are trained to consider changing systems, and to plan and design for temporal and spatial changes in the environment - all key factors in addressing risk (Mazereeuw, 2015). The discipline has both the ability and responsibility to increase urban resilience through planning and design for disaster mitigation (Copley, Bowring, & Abbott, 2015; Turer Baskaya, 2012). However, there is a need for more clarity on both the role of public open space after an earthquake and how to design open spaces to support response and recovery in the post-disaster landscape (Allan & Bryant, 2010).

The aim of this research is to conduct a systematic review of the literature in order to gain insight into how landscape architects can proactively plan and design public open space to support seismic resilience. In support of this aim, the research has three primary objectives:

- Consolidate existing literature on the research for landscape planning and design for seismic resilience from the discipline of landscape architecture and related professions;
- Analyze the literature on landscape planning and design for seismic resilience for major themes; and,

- To develop guidelines for landscape architects and related professions to better incorporate seismic resilience into the planning and design of public open spaces.

2. **Methods**

The scope of research related to public open space and seismic resilience encompasses many disciplines. Research review methods are able to recognize patterns and trends across a wide range of literature, and are a critical first step in the planning and design of new interventions (Haddaway & Bayliss, 2015; Petticrew & Roberts, 2006). A systematic review of the literature is an ideal approach to identify ways that open space can be planned, designed and retrofitted to support survival and recovery in the aftermath of major earthquakes.

Unlike a conventional review of literature, through a systematic review process, one locates, summarizes and consolidates research results in a manner that is both transparent and replicable (Palermo, 2013). Although there is no single method for conducting a systematic review (Palermo, 2013), a number of guidelines exist that detail preferred review methods.

With its roots in the medical field (Torgerson, 2003), the systematic review has proven to be an effective method for other disciplines, for instance, conservation and environmental management (Pullin & Stewart, 2006) and computer science (Breivold, Crnkovic, & Larsson, 2012).

Yet, Petticrew & Roberts (2006) acknowledge that there have been questions about the usefulness of a systematic review in an area of research still in its infancy. However, even uncovering an absence of literature can "in itself [be] an important contribution" (Petticrew & Roberts, 2006, p. 35), and can help to identify areas for future research. Ultimately the use of a systematic review contributes to the growing scholarship in the discipline of evidence-based landscape architecture (Brown & Corry, 2011).

2.1. Search Strategy

Both grey literature and peer reviewed academic papers were included in the systematic review. Grey literature is a critical component of evidence and provides vital information that increases accuracy of results (Blackhall, 2007; Haddaway & Bayliss, 2015; Lawrence, Houghton, Thomas, & Weldon, 2012; Pappas & Williams, 2011; Tranfield, Denyer, & Smart, 2003). Rothstein, Sutton, & Borenstein, (2006) caution that by excluding grey literature you run the risk of publication bias. For this study grey literature focused on government papers and professional association or design firm documents. Haddaway & Bayliss (2015) refer to this form of grey literature as "practitioner-generated research" (p. 827).

Electronic searches were carried out in July, 2017, using the following databases:

- ProQuest Databases
- Web of Science
- Google Scholar
- Google

As Higgins & Green (2011) note, "developing a search strategy is an iterative process" (section 6.4.4) and keywords evolve as the literature is reviewed. Subject headings and keywords from a scoping paper and relevant literature were assessed for words to include in the search strategy. The keywords were refined by the study authors and grouped into categories, which encapsulated the research question: type of disaster, stage in the emergency cycle, types of open space and relevant disciplines (see Table 1: Search Terms). Search strings that combined terms from the four categories were then used to locate literature.

Disaster	Emergency Cycle	Space Type	Discipline
Disaster	Mitigation	Green Space	Emergency Management
Emergency	Planning	Garden	Landscape Architecture
Hazards	Prevention	Landscape	Urban Planning
Risk	Preparedness	Open Space	Urban Design
Earthquake	Response	Plazas	
Seismic	Recovery	Parks / Parkland	
	Reconstruction	Public Space	
	Resilience	Streets	

Table 1: Search Terms

2.2. Study Selection

The systematic review inclusion criteria were purposefully broad in order to take "…account of a multiplicity of possible interventions" (Petticrew & Roberts, 2006, p. 74). Haddaway and Bayliss (2015) also note that a broader approach will generate more reliable results and further increase the reviewer's ability to pinpoint patterns and trends in the literature. Thus, articles were not excluded based on their date of publication or study approach. The Cochrane Collaboration guidelines were adapted to inform the systematic review structure (see Higgins & Green, 2011).

Articles were required to meet the following criteria for inclusion:

Stage 1: Title and Abstract Review

- Academic Literature: Terms from the *Search Terms* list appear in the title, abstract or keywords.
- Grey Literature: Terms from the *Search Terms* list appear in the title, executive summary, first two paragraphs of text and/or the database has located a search term embedded within the document.
- Full text is available in English (It is evident from the database searches that a range of scholarship from Japan and China on disaster prevention parks exists. However, while Japanese and Chinese journals provide a translation of the abstracts, no full text translation is available. Future research should include both Japanese and Chinese language articles to ensure that this source of scholarship is represented).

Stage 2: Full Text Review

- Documents must specifically address elements of open space for mitigation, preparedness, response or recovery in relation to a hazard, risk or disaster. As earthquakes can trigger a number of secondary or tertiary disasters the authors did not want to exclude articles that may address one of these disasters outside of the context of an earthquake. Consequently the inclusion criterion uses these generalized terms.
- Academic literature must adhere to basic citation protocol (While conducting the systematic review, issues pertaining to the quality of academic literature did arise. Certain academic journal articles failed to cite direct quotes, did not cite any sources, or referenced questionable sources such as Wikipedia).

