Resilient Neighbourhood Design

Exploring the relationship between built form and performance

By **Mark Poskitt**
Greenest City Scholar
September 2019

Prepared for the
City Design Studio
City of Vancouver

Executive Summary

Over the coming decades, Vancouver will need to deal with a range of growing stressors, including the worsening effects of climate change, resource scarcity, ecological degradation, growing inequality, and one of the most unaffordable housing markets in the world. The concept of resilience provides a useful and holistic lens through which to view these issues that incorporates existing city strategies and goals. A Resilient City is by necessity also a Green City, a Healthy City, a Disaster-ready City, a Creative City, and a Diverse and Equitable City.

The Resilient Neighbourhood Design Tool (RNDT) is a holistic assessment framework in-developed by the City Design Studio to assess the resilience potential of neighbourhoods and communities in the design phase. This framework takes into account a diverse range of specific indicators, which cover themes pertinent to resilience such as housing, social connection, neighbourhood pattern, and climate change adaption.

The resilience indicators used in the RNDT will allow cities to better understand the relationship between built form and performance, and to measure performance, strengths, and weaknesses against specific goals and targets. This will in turn enable the development of effective strategies and actions for improvement, a balancing of multiple city objectives, a greater understanding of synergies and trade-offs, and inform more holistic and defensible decision-making.

The purpose of this document is twofold. Firstly, it aims to provide a research summary, contextualization, and academic body of support for the choice of key indicators and metrics used in the RNDT. Secondly, it aims to act as a standalone best-practice resource for those seeking to enhance the resilience of communities and the built environment through intentional urban design. Overall, it was found that there was considerable support within the literature for most indicators used in the RNDT.

This research was undertaken by a 2019 Greenest City Scholar, Mark Poskitt, in collaboration with the City Design Studio at the City of Vancouver.

Disclaimer

This report was produced as part of the Greenest City or Healthy City Scholars Program,
a partnership between the City of Vancouver and the University of British Columbia,
in support of the Greenest City Action Plan and the Healthy City Strategy.

This project was conducted under the mentorship of City staff.
The opinions and recommendations in this report, and any errors,
are those of the author, and do not necessarily reflect the views of the
City of Vancouver or The University of British Columbia.

The following are official partners and sponsors of the
Greenest City or Healthy City Scholars Program:

Holistic Assessment Frameworks: a brief overview

Globally, there is an increasing recognition of the need to develop tangible, comprehensives, and holistic assessment frameworks that enable cities and organizations to measure their performance in relation to specific goals. As the concept of resilience has grown over the previous decades, so too has the development of holistic resilience assessment frameworks which seek to provide a way to measure resilience. Typically, these tools rely on a set of measurable indicators which provide a benchmark for performance.

Holistic resilience assessment frameworks can be categorized as those which measure resilience in the post-occupancy stage, or those which measure resilience in the design phase prior to construction. The RNDT fits into the latter of these two categories. Although both groups of frameworks fundamentally attempt to measure the same thing (resilience), the types of indicators used in design-phase tools are by necessity typically metrics which assess the physical and measurable elements of the built environment, whilst the types of indicators used in post-occupancy tools can be more wide-ranging.

To illustrate this distinction, consider the example of social capital – a widely recognized component of community resilience. Whilst a post-occupancy assessment framework may use indicators such as ‘sense of community’ or ‘voluntarism rates’ amongst neighbourhood residents as gauges of social capital, a design-phase assessment framework may use indicators which assess how conducive the built environment is to facilitating social capital, such as ‘the percentage of residential gross floor area (GFA) in a development that has access to a communal amenity space’ where socializing can occur, or whether or not the parking configuration and massing of a building is likely to foster social interaction between neighbours.

Research scope

This research does not intent to provide an exhaustive exploration of all literature pertaining to each indicator used in the RNDT, but rather aims to provide a succinct summary of the most relevant literature in relation to a selection of key indicators. Given that a primary function of this document is to act as an accessible standalone best-practice resource guide, a balance has been sought in many parts between usability, simplicity, and depth of understanding. Where technical terms are used, a definition or explanation of these is typically provided. Some baseline knowledge of urban design and resilience may help with understanding and interpreting this document, but is non-essential.

Research process

The process for this research was in many respects dynamic and non-linear. In some instances this research was an iterative process, with research findings shaping the choice of indicators and metrics, which would then inform the direction of further research. However, the core component of this research involved analyzing and synthesizing existing literature surrounding each indicator, identifying performance thresholds for indicators where applicable, and investigating the relationships between the built environment and resilience that inform these.

Document Navigation

The following document has been broken into ten core chapters that correspond to broad resilience themes such as ‘housing’, ‘pattern’ and ‘connection’, under which different indicators have been grouped. A summary of the research relevant to each indicator can be found in the individual indicator sections within these chapters. Each indicator section will typically contain a series of relevant research sub-sections, alongside an individual reference list. An overall reference list has also been compiled at the end of this document.

Table of Contents

Chapter 1: HOUSING

Chapter 2: EMPLOYMENT

Chapter 3: PATTERN

Chapter 4: DESIGN

Chapter 5: Energy + GHG

Chapter 6: EARTHQUAKES

Chapter 7: CLIMATE CHANGE

Chapter 8: ECOLOGY

Chapter 9: HEALTHY ENVIRONMENTS

Chapter 10: CONNECTION

HOUSING

Affordable Housing

As the most unaffordable province in Canada in terms of both home ownership and rental prices (Statista, 2017) housing affordability is one of the most pressing external stressors currently facing cities in British Columbia such as Vancouver (City of Vancouver, 2019a). From 2016-2017 alone, private market rents across the city increased by 4.9% and benchmark condominium prices in East Vancouver increased by 19.5% (City of Vancouver, 2018a) with the 2017 rental vacancy rate dipping below 1%, indicating an extremely competitive rental market (City of Vancouver, 2018c). The average housing prices in Vancouver have more than doubled since 2009 (Rozworski, 2019), and have significantly outpaced increases in medium incomes during this same period (City of Vancouver, 2018c).

The causes of the current housing crisis in Vancouver (and Canada more generally) are numerous and varied (Grigoryeva & Ley, 2019). In part, the crisis is a consequence of the increasing urbanization that many global regions are experiencing which increases the demand for urban housing, paired with a constrained housing supply caused by exclusionary zoning (Rozworski, 2019; City of Vancouver, 2018c). Excessive speculation driven by an era of low finance interest rates and mortgage down-payment requirements during the late 20th century onwards (which was as low as 5% down-payment during the early 1990s) has also contributed significantly to the crisis (Rozworski, 2019). Alongside a relatively weak Canadian dollar over the previous decade, this cheap credit has attracted significant foreign investment into the Canadian real estate market which serves to exacerbate speculation and local real estate demand even further (City of Vancouver, 2018c). A federal policy shift in 1993 which ended all new federal funding for social housing projects further restricted a supply of affordable housing, and this lack of funding at a federal level was for the most part (and until very recently) not substituted by additional provincial support (Rozworski, 2019; Hulchanski, 2003).

The increasing unaffordability of Vancouver has serious implications for residents (City of Vancouver, 2018c). During the 2018 Vancouver point-in time homeless count conducted by BC Non-Profit Housing Association (BCNPHA) over a 24-hour period for instance, 2,181 people were counted as homeless, with 1,522 of these in shelters and 659 living on the street (BCNPHA & Urban Matters CCC, 2018). Although the causes of homelessness are multifaceted and complex, homelessness in Vancouver is undoubtedly exacerbated by the rising rental prices and low vacancy rates symptomatic of the city's housing affordability crisis (BCNPHA & Urban Matters CCC, 2018). There is also evidence to suggest that the increasing housing unaffordability in Vancouver is driving a loss of income diversity (City of Vancouver, 2018a). Between 2005 and 2016 the share of renter households earning less than $25,000 annually fell from 38% to 27%, whilst at the same time the share of renter households earning more than $100,000 annually increased from 7% to 19% (City of Vancouver, 2018a). Given that diversity is a core tenant of urban resilience (Suarez et al, 2016), this issue is a salient concern for Vancouver. For these reasons, the Resilient Vancouver Strategy identifies housing affordability as a crucial stressor that must be navigated if Vancouver is to embrace a resilience, livable, and equitable future (City of Vancouver, 2019a).

An adequate supply of affordable housing is able to enhance urban resilience by improving the economic and social livelihoods of residents and reducing the vulnerability of residents to external stressors (Vale et al, 2014). Housing / shelter affordability has been used as an indicator in other comparable holistic resilience models within the literature, such as the City Resilience Index developed by ARUP and The Rockfeller Foundation (2014), the WILUTE model of urban sustainability developed by Zhao et al (2013), the CityLab Action Guide (Sweden Green Building Council, 2018), and the IFRC (International Federation of Red Cross) Framework for Community Resilience (2014). Closely related resilience indicators such as 'microeconomic security and social protection' (for which affordable housing can be a proxy) are also adopted in urban resilience frameworks such as that developed by De Boer et al (2016).

Whilst federal and provincial levels of government have a significant role in addressing the underlying causes of the national housing crisis through higher-level policy (Hulchanski, 2003) and funding initiatives such as the recent National Housing Strategy (2017), municipal governments can play an important role in implementing federal and provincial policy to address housing affordability at a local level through land use regulation and zoning (Eberle et al, 2011) and building design. For these reasons, the Resilient Neighbourhood Design Tool (RNDT) uses an index of housing affordability as an indicator of resilience, which takes into account elements of the built environment relevant to housing affordability that can be influenced at a municipal planning and design level. These elements include tenure, density, building height, parcel size, parking provision, construction material and building efficiency. Each of these components is explored in further depth in the following subsections.