2.3. Final Article Selection

Bibliographic information from articles that met the criteria was entered into the citation manager Zotero. A snowball search of the final articles' references was conducted and relevant sources that were not identified in previous searches were incorporated. In total, 35 documents were retained for final analysis (see Figure 1, for study selection; see Table 2, for final article summary).

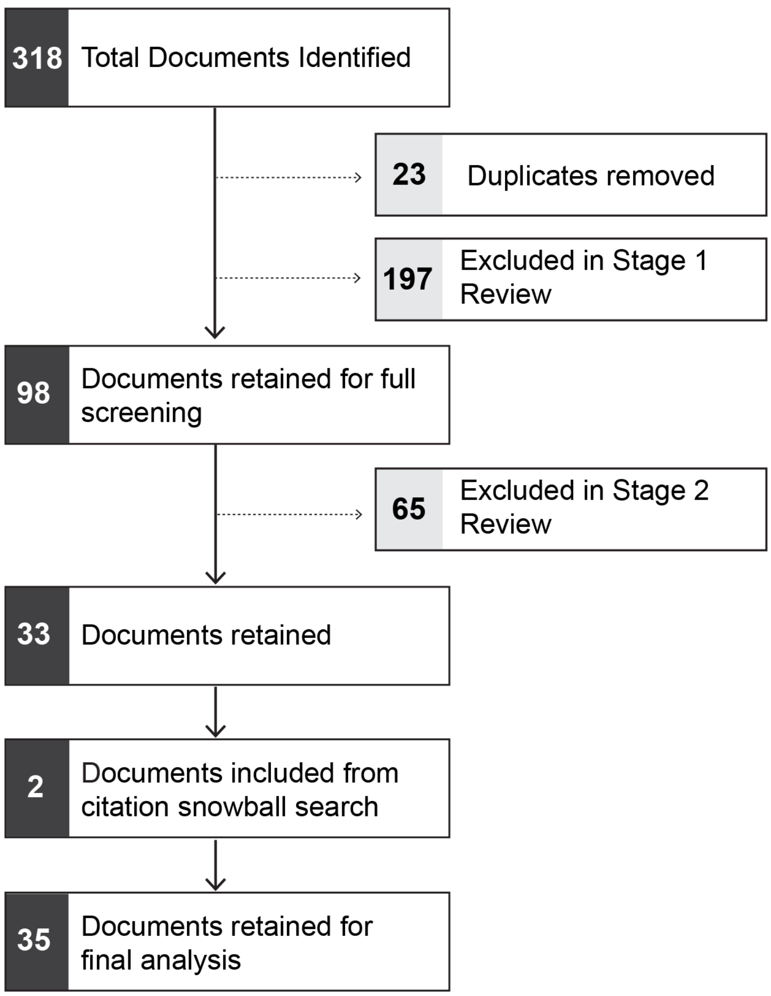

Figure 1: Systematic Review Study Selection

2.4. Final Article Summary

The types of literature identified by the systematic review were diverse in their methods and consequently analysis of the literature was narrative in nature. The literature was first summarized and key data compiled (see table 2) that identified the type of resource, hazard(s) and region(s) of focus as well as the stage(s) of the emergency cycle addressed (mitigation, preparation, response or recovery). In order to meet the study's second objective to identify major themes in the research, the authors reviewed the summaries and grouped articles based on references to either physical or social planning/design solutions. As the literature was reviewed, common sub themes were identified. Modifying themes is a necessary part of the review process as new data is added (Higgins & Green, 2011). Themes were further refined as the review progressed and during the writing phase.

#	Reference	Resource Type	Hazard	Region(s) of Focus	Emergency Cycle			
					MT	PR	RS	RC
1	Ahern (2011)	Journal Article	All-Hazards	N/A	X			
2	Allan & Bryant (2010)	Conference Paper	Earthquake	San Francisco, U.S.				X
3	Allan & Bryant (2011)	Journal Article	Earthquake	San Francisco, U.S. Concepcón, Chile	X		X	X
4	Allan et al. (2013)	Journal Article	Earthquake	Concepcón, Chile	X		X	X
5	Allan & Bryant (2014)	Journal Article	Earthquake	San Francisco, U.S. Concepcón, Chile	X		X	X
6	Anhorn & Khazai (2015)	Journal Article	Earthquake	Kathmandu, Nepal	X			
7	Bahrainy (1998)	Journal Article	Earthquake	Rasht, Iran	X			
8	Bryant & Allan (2013)	Book Chapter	Earthquake	Christchurch, New Zealand Kôbe, Japan				X
9	Campbell, Svendsen, Sonti, & Johnson (2016)	Journal Article	Hurricane	New York City, U.S.	X			X
10	Chan, DuBois, & Tidball (2015)	Journal Article	Hurricane	New York City, U.S.				X

11	CMG Landscape Architecture. (2017)	Website	Earthquake	San Francisco, U.S.	X	X	X	X
12	Dionísio et al. (2012)	Journal Article	Earthquake Fire	Tokyo & Kobe, Japan	X	X		
13	Flüchter (2003)	Journal Article	Earthquake	Tokyo, Japan	X			
14	Government of Nepal, & IOM. (2011)	Report	Earthquake	Kathmandu, Nepal	X			
15	Ishikawa (2002)	Journal Article	Earthquake Fire	Tokyo, Japan	X			
16	León & March (2014)	Journal Article	Earthquake Tsunami	Talcahuano, Chile	X		X	
17	León & March (2016)	Journal Article	Earthquake Tsunami	Iquique, Chile	X		X	X
18	Li et al. (2017)	Journal Article	Earthquake	Shanghai, China	X			
19	Li (2014)	Paper	Earthquake	China	X			
20	Liu et al. (2014)	Journal Article	Earthquake	Wenchuan County, China				X
21	Masuda (2014)	Paper	Earthquake	Japan	X			
22	Matsuda (1990)	Journal Article	Flooding Earthquake	Tokyo, Japan	X			
23	Mazereeuw & Yarina (2017)	Journal Article	All-Hazards	N/A	X	X		
24	Okvat & Zautra (2014)	Book Chapter	All-Hazards	N/A	X			X
25	Park, Takeda, Kaga, & Masuda (2016)	Journal Article	All-Hazards	Kôbe, Japan	X			
26	Pizzo, Di Salvo, Giuffré, & Pellegrino (2014)	Journal Article	Earthquake	Umbria Region, Italy	X			
27	Strusińska-Correia (2017)	Journal Article	Tsunami	Coastal Prefectures, Japan	X			X
28	The Tokyo Rinkai Disaster Prevention Park. (n.d.-a, b)	Website	All-Hazards	Tokyo, Japan	X	X		
29	Tokyo Metropolitan Government. (n.d.)	Manual	All-Hazards	Tokyo, Japan		X		
30	Tumini, Villagra-Islas, & Herrmann-Lunecke (2017)	Journal Article	Earthquake Tsunami	Mehuin & Dichato, Chile				X
31	Turer Baskaya (2015)	Journal Article	Earthquake	Istanbul, Turkey	X			
32	Villagra, Rojas, Ohno, Xue, & Gómez (2014)	Journal Article	Earthquake	Concepción & Valdivia, Chile	X			X

33	Villagra-Islas & Alves (2016)	Journal Article	Earthquake	Concepción, Chile				X
34	Villagra-Islas, & Dobbie (2014)	Journal Article	Earthquake	Concepción, Chile			X	X
35	Walker & Salt (2006)	Book	All-Hazards	Australia, Caribbean, Sweden, U.S.	-	-	-	-

MT – Mitigation, **PR** – Preparedness, **RS** – Response, **RC** – Recovery

Table 2: Final Article Summary

3. Results

The systematic review revealed an upsurge in publications over the past decade on planning and design of public open space to support seismic resilience. The relative absence of literature that predates 2010 is indicative of the novelty of this area of research. Though geophysical hazards such as earthquakes are not a new occurrence, they are having a greater impact then ever before as urbanization increases. The Sendai Framework for Disaster Risk Reduction reports that scholarly research on geophysical disasters now account for the largest number of publications (Elsevier, 2017).

The literature identified through the systematic review covers a broad range of topics on both the physical and social impacts of earthquakes. The overarching theme of multifunctionality appears throughout the results on all scales, from regional or citywide networks of open space to individual sites. The literature also reveals planning and design strategies to meet basic human needs such as water, food and sanitation, as well as qualitative environmental improvements to enhance open space function after an earthquake. Open space programming, education and community engagement are also shown to be critical in the planning, design and proper function of open space for seismic resilience.

The following section addresses designing multifunctional open spaces with embedded resilience that can adapt to different needs and conditions in the aftermath of an earthquake. Allan and Bryant (2010) refer to these multifunctional open spaces as a "second city" (p. 34), which both contribute to daily life and have the capacity to support response and recovery needs after disaster.

3.1 Multifunctionality

Multifunctionality in public open space creates a culture of flexibility and contributes to building resilient communities (León & March, 2014; Villagra-Islas & Dobbie, 2014). These multifunctional or hybrid open spaces can act as "leading components of emergency response" (Turer Baskaya, 2015, p. 741). Further, Allan et al. (2013) and Mazereeuw & Yarina (2017) note that the more embedded that disaster-resilient design and function are in daily life, the more effective they will be in the aftermath of an earthquake.

Because of the unpredictable nature of earthquakes, funding retrofits or leaving open space undeveloped can be difficult to justify economically. However, designing open space for earthquakes should not be seen as a constraint, but an opportunity to enhance the overall quality of the urban environment (Allan & Bryant, 2011; León & March, 2016; Masuda, 2014; Mazereeuw & Yarina, 2017).

The design concept developed by Hyphae Design Laboratory and CMG Landscape Architecture in 2014, for the Resilient SF Design Challenge, illustrates the alignment of both emergency and non-emergency design goals. The Golden Gate Park polo fields in San Francisco were the focus of the project. After the Great San Francisco Earthquake of 1906, parks played a critical role in response and recovery (Allan & Bryant, 2011; Allan et al., 2013). Golden Gate Park in particular was the site of a large refugee camp for displaced residents (Henderson, 2006). The design team drew on these historic roots for inspiration and proposed reinforcing the park with different layers of sustainable infrastructure (CMG Landscape Architecture, 2017).

In addition to the site's daily uses, it also hosts festivals and concerts throughout the year. The project team found that both the needs of festivals and concerts aligned with the 72-hour period that citizens are asked to prepare for in the aftermath of disaster when they are likely to be cutoff from life-lines. Those life-lines (shelter, food, water, power, waste management etc.) are also required for the concerts and festivals hosted by the park, which also typically last for three days (CMG Landscape Architecture, 2017).