Tenure

The housing continuum diagram below (adapted from CMHC, 2018) provides a useful visual summary of common conventional shelter options based on their typical affordability relative to tenure type. As this schematic shows, government assisted housing (commonly referred to as 'social' housing) is generally the most affordable tenure type, and rental tenure arrangements are typically seen to be more affordable than home ownership (City of Vancouver, 2018c). This is largely a consequence of the significant (and growing) initial cost involved with buying a house in Vancouver, which for most is far less affordable than paying rent monthly. For a tangible example of this, a recent report on the Canadian real estate market compiled by rental.ca and Bullpen Consulting (2019) found the average rental price for a 2-bedroom apartment in Vancouver to be approximately $2,100 (as of July 2019), whilst the average selling price for a house in Vancouver during July-August 2019 was reported to be $1.1million (Zolo, 2019). To convert this sale price into a monthly cost comparison, if we assume that the house purchase requires a 20% down-payment ($220,000), this will require a loan value of $880,000 (80% of purchase price). Assuming a modest interest rate of around 3% which is fairly typical for a home mortgage in Canada currently (The Mortgage Group, 2019) and an amortization period of 25 years, this purchase will require an average monthly payment of $4,173. Using the 2019 City of Vancouver residential property tax rates (City of Vancouver, 2019b) of approximately $2.56 per $1000 taxable value, this will add an additional $2,817 of costs annually. Dividing this figure by 12 gives an additional $234.77 to monthly costs, taking the overall monthly costs to $4,408. Assuming property insurance costs of approximately $130 per month typical of British Columbia homes valued between $700,000-$1,500,000 (Statista, 2019), this will raise the overall monthly costs to roughly $4,538 (more than double that of the average renter). As a recent report by Coriolis Consulting on rental affordability in metro affordability states, "rental is inherently more

The above image depicts a continuum of housing options which cater to different affordability needs. Moving along the continuum is generally associated with increasing shelter costs, with market home ownership being the least affordable option for many Canadians. Image sourced from CMHC (2018).

affordable than ownership" (Coriolis Consulting Corp & Wollenberg Munro Consulting Inc., 2019, pg.2)

> *"rental is inherently more affordable than ownership"*

As everyone's housing needs are slightly different however, encouraging a diversity of different housing options and tenures suitable to a range of incomes is seen to be an important component of a healthy housing sector and an equitable community (City of Vancouver, 2018c). For this reason, holistic resilience and sustainability frameworks often advocate for a diversity of tenure types. Neighbourhoods seeking LEED certification for instance must have a diversity of housing types and tenures, which is calculated using Simpsons Diversity Index with an index diversity target of at least 0.5 and ideally greater than 0.7 (US Green Building Council, 2009). The sustainability framework developed by the Design Centre for Sustainability has also adopted these same threshold requirements (DCS, 2009). In a Vancouver context, common housing types associated with homeownership include condos, coach houses and townhouses; whilst for rental, laneway housing, purpose-built-market rental, and developer-owned-below-market rental are the most widespread (City of Vancouver, 2018c). Types of social housing include independent living social housing, supportive housing, and co-operative housing (City of Vancouver, 2018c).

Residential Density

The relationship between residential density and affordability is complex and confounded by a multitude of other interacting factors, making it difficult to identify any single reliable association between these phenomena (Cullen, 2005). Conventionally, increasing density has often been perceived to be positively associated with affordability (Dalton, 2017). At a parcel level, increased residential density potentially permits a greater supply of housing units within a given spatial area (Aurund, 2010), which can in turn positively influence the stock of affordable housing options. For instance, in a hypothetical development where all other factors (such as developer profit margins, soft costs, land price, and location) remain constant, increased residential density will allow a developer to increase the overall floor area and thereby sell or rent a greater number of units. This will, in theory, lower the end-user costs associated with each unit (or significantly lower the end user costs for a number of units within the development which are offset by the profits derived from the other units) (Sing, 2016). For this reason, density bonusing is commonly used as a municipal tool to encourage private developers to construct more affordable units (City of Vancouver, 2018b), and has been identified by organizations such as BC Housing as a "high benefit" practice for increasing affordable housing in urban and growing urban areas (BC Housing, 2017). Greater residential density also typically encourages smaller dwelling sizes (Chan et al, 2002), which can positively impact affordability (given that the sale price for a unit is typically calculated on a square foot basis (Atlas Group, 2018)).

The relationship between neighbourhood density and affordability has been highlighted in numerous studies (Litman, 2017; Aurund, 2010; Fingleton, 2008). Fingelton (2008) for example demonstrated that residential affordability in Cambridge (UK) increased as a function of increased density, whilst Aurund (2010) found that neighbourhoods with greater density are likely to have a higher quantity of affordable rental units than low-density neighbourhoods. One of the implications of density is that affordable transport options such as transit, walking, and cycling are more feasible, which can in turn significantly reduce household spending on transportation (Litman, 2017). Grammenos (2016) for example found a strong negative relationship between the compactness of an urban area (a proxy for residential density) and the percent of household budget used on transportation. This frees up a greater proportion of household income able to be spent on accommodation, thereby potentially making a broader range of housing options 'affordable' to residents relative to overall household spending. Density then may both directly and indirectly impact affordability.

An emerging opposing body of literature however, argues that density negatively impacts on housing affordability. Burton (2000) for example, argues that increased neighbourhood residential density leads to a scarcity of land within a given urban area, which contributes to higher housing costs. This in turn leads to a lack of affordable housing (Burton, 2000). Others contend that the urban 'revitalisation' which often accompanies urban densification efforts does not increase affordable housing options for those most in need, but rather benefits "financers, developers, investors, and builders, and the middle class elites" (Kern, 2007, pg.664). As densification efforts necessarily require new construction, the relationship between residential density and affordability intersects with the relationship between building age and affordability. That is to say, urban densification requires construction of new buildings, which have been demonstrated to be less affordable than older buildings (Preservation Green Lab, 2016; Jacobs, 1961). Ergo urban density may indirectly reduce affordability by increasing new construction. Others point out the ways in which densification can lead to gentrification and a displacement of poorer, more vulnerable working class residents (Quastel, 2009). This has led some authors to argue that the commonly accepted association between density and affordability is more dogma than rational discourse, and that the widespread acceptance amongst planners that density enhances affordability shows a clear disconnect between planning practice and theory (Dalton, 2017).

Based on this research, three relationships between housing affordability and residential density tenuously emerge. Firstly, increased residential density at the parcel level where all other factors are constant (land price, location, building age) may positively impact affordability. Secondly, urban residential densification at the neighbourhood level insofar as it is associated with new construction, increasing land prices, a competitive real estate market, and urban revitalization schemes may be seen to detrimentally impact affordability. Thirdly, residential density at the neighbourhood level may simultaneously have the potential to indirectly contribute positively to affordability by facilitating alternative forms of mobility like transit, cycling and walking which reduce household spending on transportation, thereby leaving a greater proportion of household budget to be allocated towards shelter.

Parcel Size

Smaller parcel size reduces the level of equity and financing required to carry out a development, making the development more accessible to a larger cohort of smaller, local developers (Rupasinga, 2013).This may increase competition between different developers and increase the supply of development projects, which in turn can have a positive effect on housing affordability (Kuryj-Wysocka & Wisniewski, 2013). At the very least, this competition and increased opportunity for local entrepreneurship in development projects will create a more "diversified economic structure that will protect the local economy from being overly independent on one firm or establishment" (Rupasinga, 2013). In other words, smaller parcel sizes may have benefits for the sustainability and resilience of a local economy (D.Barrios & S.Barios, 2004).

Conversely, the creation of large parcels through a process of land assembly (where several smaller parcels are combined to create a single big parcel) may have the potential to negatively impact affordability through increased development costs, and increased land value. To the first of these: land assembly is typically a time-intensive process, which increases developmental costs (including soft costs such as legal and permitting fees) and time to market (Franzie, 2014). If the project goes ahead, these increased development expenses will ultimately be passed on to the end used in order for the developer to make a desired return on profit (Brueggeman & Fisher, 2008), decreasing affordability for the end user.

Land assembly is also typically associated with an increase in land value, whereby the value of a large assembled lot is worth more than the sum of each of the individual parcels (Haider, 2018). For a recent example of this, three Vancouver Specials townhouses built in 1979 were each assessed at around $1.4million during 2017, but were collectively sold for more than $10million when assembled that same year (Cheung, 2018). Increased land values provide an incentive for developers and landlords to increase selling (or rental) prices for the end user in order to cover the increased developmental costs associated with land acquisition, and higher land values have been identified as a barrier for the construction of more affordable housing (Coriolis Consulting Corp & Wollenberg Munro Consulting Inc., 2019; City of Vancouver, 2018c).

Consequently, increased parcel size may have an overall tendency to negatively impact affordability by increasing the level of equity required for development, increasing development holding costs associated with land assembly, and by increasing overall land values.

Building Height

Vertical urban growth is often associated with increasing residential unaffordability, and the price of a residential unit typically increases with its height above ground (Graham, 2016). As example of this, a recent study of residential prices in London's (UK) towers found that for every increase in floor, the cost of a residential unit would increase by 1.5% per square foot (excluding penthouse) (Frank, 2012). A key driver behind this relationship is the increased construction costs involved with building tall. Between the 10th and 50th floors in tall tower developments in London, Frank (2012) estimates there is 43% uplift in construction costs per square foot, with "the largest incremental increase in construction costs occur[ing] in the 25-40 storey range" (pg.4). Soft costs such as those associated with design and architecture also increase incrementally with height, due to the added structural complexities of building tall (Frank, 2012). As these soft and hard costs will ultimately be absorbed by the end user, the additional development costs associated with tall buildings negatively impact housing affordability.

Another reason vertical growth is associated with decreased affordability relates to the land values, financing arrangements, and risk typical of such developments. Because tall-tower residential developments often provide an optimal use for a site, they tend to occur in urban areas with high land values (Frank, 2012). As with the increased hard and soft costs involved with building tall, these high land costs will ultimately be passed on to the end user, and also demand a significant initial capital investment from the developer which is typically only made possible by external financing (Brueggeman & Fisher, 2008). Such financing carries significant risk, as changes to finance interest rates can drastically increase costs for developers, which again will typically be passed on to the end used (Brueggeman & Fisher, 2008; Pareto Securities, n.d.).