3.2. Networks

While open space for seismic resilience should operate as a self-contained module, providing protection from the vulnerability inherent in centralized systems (Ahern, 2011; Allan et al., 2013), it must also function on the scale of the collective (Allan & Bryant, 2011). Improvements to a city's network of open space can increase a community's ability to respond to earthquakes through a reduction in evacuation times (Allan et al., 2013; León & March, 2016).

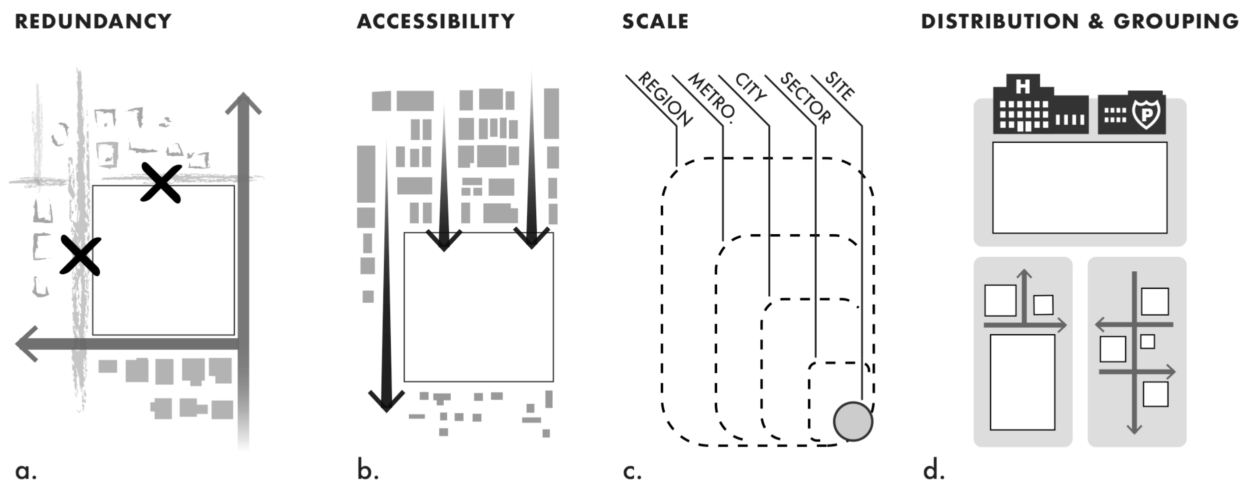

Figure 2. Network priorities include: a. Design for redundancy to distribute risk; b. Design for accessibility, prioritizing vulnerable areas; c. Design for multiple scales, from regional to site specific; d. Grouping open space with critical facilities or other open spaces.

3.2.1 Redundancy

Lack of a well-planned evacuation network can undermine the function of open space during an earthquake. Networks that provide alternative connections increase resilience through redundancy (e.g., Ahern, 2011; Bahrainy, 1998; Tumini et al., 2017), ensuring that backups are in place and that risk is more evenly distributed (Ahern, 2011; Villagra et al., 2014).

3.2.2 Accessibility

Networks also need to be designed for accessibility and have the capacity to avoid congestion in densely-populated areas after an earthquake (Bahrainy, 1998). León and March (2014) also stress that a key priority when planning networks is to connect vulnerable areas (physical or social) with safe open spaces.

3.2.3 Scale

Networks of open space must also function on multiple scales (Ahern, 2011; Allan & Bryant, 2011; Li, 2014; Turer Baskaya, 2015). In particular, planning and design for seismic resilience should consider the regional, metropolitan, city, sector and site scale (Bahrainy, 1998). In Japan, green networks address this hierarchy of scale, and are designed to operate on the regional, city and sector (or neighbourhood) level to facilitate evacuation of residents to disaster prevention parks (DPP)s, provide access for emergency vehicles, and act as a buffer to stop the spread of fire (Ishikawa, 2002; Park et al., 2016). Here, both the conventional street network and corridors of urban green space are designed to connect individual parks (Masuda, 2014).

3.2.4 Distribution and Grouping

In addition to connecting open space with well-planned networks, the distribution of open space along these networks is of critical importance (Pizzo et al., 2014; Turer Baskaya, 2015). Although Japanese planning guidelines suggest that open space should be positioned every two kilometres (Masuda, 2014; Park et al., 2016), others such as Villagra et al. (2014) encourage diversity in spatial distribution.

Moreover, open spaces should also be located in such a way as to create nodes with critical infrastructure and facilities such as hospitals, emergency services and transportation, thus aiding response time during disaster (Anhorn & Khazai, 2015; Turer Baskaya, 2015; Villagra et al., 2014). In addition to grouping open space with facilities, Turer Baskaya (2015) also discusses the concept of clustering open space in order to increase its capabilities, either by grouping small open spaces close together, or small spaces around a larger open space.

3.3. Site Location and Suitability

3.3.1. Identifying Risk

When determining the location of open space for seismic resilience it is critical to first identify areas that are exposed to risk (Anhorn & Khazai, 2015; Bahrainy, 1998; Tumini et al., 2017). Bahrainy (1998) stresses the importance of using seismic microzonation maps to determine specific areas of seismic activity and potential for secondary hazards.

In Chile, although government planning legislation stipulates the amount of open space for use after a disaster, it does not factor risk into this calculation (Tumini et al., 2017). Instead, the legislation bases the provision of public open space on population density. Although the need for public open space rises proportionally with population density (Bahrainy, 1998), Tumini et al. (2017) advise that planning must account for the level of risk faced in each area, while anticipating that areas with low risk exposure will likely need to accommodate an increase in population after an earthquake.

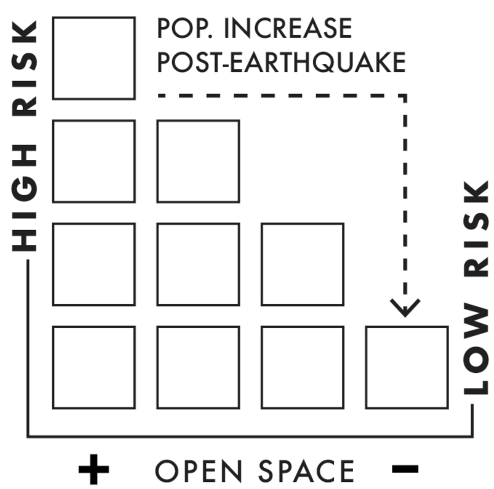

Figure 3. The need for open space for seismic resilience increases as risk grows. Open space in low risk areas should be designed to accommodate evacuees after an earthquake.

In the aftermath of the Tōhoku Tsunami that followed the 2011 Great East Japan Earthquake, a park system for the coastal city of Iwanuma (approximately 20 km south of Sendai) Miyagi Prefecture, Japan was proposed (Strusińska-Correia, 2017). The project, titled Millennium Hope Hills, consists of a network of six-tsunami disaster prevention parks, connected by raised pathways and protected by forested areas to dissipate a wave's power. Debris from the earthquake and tsunami were used to create 15 hills for vertical evacuation, with each hill able to accommodate 50 evacuees (Strusińska-Correia, 2017).

3.3.2. Scenario Planning

In addition to assessing risk exposure, it is critical to calculate the number of people expected to require shelter in an area (Anhorn & Khazai, 2015). In planning for their Golden Gate Park sustainable infrastructure concept, CMG Landscape Architects learned from the 1989 Loma Prieta Earthquake that affected Northern California, displacing 12,000 residents, to create initial design parameters (CMG Landscape Architecture, 2017).

Anhorn and Khazai (2015) recommend preparing for the "worst case scenario" (p. 790) in which almost all buildings collapse during an earthquake. In this scenario, all evacuation and shelter needs must be met solely by open space in the city. Similarly, The Government of Nepal and IOM (2011) assume dense urban areas will be uninhabitable after an earthquake, and open space on the periphery will need to accommodate the majority of displaced residents.

León & March (2016) used "'what-if' scenario analysis" (p. 840) which selects specific parts of a city where interventions can best improve the urban environment for future hazards. The study targeted three neighbourhoods in Iquique, Chile, that had the longest evacuation times and developed modifications specific to those locations that would enhance evacuation.

3.3.3. Site Conditions

When identifying appropriate areas for the location of open space, León and March (2014) consider characteristics such as area size, slope, land cover and the capacity of the site to support emergency services and infrastructure. Turer Baskaya (2015) notes that land with dense vegetation, such as "low canopy trees, shrubs and groundcover" (p. 737) that impede access or prevent shelter from being erected, was negatively correlated with location suitability.

The criterion used by individuals to select open space for use after an earthquake is also helpful to inform site selection. For instance, evacuees tended to occupy areas that had clear sight lines of surrounding areas; were accessible but with defined boundaries; contained infrastructure, facilities and water; had been used previously in disasters; and were in close proximity to their residences (Allan et al., 2013; Villagra-Islas & Alves, 2016).

3.4. Size and Function:

In Japan, research suggests that the larger the open space, the more important its perceived value for disaster prevention, while the contribution of small public open spaces to disaster prevention is seen as negligible (Dionísio, Candeia de Souza & Ota, 2012; Ishikawa, 2002). Small public open spaces are often excluded from disaster prevention plans because they do not have the capacity to support large numbers of evacuees (Dionísio et al., 2012).

Yet, Ishikawa (2002) demonstrates that small parks are indeed heavily used in the aftermath of an earthquake. Dionísio et al. (2012) conclude that integrating small and medium public open spaces into disaster prevention planning would not require large changes to the urban fabric, allowing for the preservation of existing urban form and neighbourhood character. In addition, in areas with a scarcity of open space, even small spaces can be important during a disaster (Dionísio et al., 2012).

A well-defined hierarchy of open space also exists in Japan for use during and after disaster, from command posts to shelter areas. As Masuda (2014) describes, command posts include regional, city and neighbourhood scale headquarters for disaster refuge, support for rescue, and transfer station for supplies. Shelter area refers to both large-scale regional shelter and temporary emergency shelter for residents of a particular neighbourhood.

While Masuda (2014) notes that the size of open space should be based on an average area of 2 m^2 per person, Anhorn and Khazai (2015), The Government of Nepal and IOM (2011), Tumini et al. (2017), and Villagra et al. (2014) use the guidelines provided by The Sphere Project (2011) for minimum humanitarian shelter standards, which advocates for a minimum of 3.5 m^2 per person for emergency shelter. Guidelines on size requirements of open space will change as short-term needs for shelter and services evolve in the days and months that follow an earthquake. For example, long-term shelter requires a minimum of 45 m^2 per person (The Sphere Project, 2011). Li (2014) and Masuda (2014) stress the need for DPPs to consider these changing requirements.