From this research it is apparent that overall, increased building height is negatively associated with residential affordability.

Envelope Efficiency

Buildings with greater envelope efficiency will have an improved energy performance, which will correspond to more affordable ongoing energy costs over the long term (Pacheco, 2012). This can be attributed to lower unintended heat loss and gains, which reduces the

Compact buildings such as this property in Victoria, BC, tend to be mor
implications for affordability. Image by Melissa Morris via Spacelist.

need for energy intensive heating and cooling of a building. Generally, more compact building envelopes are the most efficient building form (Parasonis et al, 2012).

As well as having a greater ongoing energy efficiency, studies by Bostancioglu (2007) and Bathurst and Butler (1982) have demonstrated that building envelopes with a smaller external wall area/floor area ratios (i.e. more compact building envelopes) are more energy efficient to construct, which corresponds to a lower construction cost per square foot (Bostancioglu, 2010). A study by Bostancioglu (2010) for example found that a compact square-shaped building could be up to 6% cheaper to construct per square foot compared to less compact building shapes such as rectangle, star, or H-shaped buildings (as well as increased operational energy savings as great as 26.92%). These results make logical sense: if a building increases the amount of wall area needing to be constructed whilst the floor area remains constant, then it follows that additional construction materials will be required for the additional wall area (Stoy & Schalcher, 2007). These additional materials used increase construction costs, which negatively impacts affordability. More compact, efficient building envelopes then not only increase affordability by reducing operational costs over the long term, but also by being cheaper to construct (Bostancioglu, 2010).

e energy efficient to construct and operate, which can have positive

Parking Provision

A growing body of research indicates that parking provision is negatively associated with residential affordability (Litman, 2019; Portland Bureau of Planning and Sustainability, 2012; Jung, 2009). As an example of this, an analysis of San Francisco found that single-detached houses and condominiums which include off-street parking are more than 10% more costly than those that do not (Jia & Wachs, 1999). The Victoria Transport Policy Institute estimates that for typical affordable housing development, one parking space per unit will increase costs by 12.5%, whilst two parking spaces per unit can increase costs by up to 25% (Litman, 2019). These results are supported by studies elsewhere in North America. A recent study carried out by Portland's Bureau of Planning and Sustainability (2012) for instance found that providing basic surface parking in a low-end rental building increased rents by 50%, whilst the provision of underground parking could increase rents by roughly 62%.

In addition to directly reducing affordability through increased construction costs, offstreet parking in urban areas is often frequently underused, which can limit opportunities for residential development within a city and restrict the supply of affordable housing options (Clowers, 2017). A recent study on parking in Seattle for instance, found that 35% of residential parking spaces were chronically not in use (Clowers, 2017). In summary, there is a clear and growing recognition within the literature that parking provision negatively impacts residential affordability.

Construction type

In residential developments construction costs are typically passed on to renters and buyers (Brueggeman

& Fisher, 2008; CityLab, n.d.). This means that the type of materials used in construction and the relative cost of these can have a significant influence on the affordability of a residential project.

In Canada, the cost of concrete construction per square foot (SF) is more expensive than comparable wooden construction (Atlas Group, 2018) – typically by at least 12%. In Vancouver during 2018 for instance, a 6-storey concrete midrise apartment cost between $220-$290 per SF (square foot) to construct, whilst a comparable 6-storey wooden framed condo cost between $190-$250 per SF (roughly 16% difference) (Atlas Group. 2018). Similarly, a report conducted by Walker Consulting Group comparing concrete versus wooden construction in Ontario estimated that for both 4 and 6-storey building typologies, concrete construction would cost between 12%-15% more than light wooden framed construction (Walker, n.d.). Similar construction price differences are evident elsewhere in North America more broadly. For example, a recent study of construction costs in midrise (4-storey) residential buildings across the USA, Walter and Schneider (2017) found that a conventional midrise wooden building in Dallas would cost approximately $179 per SF to construct, whilst a comparably sized concrete building would cost $215 to construct (roughly 20% more). Given that construction costs are typically absorbed by the end user (Brueggeman & Fisher, 2008), wooden housing is likely to be more affordable than concrete housing for low-midrise building typologies. In part because of this, the BC Housing Design Guidelines recommend that for new buildings up to six storeys in height, wood frame construction should be the standard form of construction (BC Housing, 2019).

Although conventionally wooden construction has been restricted to low-midrise building typologies (less than 6-storeys in height), new mass timber technologies are allowing taller structures to be built from wood. The 18-storey hybrid mass timber Brock Commons Tallwood House at the University of British Columbia constructed in 2017 is a recent example of such technology (see Canadian Wood Council (2018) for an overview of this case study). However, at its current level of technology the association between increased affordability and wooden construction in low-midrise building typologies does not appear to unanimously translate to mass timber CLT (Cross Laminated Timber) construction (Cary Kopczynski & Company, 2018). A recent study on the feasibility of CLT structures conducted by Cary Kopczynski & Company (2018) for instance found that a hypothetical 10-storey residential structure would cost roughly between 16%-29% more in the construction phase than a cast in place reinforced concrete option, although the author of this study suggests that CLT technologies will likely become significantly more affordable to construct in the near future as familiarity with CLT amongst contractors increases and CLT materials become cheaper. In contrast to these findings, other recent studies have reported increased construction affordability for mass timber structures per SF by up to 28% relative to concrete and steel options (Mallo & Espinoza, 2016), whilst some report more modest price differences of around 4% in favor of CLT construction (Smith et al, 2015). Some cost analyses elsewhere estimate that the affordability of reinforced concrete and mass timber for mid-highrise construction (greater than 8-storeys) is likely to be similar (Seagate Structures Ltd, 2017; Alina, 2017). It is important to note too that the carbon footprint of CLT mass timber is considerably lower than concrete construction (Cary Kopczynski & Company, 2018), which has positive implications for urban resilience separate from affordability. Mass timber also typically

In Canada, the cost of concrete construction per square foot (SF) is more expensive than comparable wooden construction (Atlas Group, 2018) – typically by at least 12%.

has a shorter construction period than concrete buildings (generally by between 10-30% depending on the site (Smyth, 2018)), which can in some situations translate into increased affordability (Smyth, 2018) - especially in the case of high financing interest rates during the construction phase of a large development.

Based on this research the relationship between construction type and affordability appears to be intrinsically related to height. Light wood frame construction in lower building typologies (less than 6-storeys) is more affordable than comparably sized concrete construction. The affordability of mass timber CLT technologies and steel reinforced concrete in taller buildings however appears to be relatively comparable at this point in time, although it is possible that this may change in the near future.

Building Age

With increasing age, buildings tend to depreciate and degenerate, and become more affordable accordingly (Somerville & Holmes, 2001). As Salviati (2018) writes, “in a healthy housing market, buildings become less desirable as they age, leading to falling rents” and increasing affordability. This process is known as ‘filtering’ and means that buildings typically become more affordable with age, so long as the supply of new housing continues to meet demand (Gray, 2019). The importance of old buildings for maintaining residential affordability within a city is highlighted in old and new research alike (Preservation Green Lab, 2016; Jacobs, 1961).

It is important to note here that the value of a building is independent to the value of land, and the potential affordability improvements gained with building age may in some case be offset by increases in land value which detrimentally impact affordability. This is particularly true of the urban cores in which many older buildings are located, which, as a consequent of urban renewal and densification have experienced significant increases in land prices over the previous decades (Bieda, 2017; Kovacs, 2013). However, independent of confounding factors such as land prices there appears to be a general consensus within the literature that increased building age corresponds to increased affordability.

Synergies + Trade-offs:

Transit Stations

Although much of the focus on residential affordability is centred on the cost of housing, it is important to note that housing affordability is influenced by a range of other factors. One particularly salient factor is household income spend on transportation, which is in turn influenced by mobility choices and accessibility to public transit. In a national survey of household spending during 2017, Statistics Canada identified the largest portions of household budget go to shelter and transportation, with 29.2% and 19.9% of household spending being attributed to these two areas respectively (Statistics Canada, 2018). Most of this spending on transportation can be attributed to private transportation costs, such as the purchase of cars and the operating costs involved with these. For instance, the average Canadian household paid $12,707 for transportation in 2017, and of this an average of $11,433 was spent on private transportation (Statistics Canada, 2018).

> *The average Canadian household paid $12,707 for transportation in 2017, and of this an average of $11,433 was spent on private transportation.*

Such numbers highlight the importance of the availability and accessibility of public transportation in reducing household spending. Accessibility to rapid transit for example has the potential to significantly lower household spending on transport (Renne et al, 2016). This frees up a greater proportion of household budget able to be spent on accommodation, thereby making a broader range of housing options 'affordable' to residents relative to overall household spending. This relationship between transit accessibility and affordable housing is also bidirectional however. For example, low-income households that need highly affordable housing options are less likely to own cars and more likely to use transit which can improve transit ridership (Tumlin & Millard-Ball, 2003).

It should be acknowledged that although accessibility to transit has the potential to improve social equity and urban resilience, the development that typically accompanies accessible transit has the potential to increase land prices, which may negatively impact residential affordability (Pendall et al, 2012). This is especially true if the demand for housing in areas immediately proximate to transit exceeds the supply of housing options (Renne et al, 2016). In Burnaby (British Columbia) for example, Jones and Ley (2016) found that the development next to transit stations led to a loss of affordable housing. However, the increased cost of housing close to transit is more than often offset by the significantly lower spending on transportation that accompanies this type of development, which means that the total housing and transportation costs for residents near transit is still less than for households far away from transit. A study by Renne et al (2016) for instance found that the combined housing and transportation costs within a Transit Orientated Development area were 4% lower than in adjacent developments.