The transition from response to recovery is often not clearly defined, and actions associated with the response phase frequently overlap with recovery (World Bank & United Nations, 2010). Though a great deal of overlap also exists in the roles various sizes and types of open space play after a disaster, Masuda (2014) attempts to illustrate the correlation between open space size and the emergency management cycle. In addition to immediate needs such as medical assistance and evacuation, the response phase of a disaster includes the provision of emergency shelter (typically overnight stays) and temporary shelter (several days) (Quarantelli, 1995). Masuda (2014) notes that small green space ($1000m^2$ to $2000m^2$) are appropriate for emergency shelter immediately following an earthquake, and neighbourhood parks ($1000m^2$ to over 3ha) are suitable for temporary shelter of up to a week. Large-scale urban and suburban parks are best suited to accommodating temporary or transitional settlements during the recovery phase of a disaster (Masuda, 2014).

3.5. Site Elements:

3.5.1 Water

The presence of water is a critical attribute, both as a predictor of open space use after an earthquake (e.g. Villagra-Islas & Alves, 2016; Villagra-Islas & Dobbie, 2014) and as a requirement for the location of open space for seismic resilience (Government of Nepal & IOM, 2011; León & March, 2014; Turer Baskaya, 2015).

In Tokyo, DPPs are equipped with emergency water-supply tanks and manual water pumps that will function in the event of a power outage (Tokyo Metropolitan Government, n.d.). As Bryant and Allan (2013) observe, smaller machizukuri council (citizen-led neighbourhood planning groups) parks in Kôbe, Japan also incorporated wells, water supply tanks, pumps and water features in their design for use in the aftermath of an earthquake. The Golden Gate Park sustainable infrastructure concept proposed the construction of an observation tower that would serve as both a viewing platform and function to draw water from the park's aquifer, passively filtering and pressurizing the water for potable use (CMG Landscape Architecture, 2017).

The availability of water is also critical for fire suppression. In the aftermath of the Hanshin Earthquake of 1995, 80% of the wooden housing was destroyed by fire in the Matsumoto district of Kôbe (Ishikawa, 2002). Citizens reflecting on their experience during the earthquake, felt that, had there been more sources of water available to them, there would have been far less damage from fires (Ishikawa, 2002). In addition to adding new parks and re-enforcing existing green space, a key component of the reconstruction plan for the centre of the Matsumoto district was the creation of a stream incorporated into the city street (Ishikawa, 2002).

3.5.2 Sanitation

The Tokyo Metropolitan Government (n.d.) describes issues with sanitation as one of the most "distressing" (p. 121) during a disaster. DPPs in Tokyo are equipped with temporary toilets that directly connect to the sewer systems and do not require water or electricity to function. During a disaster, manhole covers can be fitted with toilet seats and privacy tents erected around each unit (Tokyo Metropolitan Government, n.d.).

Similar emergency sanitation systems were also mentioned in the context of The Yuan Dynasty City Wall Relics Park (China's first DPP) in Beijing (Li, 2014) and the machizukuri council park Rokko Kaze No Sate Koen in Kôbe (Bryant & Allan, 2013). The Golden Gate Park sustainable infrastructure concept envisioned a waste management system comprised of composting toilets, and constructed wetlands for the treatment of grey water (CMG Landscape Architecture, 2017).

3.5.3 Food

As Allan and Bryant (2011) describe after the 1906 earthquake in San Francisco, residents used campfires or assembled makeshift kitchens in the street to prepare food. In Tokyo and Kôbe, both large DPPs and machizukuri council parks have formalized this function, installing benches or seating that convert into wood burning stoves or cooking pits when the seat top is removed (Bryant & Allan, 2013; Tokyo Metropolitan Government, n.d.)

Further, Chan, DuBois, and Tidball (2015) discuss enhancing food security after disaster through the development of community gardens. In the design of Rokko Kaze No Sate Koen, Kôbe, the community selected species of trees with edible fruit in anticipation of needs following an earthquake. Larger scale DPPs in Japan also include supply storehouses containing, food, water and medical supplies (Flüchter, 2003). Masuda (2014) notes that even small-scale open space should have storage with basic supplies.

3.5.4 Power and Lighting

The loss of lifelines such as power are among the primary reasons for why people evacuate to shelter sites (Li, Zhao, Huang, & Hu, 2017). To help mitigate this issue, space allocated for solar power generation and solar-powered lighting is a standard feature of DPPs in Japan (Masuda, 2014; Tokyo Bureau of Construction, n.d.). If an earthquake strikes at night and power is disrupted, evacuation can be negatively impacted by lack of streetlights (León & March, 2014). León and March (2014) discuss three types of lighting that could play a role in guiding people to safety during an emergency: beacons (located in safe open space), solar-powered street lighting and backup ground illumination directing people towards open spaces.

3.5.5 Way-finding and Communication

Other design interventions to strengthen wayfinding were proposed by León & March (2014) including themed or colour-coded components of key streets (building facades, street furniture, signage, pavement, etc.) as visual cues to assist evacuees with route selection. In normal times, León and March (2014) suggest that these cues can help maintain awareness of the area's potential for disaster.

León and March (2014) also list communication as one of the main objectives of open space design for resilience. In Japan, DPPs contain radio broadcasting facilities that are tasked with communicating to the public and coordinating emergency response (Masuda, 2014).

Mazereeuw & Yarina (2017) discuss a research prototype that incorporates the elements of wayfinding, communication, power and lighting into modular units that can be installed in public open space and modified according to location and community needs. The Emergency Preparedness Hub (PREPHub) developed by the Urban Risk Lab at The Massachusetts Institute of Technology is intended to be a network of illuminated landmarks distributed throughout a city that guide residents during evacuations. During daily use the PREPHub is an interactive piece of street furniture (Mazereeuw & Yarina, 2017).