References

Alina. (2017). Residential Timber Cost Model. Building Magazine. Retrieved from http://www.alineacostconsulting.com/wp-content/uploads/2017/06/20170609_alinea-for-building_Residential-Timber-CM.pdf

ARUP and The Rockfeller Foundation. (2014). City Resilience Index; understanding and measuring city resilience.

Atlas Group (2018). 2018 Canadian Cost Guide. Retrieved from http://creston.ca/DocumentCenter/View/1957/Altus-2018-Construction-Cost-Guide-web-1w

Barrios, S., & Barrios, D. (2004). Reconsidering economic development: The prospects for economic gardening. Public Administration Quarterly, 70-101.

Bathurst, P. E., & Butler, D. A. (1973). Building cost control techniques and economics. Heinemann Educational Books.

BC Housing. (2019). Design Guidelines and Construction Standards. Retrieved from https://www.bchousing.org/.../BCH-Design-Guidelines-Construction-Standards.pdf

BC Housing. (2017, October). A Scan of Leading Practices in Affordable Housing. Retrieved from https://www.bchousing.org/research-centre/library/housing-affordability/scan-leading-practices-affordable-housing&sortType=sortByDate

BCNPHA & Urban Matters CCC. (2018, July). Vancouver Homeless Count 2018. Retrieved from https://vancouver.ca/files/cov/vancouver-homeless-count-2018-final-report.pdf

Bieda, A. (2017). Urban renewal and the value of real properties. In Studia Regionalne I Lokalne.

Bostancıoğlu, E. (2007). Factors Affecting Residential Buildings Cost in Pre Design Phase.

Bostancioğlu, E. (2010). Effect of building shape on a residential building's construction, energy and life cycle costs. Architectural Science Review, 53(4), 441-467

Brueggeman, W.B., & Fisher, J.D. (2008). Real estate and finance investment (14th ed.). Boston: McGraw-Hill Irwin.

Canadian Federal Government. (2017). Canada's National Housing Strategy: A Place to Call Home. Retrieved from https://www.placetocallhome.ca/-/media/sf/project/placetocallhome/pdfs/canada-national-housing-strategy.pdf

Canadian Wood Council. (2018). Brock Commons Tallwood House, University of British Columbia Vancouver Campus. The advent of tall wood structures in Canada, A Case Study. Retrieved from http://cwc.ca/wp-content/uploads/2018/07/CS-BrockCommon.Study_.23.lr_.pdf

Chan, E. H., Tang, B. S., & Wong, W. S. (2002). Density control and the quality of living space: a case study of private housing development in Hong Kong. Habitat international, 26(2), 159-175.

Cheung, C. (2018, February 21). Meet the realtor transforming Vancouver one block at a time. Vancouver Courier. Retrieved from https://www.vancourier.com/real-estate/meet-the-realtor-transforming-vancouver-one-block-at-a-time-1.23180020

City of Vancouver. (2018a). Housing Vancouver Strategy Annual Progress Report and Data Book 2018. Retrieved from https://vancouver.ca/files/cov/2018-housing-vancouver-annual-progress-report-and-data-book.pdf

City of Vancouver. (2018b, September). Density Bous Zoning & Public Benefits. Retrieved from https://vancouver.ca/files/cov/density-bonus-zoning-bulletin.pdf

City of Vancouver. (2018c). Housing Vancouver Strategy. Retrieved from https://council.vancouver.ca/20171128/documents/rr1appendixa.pdf

City of Vancouver. (2019a). Resilient Vancouver Strategy. Retrieved from https://vancouver.ca/files/cov/resilient-vancouver-strategy.pdf

City of Vancouver. (2019b). Residential property tax rates. Retrieved from https://vancouver.ca/home-property-development/residential.aspx

CityLab. (n.d.). Is Inefficient Construction Worsening the Affordable Housing Crisis? Retrieved from https://www.citylab.com/sponsored/Katerra/is-inefficient-construction-worsening-the-affordable-housing-crisis/134/

Clowers, G. (2017). Director's Report and Recommendation Neighbourhood Parking September 2017. Retrieved from http://www.seattle.gov/dpd/cs/groups/pan/@pan/documents/web_informational/p3494121.pdf

CMHC. (2018). About Affordable Housing in Canada. Retrieved from https://www.cmhc-schl.gc.ca/en/developing-and-renovating/develop-new-affordable-housing/programs-and-information/about-affordable-housing-in-canada

Coriolis Consulting Corp. & Wollenberg Munro Consulting Inc. (2019). Reducing the Barrier of High Land Cost: Strategies for Facilitating More Affordable Rental Housing Construction in Vancouver, Phase 2 of The Transit-Oriented Affordable Housing Study. Retrieved from http://www.metrovancouver.org/services/regional-planning/PlanningPublications/ReducingBarrierHighLandCost.pdf

Cullen, A. J. (2005). Urban intensification and affordable housing in Auckland (Doctoral dissertation, Centre for Housing Research Aotearoa New Zealand).

Dalton, M. (2017). Density and Housing Affordability. Retrieved from http://theoryandpractice.planning.dal.ca/_pdf/multiple_plans/mdalton_2017.pdf

De Boer, J., Muggah, R., Patel, R. (2016). Conceptualizing City Fragility and Resilience. United Nations University Centre for Policy Research Working Paper 5. Retrieved from https://ocw.tudelft.nl/wp-content/uploads/2Conceptualising-city-fragility-and-resilience.pdf

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Eberle, M., Woodward, J., Thomson, M., & Kraus, D. (2011). Municipal measures for housing affordability and diversity in Metro Vancouver. Retrieved from http://www.housing.gov.bc.ca/pub/CMHC_

Reference

MunicipalMeasures.pdf

Fingleton, B. (2008). Housing supply, housing demand, and affordability. Urban Studies, 45(8), 1545-1563.

Franzie, C. (2014, April 4). Land Assembly: A Brief Overview. Retrieved from https://www.camoinassociates.com/landassembly

Frank, K. (2012). Tall Towers 2012: London's high-rise residential developments. Retrieved from https://content.knightfrank.com/research/478/documents/en/2012-1101.pdf

Graham, S. (2016). Vertical: The City from Satellite to Bunkers. Verso: London.

Gray, N. (2019, June). How Luxury Units Turn Into Affordable Housing. Retrieved from https://www.citylab.com/perspective/2019/06/housing-supply-debate-affordable-home-prices-rent-yimby/591061/

Grigoryeva, I., & Ley, D. (2019). The price ripple effect in the Vancouver housing market. Urban Geography, 1-23.

Haider, M. (2018, August 2). For Neighbours, the dividends of selling homes together as part of a larger plot can be huge. Financial Post. Retrieved from https://business.financialpost.com/real-estate/haider-moranis-bulletin-in-land-assembly-two-plus-two-can-equal-more-than-four

Hulchanski, J. D. (2003). What factors shape Canadian housing policy? The intergovernmental role in Canada's housing system. Municipal-federal-provincial relations in Canada, 221-250.

IFRC. (2014). IFRC Framework for community resilience. International Federation or Red Cross and Red Crescent Societies, Geneva, Switzerland.

Jia, W., & Wachs, M. (1999). Parking requirements and housing affordability: Case study of San Francisco. Transportation Research Record, 1685(1), 156-160.

Jones, C. E., & Ley, D. (2016). Transit-oriented development and gentrification along Metro Vancouver's low-income SkyTrain corridor. The Canadian Geographer/Le Géographe Canadien, 60(1), 9-22.

Jung, O. (2009). Who is really paying for your parking space? Estimating the marginal implicit value of off-street parking spaces for condominiums in central Edmonton, Canada. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.192.202&rep=rep1&type=pdf

Kern, L. (2007). Reshaping the boundaries of public and private life: Gender, condominium development, and the neoliberalization of urban living. Urban Geography, 28(7), 657-681.

Kovács, Z., Wiessner, R., & Zischner, R. (2013). Urban renewal in the inner city of Budapest: Gentrification from a post-socialist perspective. Urban Studies, 50(1), 22-38.

Kuryj-Wysocka, O., & Wiśniewski, R. (2013). The problem of competition on real estate market on the example of the local housing market in Olsztyn. Real Estate Management and Valuation, 21(1), 69-76.

Litman, T. (2017). Evaluating Transportation Diversity. Victoria Transport Policy Institute.

Litman, T. (2019). Parking Requirements Impacts on Housing Affordability. Retrieved from http://vtpi.org/park-hou.pdf

Mallo, M. F. L., & Espinoza, O. (2016, January). Cross-laminated timber vs. concrete/steel: cost comparison using a case study. In WCTE 2016–World Conference on Timber Engineering.

Pacheco, R., Ordóñez, J., & Martínez, G. (2012). Energy efficient design of building: A review. Renewable and Sustainable Energy Reviews, 16(6), 3559-3573.

Pareto Securities. (n.d.). Project Finance. Retrieved from http://www.paretosec.com/download/compliance/Risk%20Pareto%20Securities%20Project%20Finance.pdf

Portland Bureau of Planning and Sustainability. (2012). Cost of Onsite Parking and Impacts on Affordability.

Preservation Green Lab. (2016, November). The Atlas of ReUrbanism, Buildings and blocks in American cities. Retrieved from https://forum.savingplaces.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=4219579b-fd10-8cea-1fd1-c8763bb07d81&forceDialog=0

Quastel, N. (2009). Political ecologies of gentrification. Urban Geography, 30(7), 694-725.

Rentals.ca & Bullpen Consulting (2019, July). July 2019 Rent Report. Retrieved from https://rentals.ca/national-rent-report#municipal-rental-rates

Rozworski, M. (2019, June 14). The roots of our housing crisis: Austerity, debt and extreme speculation. Retrieved from https://www.policynote.ca/the-roots-of-our-housing-crisis-austerity-debt-and-extreme-speculation/

Rupasingha, A. (2013). Locally owned: Do local business ownership and size matter for local economic well-being? (No. 2013-01). Federal Reserve Bank of Atlanta.

Salviati, C. (2018, September). What Can Old Housing Tell Us About the Future of Affordability? Rentonomics. Retrieved from https://www.apartmentlist.com/rentonomics/older-buildings-losing-affordability/

Seagate Structures Ltd. (2017). Mass timber vs. concrete comparison chart. Retrieved from https://seagatestructures.com/wp-content/uploads/2017/10/Seagate-Structures-Mass-Timber-vs-Concrete-Comparison-Chart-TaskChecklist-28129.pdf?ct=t(Come_Join_Us5_9_2017)

Sing, N.S. (2016). Effectiveness of Density Bonusing in Securing Affordable Housing: A study of Toronto Downtown and waterfront area. Retrieved from https://ecologicaldesignlab.ca/site/uploads/2018/02/Shakya-Singh-Nisha-1.pdf

Somerville, C. T., & Holmes, C. (2001). Dynamics of the affordable housing stock: Microdata analysis of filtering. Journal of Housing Research, 12(1), 115-140.

Smith, R., Griffin, G. and Rice, T. (2015). Solid Timber Construction

Reference

Process Practice Performance. OffSite Studies. Retrieved from: https://cdn.ymaws.com/www.nibs.org/resource/resmgr/OSCC/OffSite_Studies_STC.pdf

Statistics Canada. (2018). Survey of Household Spending, 2017. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/181212/dq181212a-eng.htm

Statista. (2019). Monthly average insurance cost of owned home in British Columbia 2016 value. Retrieved from https://www.statista.com/statistics/580597/owned-home-insurance-cost-bc-by-home-value/

Stoy, C., & Schalcher, H. R. (2007). Residential building projects: Building cost indicators and drivers. Journal of construction engineering and management, 133(2), 139-145.

Suárez, M., Gómez-Baggethun, E., Benayas, J., & Tilbury, D. (2016). Towards an urban resilience Index: a case study in 50 Spanish cities. Sustainability, 8(8), 774.

Sweden Green Building Council. (2018). CityLab Action Guide – Version 2.0. Retrieved from http://www.decodeprojektet.se/media/1167/eng-citylabactionguide-180516-webb_com.pdf

The Mortgage Group. (2019, May 8). Compare Canadian Mortgage Rates. Retrieved from https://www.superbrokers.ca/tools/mortgage-rates-comparison/

US Green Building Council. (2009). LEED 2009 for Neighbourhood Development.

Walker, J. (n.d.). Wood solutions in mid-rise construction. Retrieved from http://wood-works.ca/wp-content/uploads/Wood-Solutions-in-Mid-Rise-Construction-Walker-Condensed-Report-FINAL.pdf

Zhao, P., Chapman, R., Randal, E., & Howden-Chapman, P. (2013). Understanding resilient urban futures: a systemic modelling approach. Sustainability, 5(7), 3202-3223.

Zolo. (2019, August). Vancouver Real Estate Trends, Housing Market Report for August 2019. Retrieved from https://www.zolo.ca/vancouver-real-estate/trends

EMPLOYMENT

Jobs Density

Job density refers to the concentration of jobs within a given spatial area. As it is only possible to assess the actual number of jobs in a given area in the post-occupancy stage of development, measuring job density during the design phase will involve estimating the likely number of jobs a development will support. Given that the provision of commercial space has been demonstrated to generate new jobs (Patton, 1988), a useful way to carry out this estimation is by measuring the amount of commercial space in an area (commercial GFA) and the space utilization per job (how much space is required per job) as a proxy for the likely number of jobs this space will create (Minneapolis-Saint Paul Metropolitan Council, 2016). The space utilization per job will vary depending on the type of job, although the median space per worker by industry during 2012 in the U.S. described by Miller (2012) provides a rough benchmark for calculating job density. According to Miller (2012), call centres had the least space per worker (approximately 125 square feet), followed by those working in real estate (210 sf), communications (260 sf), accounting (260 sf), IT (265 sf), architecture (275 sf), insurance (280 sf), finance (300 sf), government (310 sf), and law (410sf). Despite the increasing trend towards smaller spaces per worker across North America (Miller, 2012), organizations such as the U.S. Information Administration (EIA, 2016) recommend providing a substantially higher amount of space per worker. For example, the EIA (2016) suggests providing 1,033 sf per employee for those in the education and food sales industry, around 550 sf for those in the medical profession, between 900-1,400 sf / worker for those in retail, and 1,200 for those in the service industry. Taking a very rough average of the figures provided by Miller (2012) however (assuming an equal split between sectors) gives a space utilization of around 270 sf per worker. Calculating the likely number of jobs that could be supported by a hypothetical neighbourhood development with around 20,000 sf commercial floor space then would involve dividing the total commercial floor space (20,000 sf) by the average space utilization per worker (270 sf) to give a total of 74 jobs.

The availability of decently paid jobs within a community has been linked to urban resilience within the literature, and the creation of jobs and employment opportunities is perceived to be positively associated with economic vitality and resilience (Burton, 2015; Drobniak, 2012). Economic clustering (i.e. the spatial concentrations of interconnected companies and economic activities) has been demonstrated to contribute to the resilience of an economy (Treado & Giarratani, 2008), and job density specifically has been used as a criterion for assessing urban resilience in some holistic resilience assessments (Sharifi & Yamagata, 2016). Closely related indicators which attempt to quantify the amount of employment within a given community, such as 'percentage of population employed', have also been used in holistic resilience models (e.g. Cutter et al, 2010). Retail employee density (measured as the number of retail workers within one mile of residence) has been used as an indicator for neighbourhood accessibility, with increased retail employee density being associated with increased neighbourhood accessibility and walkability for pedestrians (Krizek, 2003). More pertinent to a design context, commercial FAR (Floor Area Ratio), a proxy for commercial job space density, has been linked to increased walkability and improved sense of community, suggesting that "providing retail in communities can promote social capital and have mental health benefits" (Wood et al, 2010, pg.1388). The association between commercial job space density and walkability is generally well-accepted within the literature, with leaders in the field of walkability such as Dr. Lawrence Frank using retail FAR as a key metric for determining the walkability of a neighbourhood (Frank et al, 2010; Sallis et al, 2009; Frank et al, 2006).

For these reasons, the RNDT has included 'job density' (measured as the amount of commercial FSR (Floor Space Ratio) – the same metric as commercial FAR) as an indicator of resilience.

> ***"providing retail in communities can promote social capital and have mental health benefits"***

References

Burton, C. G. (2015). A validation of metrics for community resilience to natural hazards and disasters using the recovery from Hurricane Katrina as a case study. Annals of the Association of American Geographers, 105(1), 67-86.

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1).

Drobniak, A. (2012). The urban resilience–economic perspective. Journal of Economics and Management, 10, 5-20.

U.S. Energy Information Administration (EIA). (2016). Commercial Buildings Energy Consumption Survey (CBECS). Retrieved from https://www.eia.gov/consumption/commercial/data/2012/bc/cfm/b2.php

Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., & Bachman, W. (2006). Many pathways from land use to health: associations between neighborhood walkability and active transportation, body mass index, and air quality. Journal of the American planning Association, 72(1), 75-87.

Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). The development of a walkability index: application to the Neighborhood Quality of Life Study. British journal of sports medicine, 44(13), 924-933.

Krizek, K. J. (2003). Operationalizing neighborhood accessibility for land use-travel behavior research and regional modeling. Journal of Planning Education and Research, 22(3), 270-287.

Miller, N. (2012). Estimating office space per worker. Burnham-Moores Center for Real Estate University of San Diego.

Minneapolis-Saint Paul Metropolitan Council. (2016). Measuring Employment, How to Measure Employment Intensity and Capacity. In Local Planning Handbook. Retrieved from https://metrocouncil.org/Handbook/Files/Resources/Fact-Sheet/ECONOMIC-COMPETITIVENESS/How-to-Measure-Employment-Intensity-and-Capacity.aspx

Patton, C. V. (1988). Jobs and Commercial Office Development: Do New Offices Generate New Jobs?. Economic Development Quarterly, 2(4), 316-325.

Sallis, J. F., Saelens, B. E., Frank, L. D., Conway, T. L., Slymen, D. J., Cain, K. L., ... & Kerr, J. (2009). Neighborhood built environment and income: examining multiple health outcomes. Social science & medicine, 68(7), 1285-1293.

Sharifi, A., & Yamagata, Y. (2016). Urban Resilience Assessment: Multiple Dimensions, Criteria, and Indicators. In Urban Resilience (pp. 259-276). Springer, Cham.

Treado, C. D., & Giarratani, F. (2008). Intermediate steel-industry suppliers in the Pittsburgh region: a cluster-based analysis of regional economic resilience. Economic Development Quarterly, 22(1), 63-75.

Wood, L., Frank, L. D., & Giles-Corti, B. (2010). Sense of community and its relationship with walking and neighborhood design. Social science & medicine, 70(9), 1381-1390.

Jobs Diversity

A diversity of employment options has been demonstrated to improve economic resilience against stressors such as economic downturn and recessions (Brown & Greenbaum, 2017), which positively impacts overall urban resilience. As Garmestani et al (2006) write, "It has generally been accepted that greater business diversity is a desirable condition for a community, because it is unlikely that different types of businesses will have the same seasonal and cyclic fluctuations" (p.537). That is, different sectors and industries will respond to external stressors differently, and a diversity of jobs reduces the vulnerability of an economy to a single type of shock (Garmestani et al, 2006). This can have positive implications for urban resilience in the face of significant external stressors, such as natural disasters (Xiao & Drucker, 2013; Norris et al, 2008). A study by Xiao and Drucker (2013) for example found that economic diversity aided countries in recovering from natural disasters, and expedited their return to pre-disaster economic performance. These results are supported by the work of Norris et al (2008), who confirms that "efforts to create economic diversity increase the probability that the community can withstand adversity or surprise" (p.143). For these reasons, a diversity of employment options is frequently used as an indicator in holistic resilience assessment frameworks. In the Disaster Resilience Index developed by Cutter et al (2010) for example, 'single sector employment dependence' (defined as the percent of population not employed in farming, fishing, forestry, and extractive industries) is used as a resilience indicator (where a higher percentage of population not reliant on a single primary industry is seen as beneficial to resilience) alongside 'business size' (defined as the ratio of large to small businesses where an equal balance of small and large businesses is seen as conducive to resilience), whilst 'diverse livelihood and employment' is used as an indicator in the City Resilience Index developed by ARUP and the Rockfeller Foundation (2014).