3.6.Social Resilience

3.6.1 Programming

Along with improving physical resilience, Chan, DuBois, and Tidball (2015) and Okvat and Zautra (2014) stress the importance of increasing the social resilience of a community before a disaster.

As the authors suggest, this will help ensure social networks can be relied upon to provide support during emergency response and recovery.

Parks are important social spaces that support the creation of personal connections and overall sociability (Campbell, Svendsen, Sonti & Johnson, 2016). Open space programming such as the provision of gathering spaces (e.g., seating areas and fire pits) encourage participation in social activities, which in turn helps people to "engage in coping strategies against chronic stressors in the urban environment" (Campbell et al., 2016, p. 41).

Okvat and Zautra (2014) also suggest creating an "extensive network of community gardens" (p. 73) as part of disaster preparedness planning. Engaging in positive activities, such as gardening in high-stress environments, can also create positive emotions and increase individual and community resilience (Okvat and Zautra, 2014).

3.6.2 Community Engagement

One of the primary goals outlined by the Tokyo Metropolitan Government for the development of a disaster-proof city is the inclusion of the community in any disaster prevention work, ensuring a sense of ownership and responsibility for its own safety (Matsuda, 1990). Masuda (2014) stresses that community participation is "essential" (p. 57) in the planning process; it equips residents with better knowledge of local disaster prevention plans and empowers local self-sufficiency.

Although top-down government-led construction projects are efficient after an earthquake in many respects, they often preclude community consultation and engagement with other stakeholders who have important local knowledge and expertise (e.g., Liu, Lin & Wang, 2014). Mazereeuw &

Yarina (2017) note that it is becoming more common for disaster management to incorporate existing frameworks, organizations and infrastructure in disaster mitigation plans. Identifying and fortifying these resources necessitates local level, community engagement (Mazereeuw & Yarina, 2017). Much like the Japanese machizukuri councils that facilitate communication between local residents and the government, design professions must also act as mediators who are responsible for finding the most appropriate design interventions that respond to the specific needs of local residents (Allan & Bryant, 2011).

3.6.3 Education

Understanding a space's functionality and ensuring that residents have the ability to independently use its features, both in daily life and during an emergency, are critical (Masuda, 2014). The education of the community through events and drills "further embed knowledge of the disaster functions of these parks" (Mazereeuw & Yarina, 2017, p. 66). As part of their design proposal for the Golden Gate Park sustainable infrastructure concept, CMG Landscape Architects suggested an annual overnight event called 'Camp the Park' to increase familiarity with the park infrastructure and boost general disaster preparedness (Public Architecture, 2013).

Villagra-Islas and Dobbie (2014) also address the potential to design open spaces that can alert users to various hazards in the landscape. Although these authors acknowledge that this area of research requires further study, they give the example of landscape elements that could "alert users to the instability of the land during an earthquake" (Villagra-Islas & Dobbie, 2014, p. 678).

4. **Discussion**

The results of the systematic review identified six key themes. These themes serve as a foundation for future development of more specific guidelines to direct planning and design of open space. The following discussion addresses each theme individually and reflects on their potential application.

4.1. Multifunctionality

The concept of multifunctionality perhaps best encapsulates the underlying aim of public open space design for seismic resilience. The challenge with implementing multifunctionality is finding a suitable alignment of function or places where functions can be embedded in design for daily use. The precedent set by the Golden Gate Park design concept is an effective illustration of the potential for multifunctionality and the alignment of both daily and emergency needs. While the concept was based on the Park's polo field, other open space typologies offer different opportunities to support disaster response and recovery.

For example, parking lots (excluding multi-story parking structures) provide a flat open space that could be suitable to support evacuees in the aftermath of a disaster. Parking stall measurements could dovetail with humanitarian guidelines on per-person space requirements for establishing emergency shelter. In addition, with the wider adoption of electric vehicles, some parking stalls now include charging stations with solar panel roofs that could provide both power and shelter during post-earthquake response and recovery (e.g., Envision Solar, 2017).

4.2. Networks

Results from this section overlap with emergency management and evacuation planning, and reflect established principles in urban planning and design. The American Planning Association encourages planning for redundancy when designing street networks to ensure multiple entrance and exits in the event that certain streets are blocked during a disaster (e.g., Schwab, 2014). Of the six themes discussed here, the design of networks has perhaps the most limited opportunities for modification. While it is conceptually important to understand relationships between scale, redundancy and connectivity, the feasibility of implementing changes are limited in well established urban forms.

4.3. Location and Suitability

The process of determining location and suitability is connected to land use planning. Mileti (1999) describes land use planning as being among the most useful tools for hazard mitigation. Determining the placement of open space for seismic resilience should align with local land use plans and area hazard maps. Anhorn and Khazai (2015), CMG Landscape Architecture (2017) and León & March (2016) also employed various forms of scenario planning to determine the location and type of appropriate intervention. While scenario planning can be useful, Bryant & Allan (2015) caution against its use in the context of general resilience, warning that it can place too much emphasis on a specific risk at the expense of considering the whole system.

The site conditions for suitability mentioned in the results were non-specific and referred to general characteristics such as density of vegetation, accessibility, slope and sight lines (León & March, 2014; Turer Baskaya, 2015). The site inventory and analysis phase of a project should also assess soil type and hydrology for susceptibility of the site to liquefaction during an earthquake. Further, it is important to consider potential hazards associated with vegetation. For instance, species that are highly flammable (e.g., Juniperus spp. and Taxus spp.) should be replaced with fire-resistant vegetation.