At a neighbourhood scale, a diversity of physical spaces and mixed use areas can facilitate economic diversity by providing opportunities for different kinds of activities to take place (Grant, 2007; Jacobs, 1961). In Life and Death of Great American Cities, Jacobs (1961) argues that compact neighbourhoods with small blocks and a "close-grained" mix of spaces and building types increases economic activity, vitality, and diversity, which can enhance resiliency against economic downturn (Jacobs, 1961). Similarly, others such as Montgomery (1998) have argued that a "variety of building types, styles and design" alongside the "availability of differing unit sizes of property at varying degrees of cost" can contribute to economic diversity at a neighbourhood level (pg.99). Generally, more dense urban settlements and neighbourhoods are considered to be better able to support economic diversity by creating sufficient demand for a wide range of economic activities (Montgomery, 1998). These neighbourhood design characteristics (density, land use diversity, and a range of mixed-use spaces) which contribute to job diversity have also been shown to reduce car dependency and encourage walking (Talen & Koschinsky, 2014). Such outcomes can improve street level air quality and reduce transport-related mortalities and emissions (Woodcock et al, 2007), as well as facilitating opportunities for increased social interaction and social connectedness - something which has been demonstrated to strengthen communities and enhance resiliency in the face of disaster (Chandra et al, 2011).

Because of the numerous direct and indirect ways employment diversity can contribute to urban resilience, the RNDT has adopted 'jobs diversity' as a resilience indicator, which uses Simpsons Diversity Index to calculate the diversity of job spaces created in the design phase.

> *"It has generally been accepted that greater business diversity is a desirable condition for a community, because it is unlikely that different types of businesses will have the same seasonal and cyclic fluctuations"*

References

ARUP and The Rockfeller Foundation. (2014). City Resilience Index; understanding and measuring city resilience.

Brown, L., & Greenbaum, R. T. (2017). The role of industrial diversity in economic resilience: An empirical examination across 35 years. Urban Studies, 54(6), 1347-1366.

Chandra, A., Acosta, J., Howard, S., Uscher-Pines, L., Williams, M., Yeung, D., ... & Meredith, L. S. (2011). Building community resilience to disasters: A way forward to enhance national health security. Rand health quarterly, 1(1).

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1).

Garmestani, A. S., Allen, C. R., Mittelstaedt, J. D., Stow, C. A., & Ward, W. A. (2006). Firm size diversity, functional richness, and resilience. Environment and Development Economics, 11(4), 533-551.

Grant, J. (2007). Encouraging mixed use in practice. Incentives, regulations and plans: The role of states and nation-states in smart growth planning, 1(10), 57-76.

Montgomery, J. (1998). Making a city: Urbanity, vitality and urban design. Journal of urban design, 3(1), 93-116.

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. American journal of community psychology, 41(1-2), 127-150.

Talen, E., & Koschinsky, J. (2014). Compact, walkable, diverse neighborhoods: Assessing effects on residents. Housing Policy Debate, 24(4), 717-750.

Woodcock, J., Banister, D., Edwards, P., Prentice, A. M., & Roberts, I. (2007). Energy and transport. The Lancet, 370(9592), 1078-1088.

Xiao, Y., & Drucker, J. (2013). Does economic diversity enhance regional disaster resilience?. Journal of the American Planning Association, 79(2), 148-160.

Scale of Development

Smaller scale developments and parcel sizes will likely lead to a greater variety of mixed land uses and job spaces, as well as a more diversified economic structure by encouraging local entrepreneurship (Rupasingha, 2013). A diversified economic structure contributes directly to urban resilience, by reducing the extent to which the entire economy will be significantly impacted by any one stressor (Norris et al, 2008). As Rupasingha (2013) writes, "the development of local entrepreneurship can lead to a diversified economic structure that will protect the local economy from being overly dependent on one firm or establishment, or one industry" (pg.4). In other words, local entrepreneurship and smaller scale developments reduce the opportunity for the entire fate of an urban economy to be tied solely to one industry or organization, and enhances the capacity of the economy to respond positively to external stress.

More succinctly, smaller scale development and the diverse economic structure this encourages creates more redundancy, which has positive implications for the long term sustainability and resilience of a local economy (D.Barrios & S.Barrios, 2004). Because of this relationship between the scale of development, local entrepreneurship and urban resilience, the City Resilience Index developed by ARUP and The Rockfeller Foundation (2014) uses an indicator on 'local business development and innovation' as a measure of resilience. A key way smaller scale developments encourage local entrepreneurship is by lowering the level of equity and financing required to carry out a development. This makes potential development opportunities more accessible to local developers who may not have the equity and capacity of large international development firms, yet who may be more cognizant of local context and sensitivity relating to development projects (Rupasinga, 2013).

Because of its relevance to urban resilience, the RNDT has adopted 'scale of development' as an indicator, where a smaller parcel size is indicative of a greater potential to encourage local entrepreneurship and contribute to a resilient local economy.

References

ARUP and The Rockfeller Foundation. (2014). City Resilience Index; understanding and measuring city resilience.

Barrios, S., & Barrios, D. (2004). Reconsidering economic development: The prospects for economic gardening. Public Administration Quarterly, 70-101.

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. American journal of community psychology, 41(1-2), 127-150.

Rupasingha, A. (2013). Locally owned: Do local business ownership and size matter for local economic well-being? (No. 2013-01). Federal Reserve Bank of Atlanta.

> *“The development of local entrepreneurship can lead to a diversified economic structure that will protect the local economy from being overly dependent on one firm or establishment, or one industry.”*

PATTERN

Residential Density

Residential density refers to the ratio of population to a given residential land area (Cheng, 2009). Residential density may positively contribute to urban resilience in a number of ways, including for instance, by creating a more compact urban form which discourages automobile usage, and encourages more sustainable and environmentally friendly forms of mobility such as walking, cycling, and transit use (Newman et al, 2009). The relationship between residential density and car usage has been thoroughly explored within the literature, with higher densities corresponding to reduced automobile usage (Talen & Koschinsky, 2014). This relationship is also multidirectional, meaning that decreased urban density typically encourages car usage (Frank et al, 2006). As Newman and Kenworthy (2006) describe, in areas with residential density below 86 residents per acre (roughly 35 persons per hectare) "the physical constraints of distance and time enforce car use as the norm" (pg.35). In a different study of cities across the American Midwest, Stone Jr et al (2007) found that a 10% increase in population density was associated with a 3.5% reduction in household vehicle travel and emissions.

Density thresholds have also been identified within the literature for the use of other forms of mobility. For example, the literature review conducted by Holtzclaw (1994) on transit use and residential density suggests that a density thresholds of roughly 35 people p/ha for light rail, and 50 p/ha for metro rail provide an indication of the lowest level at which these mobility are feasible. The reduced automobile usage associated with residential density has the potential to reduce GHG emissions and vehicular air pollution, which in turn enhances climate change resiliency (Newman et al, 2009).

Walking, cycling, and other forms of active mobility that are facilitated by residential density also contribute to urban resilience by improving the health outcomes of individuals within a community (Lovasi et al, 2011). For instance, walkable environments with a high residential density have been associated with increased physical activity in adults (Van Dyck, 2010), which contributes to lower rates of cardiovascular disease and obesity (Lovasi et al, 2011). This in turn can increase the overall physical health and wellbeing of a community, which has positive implications for community resilience. The economic benefits of residential density and walkability through reduced public health spending, increased accessibility, and more efficient land use (Litman, 2018) can also contribute to the economic resilience of a community. Closely related to this point is that residential density provides the necessary demand to support a diversity of economic jobs and activities, which contribute to urban resilience against external stressors such as economic downturn and recession (Brown & Greenbaum, 2017). Furthermore, walkable environments have been associated with greater levels of social capital amongst communities (Leyden, 2003), which can in turn enhance social resilience (Osth et al, 2018).

Although increased residential density is generally associated with improved urban resilience outcomes, this relationship may not always be entirely linear, and some resilience benefits may plateau at certain thresholds and even start to drop off. When extreme urban density manifests in the form of very frequent very tall buildings for instance, this has the potential to detract from the some of the social benefits associated with more street-orientated building typologies (Kearns et al, 2012; Evans et al, 2003; Zaff & Devlin, 1998), such as passive surveillances,

> ***Walking, cycling, and other forms of active mobility that are facilitated by residential density also contribute to urban resilience by improving the health outcomes of individuals within a community.***

security, and increased opportunities for social interaction (Montgomery, 2013; MacDonald, 2005; Jacobs, 1965). Given that significantly increased density typically requires the construction of new buildings, this can also have negative ramifications for the heritage of an area which is a crucial element of neighbourhood character and cultural identity (Searle, 2010; Hutton, 2009; Jacobs, 2009). As Jane Jacobs articulated during a phone call to The Globe in 2005: "in the absence of a pedestrian scale, density can be big trouble" (Wickens, 2018). Urban density may also indirectly present challenges to the resilience of communities during disaster, due to the high dependence on centralized infrastructure (such as transit, or elevators in high rise buildings) (Sharifi et al, 2017). Reduced access to daylight and increased noise pollution can also incrementally accrue as a function of increased residential density (Sweden Green Building Council, 2018). A study of walkability in different cities conducted by Sugiyama et al (2014) found that perceived residential density was positively associated with walking for recreation up to an optimal point before beginning to decline – most likely as a consequence of pedestrian congestion associated with extremely high densities in cities such as Hong Kong. Although the author of this study does not define this optimal point numerically, they suggest that lies about halfway between the average density of Hong Kong and a European city such as Pamplona (Spain), and that exceeding this optimal point would only be possible in extremely dense urban environments where highrise buildings greater than 20 stories are the norm (Sugiyama et al, 2014; Cerin et al, 2013).