4.4. Size and Function

While shelter appears throughout the functions listed for disaster prevention parks in Japan (e.g., Masuda, 2014), it was unclear from the literature what form this shelter would take. Considering past earthquakes, it is likely that tents or temporary structures will be erected by emergency management agencies. However, this leaves a gap in the provision of shelter during the first 72 hours after a disaster. Returning to the concept of multifunctionality, many types of outdoor structures, such as pergolas, bandstands, gazebos or picnic shelters could be designed to function as an emergency shelter.

An additional consideration when planning shelter is seasonality. If an earthquake were to occur in winter, could these shelters be designed to provide some form of heating, or conversely cooling in the summer? In addition, attention should be paid to designing comfortable microclimates, considering elements such as wind, shade, orientation, and thermal properties of building materials (e.g., Brown, 2010; Middel, Häb, Brazel, Martin, & Guhathakurta, 2014).

Though Japanese disaster prevention parks include a range of sizes, there appears to be increasing focus on smaller-scale sites (Bryant & Allan, 2013; Dionísio et al., 2012; Ishikawa, 2002). As mentioned above, large adjustments to networks may prove economically and logistically challenging. However, infusing a city's urban form with more small open spaces could enhance the network without major modifications.

4.5. Site Elements

These small open spaces should also be designed to meet the basic needs of evacuees. While humanitarian standards such as The Sphere Project were mentioned in the context of calculating shelter size, these standards should also be consulted when planning other site elements. The Sphere Project provides guidance on four groups of minimum humanitarian standards for water, hygiene and sanitation; nutrition and food security; shelter and supplies; and health. Although the guidelines were intended for use by humanitarian organizations to guide appropriate response to disaster, they can also be applied to disaster preparedness activities (The Sphere Project, n.d.)

The provision of food poses a greater design challenge. Although community gardens and edible plant species were addressed, the likelihood of either sustaining a population of evacuees is minimal, especially if an earthquake were to occur in the winter. At best these features would supplement food supplies. As Flüchter (2003) previously mentioned, disaster prevention parks are required to have supply storehouses that contain food, yet it is unclear how these supplies are managed or accessed.

4.6. Social Resilience

4.6.1. Programming

While providing basic physical necessities is critical, investing in open space programming builds social capital, ultimately contributing to community resilience. Incorporating programming and features that encourage social interaction should be a priority of open space design for seismic resilience. Although community gardens may not be a reliable source of food in a disaster scenario, they are an important buffer from stressful life events and facilitate the creation of support networks (Campbell et al., 2016; Chan et al., 2015).

4.6.2 Community Engagement

Landscape architects who deal with projects in the public domain are well versed in this type of participation (Juarez & Brown, 2008). An additional benefit to smaller scale projects (as mentioned above) is the ability to work more closely with the community. However, it is important to consider that vulnerable groups who are likely to rely on open space after disaster may not necessarily be represented (Larsen, 2004). Efforts to include vulnerable populations in community-level planning for seismic resilience should be made a priority.

4.6.3 Education

Without a continued education component, the utility of the open space may be undermined. The results suggest a range of education activities that could take place within open space to increase familiarity with park features, from training and drills to events and information campaigns (e.g., León & March, 2014; Mazereeuw & Yarina, 2017). Although ongoing organization of many of these activities remain outside of the domain of landscape architecture, they can be addressed directly in design proposals, as demonstrated by CMG Landscape Architects 'Camp the Park' event (Public Architecture, 2013).

5. Conclusion

This work contributes to developing a foundation for landscape architecture and allied design disciplines to better incorporate seismic resilience into the planning and design of public open spaces. Research on interactions with the post-disaster environment offers insight into the needs, uses and perceptions of open space after an earthquake. The results from the 35 articles identified in the review provide a clearer picture of what open space for seismic resilience could look like. According to the results, public open space for seismic resilience is:

- Multifunctional with disaster function embedded in design for daily use;
- Connected by a redundant, accessible and legible multi-scale network; grouped to create nodes with critical infrastructure, facilities and other open spaces;
- Located in relation to risk exposure and population density;
- Composed of a range of site scales and functions;
- A place where basic human needs can be met; and,
- Programmed to create opportunities for social interaction and build social capital; designed with the community and local stakeholders; and, a place for continued education and training in disaster preparedness

If open space for seismic resilience is to function in both daily life and emergencies, it is important to address how these spaces will be used by different populations and regions with varying levels of development. Where there is a daily need for essentials such as food, water and shelter, it becomes difficult to justify only using this embedded infrastructure after an earthquake. Determining how and if current disaster prevention parks in countries like Japan and China are used by populations, such as the homeless, should be addressed in future research. In addition, there is a gap in the literature evaluating the performance and effectiveness of DPPs. Future research should focus on how these spaces functioned during events like the 2011 Tōhoku earthquake and tsunami in Japan.

By 2050 populations in major cities at risk of earthquakes is projected to double (World Bank & United Nations, 2010). As people continue to develop in areas that act as natural hazard buffers such as regions along fault lines, disaster risk increases (Shannon, 2015). There is growing urgency, therefore, to create or fortify existing open space to support response and recovery efforts. What residents find when they arrive in these spaces will depend on the integration and alignment of daily and emergency needs and a collective willingness to pro-actively mitigate hazards, rather than over-reliance on the post-disaster response.

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