Some researchers such as Eom and Cho (2015) have suggested that in urban environments of extreme desnity such as Hong Kong, the benefits of density for walkability can platau and begin to decline at a certain threshold. Photo credit: Kim Lo via

Similarly, Eom and Cho (2015) found a significantly increased probability of recreational walking and reduced probability of driving between residential densities of 91-161 persons / ha (hectare), but beyond this point a decline in likelihood of walking. Due to the fundamental importance of density to urban form and different resilience outcomes, the RNDT has adopted residential density (measured as the number of residents per unit area) as an indicator. Similar metrics have been adopted in other holistic frameworks. Rueda's (2012) Ecological Urbanism model for instance uses 'net housing density' (defined as the number of dwelling units/ha) as an indicator, with a desired density target of more than 100 units

/ ha. The Canada Green City Index (Economist Intelligence Unit, 2012) likewise uses population density as a key indicator, and cities or communities seeking LEED certification must have a minimum density of 25 dwelling units (DU) /ha, and a desired density threshold of greater than 156 DU / ha (U.S. Green Building Council, 2009). The sustainability framework developed by the Design Centre for Sustainability at the University for British Columbia recommends a residential density of at least 50 people / ha in order to support more sustainable mobility forms such as transit, with a target of more than 150 people / ha (DCS, 2009). These threshold targets, alongside those previously discussed in relation to walkability and transit, are summarized in table 1 below. To enable a level comparison, all results have been converted to the number of people per hectare (ha) where applicable. Where conversions have been made from the number of dwelling units or households per hectare, the average Vancouver household size of 2.2 persons (City of Vancouver, 2017) has been used as a conversion reference point.

Source	NET / GROSS density	Min. Res. Density (people per hectare)	Target Res. Density (people per hectare)	Max. Res. Density (people per hectare)	Approach / justification for density target
Rueda (2012)	NET	220	220-350	350	Holistic design framework
LEED (2009) *	NET	55	156 <		Holistic design framework
Towers (2002) *	NET		248		Efficient transport and service
Jacobs (1965) *	NET	44	220	1100	Neighbourhood safe and vitality
Jacobs & Appleyard (1987)	NET	74-148	148-474	494	Urban livability
Newman & Kenworthy (2006)	GROSS	35			Automobile dependence
Eom & Cho (2015)	GROSS	91	91-161	161	Walkability
City of Toronto (2017) **	GROSS		200		Official City Plan growth target
DCS (2009)	GROSS	50	150		Holistic design framework
Litman (2016)	GROSS	30	80		Smart Growth

Table 1 above shows a range of residential density targets within the literature. To enable an even comparison, all units have either been:
**Converted to "persons per hectare" using the average Vancouver household size of 2.2 people as a conversion reference point; or*
***Converted from "people and jobs per hectare" to "people per hectare" assuming a 50/50 split of jobs to people in an area.*

References

Brown, L., & Greenbaum, R. T. (2017). The role of industrial diversity in economic resilience: An empirical examination across 35 years. Urban Studies, 54(6), 1347-1366.

Cerin, E., Conway, T. L., Cain, K. L., Kerr, J., De Bourdeaudhuij, I., Owen, N., ... & Christiansen, L. B. (2013). Sharing good NEWS across the world: developing comparable scores across 12 countries for the Neighborhood Environment Walkability Scale (NEWS). BMC public health, 13(1), 309.

Cheng, V. (2009). Understanding density and high density. In Designing High-Density Cities (pp. 37-51). Routledge.

City of Toronto. (2017). City of Toronto Official Plan Indicators. Retrieved from https://www.toronto.ca/legdocs/mmis/2017/pg/bgrd/backgroundfile-107360.pdf

City of Vancouver. (2017, April 30). Housing Characteristics Fact Sheet. Retrieved from https://vancouver.ca/files/cov/housing-characteristics-fact-sheet.pdf

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Economic Intelligence Unit. (2010). US and Canada Green City Index: Assessing the environmental performance of 27 major US and Canadian Cities.

Eom, H. J., & Cho, G. H. (2015). Exploring thresholds of built environment characteristics for walkable communities: Empirical evidence from the Seoul Metropolitan area. Transportation Research Part D: Transport and Environment, 40, 76-86.

Evans, G. W., Wells, N. M., & Moch, A. (2003). Housing and mental health: a review of the evidence and a methodological and conceptual critique. Journal of social issues, 59(3), 475-500.

Frank, L. D., & Pivo, G. (1994). Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking. Transportation research record, 1466, 44-52.

Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., & Bachman, W. (2006). Many pathways from land use to health: associations between neighborhood walkability and active transportation, body mass index, and air quality. Journal of the American planning Association, 72(1), 75-87.

Holtzclaw, J. (1994). Using residential patterns and transit to decrease auto dependence and costs (Vol. 11). San Francisco, CA: Natural Resources Defense Council.

Hutton, T. A. (2009). The new economy of the inner city: Restructuring, regeneration and dislocation in the 21st century metropolis. Routledge.

Jacobs, A., & Appleyard, D. (1987). Toward an urban design manifesto. Journal of the American Planning Association, 53(1), 112-120.

Jacobs, J. (1965). The death and life of great American cities. Harmondsworth, UK: Penguin.

Kearns, A., Whitley, E., Mason, P., & Bond, L. (2012). 'Living the high life'? Residential, social and psychosocial outcomes for high-rise occupants in a deprived context. Housing Studies, 27(1), 97-126.

Leyden, K. M. (2003). Social capital and the built environment: the importance of walkable neighborhoods. American journal of public health, 93(9), 1546-1551.

Litman, T. (2016, July). Determining Optimal Urban Expansion, Population and Vehicle Density, and Housing Types for Rapidly Growing Cities. In Proceedings of the World Conference on Transport Research, Shanghai, China (pp. 10-15).

Litman, T. (2018). Economic Value of Walkability. Retrieved from https://www.vtpi.org/walkability.pdf

Lovasi, G. S., Grady, S., & Rundle, A. (2011). Steps forward: review and recommendations for research on walkability, physical activity and cardiovascular health. Public health reviews, 33(2), 484.

Macdonald, E. (2005). Street-facing dwelling units and livability: The impacts of emerging building types in Vancouver's new high-density residential neighbourhoods. Journal of Urban Design, 10(1), 13-38.

Montgomery, C. (2013). Happy city: Transforming our lives through urban design. Macmillan.

Newman, P., & Kenworthy, J. (2006). Urban design to reduce automobile dependence. Opolis, 2(1).

Newman, P., Beatley, T., & Boyer, H. (2009). Resilient cities: responding to peak oil and climate change. Island Press.

Östh, J., Dolciotti, M., Reggiani, A., & Nijkamp, P. (2018). Social capital, resilience and accessibility in urban systems: a study on Sweden. Networks and Spatial Economics, 18(2), 313-336.

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

Searle, G. (2010). Too concentrated? The planned distribution of residential density in SEQ. Australian Planner, 47(3), 135-141.

Sharifi, A., Chelleri, L., Fox-Lent, C., Grafakos, S., Pathak, M., Olazabal, M., ... & Yamagata, Y. (2017). Conceptualizing dimensions and characteristics of urban resilience: insights from a co-design process. Sustainability, 9(6), 1032.

Stone Jr, B., Mednick, A. C., Holloway, T., & Spak, S. N. (2007). Is compact growth good for air quality?. Journal of the American Planning Association, 73(4), 404-418.

Sugiyama, T., Cerin, E., Owen, N., Oyeyemi, A. L., Conway, T. L., Van Dyck, D., ... & Mitáš, J. (2014). Perceived neighbourhood environmental attributes associated with adults' recreational walking: IPEN Adult study in 12 countries. Health & place, 28, 22-30.

Talen, E., & Koschinsky, J. (2014). Compact, walkable, diverse neighborhoods: Assessing effects on residents. Housing Policy Debate, 24(4), 717-750.

Towers, G. (2002). The implications of housing density. Challenges and Opportunities in Housing: New Concepts, Policies and Initiatives, CIB WC, 69.

US Green Building Council. (2009). LEED 2009 for Neighbourhood Development.

Van Dyck, D., Cardon, G., Deforche, B., Sallis, J. F., Owen, N., & De Bourdeaudhuij, I. (2010). Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. Preventive medicine, 50, S74-S79.

Wickens, S. (2018, May 1). Jane Jacobs: Honoured in the breach. The Globe and Mail. Retrieved from https://www.theglobeandmail.com/arts/jane-jacobs-honoured-in-the-breach/article597904/

Zaff, J., & Devlin, A. S. (1998). Sense of community in housing for the elderly. Journal of community psychology, 26(4), 381-398.

Land Use Diversity

Land use diversity has been linked to increased economic resilience in numerous contexts, including the agricultural sector (Abson et al, 2013; Lin, 2011), strategic management (Reinmoeller & Van Baardwijk, 2005), and urban development, where "mixed land use types directly contribute to urban resilience" (Drewes et al, 2018, pg.9). Urban land use diversity promotes a diversity of economic activities, which in turn has been associated with greater productivity, output, and growth (Quigley, 1998). The diversity of economic activities facilitated by land use diversity has been demonstrated to improve resilience against large external stressors such as economic downturn and recessions (Brown & Greenbaum, 2017). In a recent literature review on mixed-use development (a primary physical manifestation of land use diversity in the built environment), Rabianski et al (2009) found that mixed use developments are conducive to greater residential density, increased pedestrian friendliness and a reduction in personal vehicle use. Such outcomes can be beneficial to urban climate resilience by reducing automobile dependencies, energy usage, emissions rates, and improving urban air quality (Newman et al, 2009). A diverse mix of land uses within a neighbourhood can contribute to a complete community, whereby residents have easy walking access to the variety of activities and services

Source	Diversity index used	Number of land use categories
DCS (2009)	Simpson's diversity index	9
Suarez et al (2016)	Shannon diversity index	9
Bourdic et al (2012)	Untitled (unique index developed by authors)	4
Van Eck & Koomen (2008)	Simpson's diversity index	14
Yamada et al (2012)	Simpson's diversity index	6
Liu et al (2019)	Shannon diversity index	13

Table 2 provides an overview of some of the assessment tools and studies within the literature that have adopted land use diversity as an indicator. Simpson's diversity index and the Shannon diversity index seem to be the two most commonly used metrics, with the former being more popular overall than the latter. In all examples, a greater diversity value (the exact figure of which will depend on the index used and the number of land use categories) is considered to be better / more conducive to resilience outcomes.

"mixed land use types directly contribute to urban resilience"

which contribute to their daily needs, including "a full complement of live, work, shop, and play options" (Urban Strategies Inc., 2008, pg.16). Compact, walkable neighbourhoods with diverse land uses have also been shown to positively impact social interaction, health, and safety (Talen & Koschinsky, 2014). Each of these outcomes is directly germane to urban resilience. For instance, the increased physical activity associated with more diverse mixed-used walkable environments (Van Dyck, 2010) contributes to lower rates of cardiovascular disease and obesity amongst residents (Lovasi et al, 2011), which in turn benefits the physical health of a community and reduces public health spending. Similarly, the increased opportunities for social interaction in diverse and compact neighbourhoods can enhance social capital amongst community members (Leyden, 2003), which increases social resilience (Osth et al, 2018). Today, there is general consensus amongst planning theorists on the environmental, functional, and social benefits of mixed use (Talen & Knaap, 2003) compared to more conventional separated land use classification that was a primary focus of most North American planning for much of the 20th century (Hirt, 2007).

Diversity in general (including land use diversity) is seen to be a crucial component of urban resilience (Suarez et al, 2016), and as a fundamental property of a resilient system (Fiksel, 2003). Measures of diversity have been adopted as key indicators in comparable models, such as the Toolkit for Resilient Cities developed by Siemens (2013), and 'land use diversity' specifically is used as an indicator of resilience in the Urban Resilience Index developed by Suarez et al (2016) and is one of the spatial indicators used in the Urban Sustainability Tool developed by Bourdic et al (2012).

Accordingly, land use diversity has been incorporated

References

Abson, D. J., Fraser, E. D., & Benton, T. G. (2013). Landscape diversity and the resilience of agricultural returns: a portfolio analysis of land-use patterns and economic returns from lowland agriculture. Agriculture & food security, 2(1), 2.

Bourdic, L., Salat, S., & Nowacki, C. (2012). Assessing cities: a new system of cross-scale spatial indicators. Building Research & Information, 40(5), 592-605.

Brown, L., & Greenbaum, R. T. (2017). The role of industrial diversity in economic resilience: An empirical examination across 35 years. Urban Studies, 54(6), 1347-1366.

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Drewes, J. E., van Aswegen, M., & Richter, M. (2018). Towards More Resilient Cities: Land Use and Urban Efficiency. The Academic Research Community publication, 2(1), 12.

Fiksel, J. (2003). Designing resilient, sustainable systems. Environmental science & technology, 37(23), 5330-5339.

Hirt, S. (2007). The mixed-use trend: Planning attitudes and practices in Northeast Ohio. Journal of architectural and planning research, 224-244.

Lin, B. B. (2011). Resilience in agriculture through crop diversification: adaptive management for environmental change. BioScience, 61(3), 183-193.

Liu, Z., Xiu, C., & Song, W. (2019). Landscape-Based Assessment of Urban Resilience and Its Evolution: A Case Study of the Central City of Shenyang. Sustainability, 11(10), 2964.

Lovasi, G. S., Grady, S., & Rundle, A. (2011). Steps forward: review and recommendations for research on walkability, physical activity and cardiovascular health. Public health reviews, 33(2), 484.

Newman, P., Beatley, T., & Boyer, H. (2009). Resilient cities: responding to peak oil and climate change. Island Press.

Östh, J., Dolciotti, M., Reggiani, A., & Nijkamp, P. (2018). Social capital, resilience and accessibility in urban systems: a study on Sweden. Networks and Spatial Economics, 18(2), 313-336.

Quigley, J. M. (1998). Urban diversity and economic growth. Journal of Economic perspectives, 12(2), 127-138.

Rabianski, J., Gibler, K., Tidwell, O. A., & Clements III, J. S. (2009). Mixed-use development: A call for research. Journal of Real Estate Literature, 17(2), 205-230.

Reinmoeller, P., & Van Baardwijk, N. (2005). The link between diversity and resilience. MIT Sloan Management Review, 46(4), 61.

Suárez, M., Gómez-Baggethun, E., Benayas, J., & Tilbury, D. (2016). Towards an urban resilience Index: a case study in 50 Spanish cities. Sustainability, 8(8), 774.

Talen, E., & Knaap, G. (2003). Legalizing smart growth: An empirical study of land use regulation in Illinois. Journal of Planning Education and Research, 22(4), 345-359.

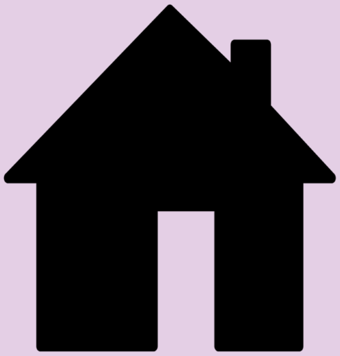
Talen, E., & Koschinsky, J. (2014). Compact, walkable, diverse neighborhoods: Assessing effects on residents. Housing Policy Debate, 24(4), 717-750.

Urban Strategies Inc. (2008). Sustainable Community Design. Vaughan Tomorrow: Background Paper. Retrieved from https://www.vaughan.ca/projects/policy_planning_projects/General%20Documents/Background%20Papers/Additional%20Studies%20and%20Presentations/18Sustainability2.pdf

Van Dyck, D., Cardon, G., Deforche, B., Sallis, J. F., Owen, N., & De Bourdeaudhuij, I. (2010). Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. Preventive medicine, 50, S74-S79.

Van Eck, J. R., & Koomen, E. (2008). Characterising urban concentration and land-use diversity in simulations of future land use. The Annals of Regional Science, 42(1), 123-140.

Yamada, I., Brown, B. B., Smith, K. R., Zick, C. D., Kowaleski-Jones, L., & Fan, J. X. (2012). Mixed land use and obesity: an empirical comparison of alternative land use measures and geographic scales. The Professional Geographer, 64(2), 157-177.



Jobs-Housing Balance

‘

Jobs-housing balance’ refers to an idealized ratio between the number of jobs and number of people within a given area. A jobs-housing balance can shorten commuter distances, reduce vehicle miles travelled (VMT) and vehicle hours travelled (VHT), and improve accessibility to employment (Cervero & Duncan, 2006). This in turn reduces transport-related energy requirements, emissions, and costs whilst also improving overall accessibility to key amenities, each of which enhance resilience at an urban scale (Hibberd & Nelson, 2018). Reduced automobile usage as a consequence of a good jobs-housing balance can also lead to reduced public health spending (primarily through a reduction in inactivity facilitated by this automobile use), as well as greater family stability and improved quality of life (Armstrong & Sears, 2001). It is thought that the greater family stability and cohesion associated with jobs-housing balance is the product of shorter commute times, which increases the amount of time family members are able to spend together, reduces individual stress related to longer commutes, and decreases family spending on transportation (Armstrong & Sears, 2001).

Measuring jobs-housing balance typically involves comparing the number of jobs in an area against either the number of housing units (Ewing, 1996), households (CPR, 2008), workers (Cervero, 1996), or residents within a community (Giuliano, 1991), where an equal ratio signifies a perfect balance of employment and residence opportunities (Hipp et al, 2017; Weitz, 2003). An imbalanced ratio may signify concentrations of employment relative to housing or vis versa (Hipp et al, 2017). Ergo residential density and job density are the two key elements which influence jobs-housing balance. If job density increases relative to the number of housing units within an area for example, then this will create an imbalance between the available jobs and housing (Giuliano, 1991).

The wide range of variables frequently used for measuring jobs-housing balance suggest that there is no widely accepted set standard for quantifying jobs-housing balance (Wu et al, 2015), and that the ideal ratio targets will depend to a large degree on local context. For this reason some researchers have even argued "….against any universal standard for jobs-housing balance" (Cervero, 1996, pg.508). Similarly, a range of methodologies and assumptions for actually calculating jobs-housing ratio have been adopted by different studies within the literature (Wu et al, 2015), which influences how ideal ratio targets are defined and set. For instance, Frank and Pivo (1994) recommend a jobs-housing ratio of between 0.8 – 1.2 whereas Ewing et al (1996) recommends a ratio between 1.3 – 1.7. Alternatively, Peng (1997) recommends a ratio of between 1.2 – 2.8. A summary of these target ratio thresholds, alongside several others within the literature, is presented in table 3.

Source	Jobs / household ratio target
CityLab Action Guide (2018)	0.43[1]
Peng (1997)	1.2 – 2.8
Ewing et al (1996)	1.3 – 1.7
Frank & Pivo (1994)	0.8 – 1.2
Armstrong & Sears (2001)	1 – 1.29
RNDT	1.5

Table 3 above depicts several different jobs / household ratio targets used within the literature. Apart from the CityLab Action Guide (2018), all ratios are calculated based on the number of jobs / household.

[1] *The CityLab Action guide uses a ratio of work area/ household area with a 30:70 split respectively, which explains the variance between this figure and other ratios in the above table, which are otherwise relatively comparable.*

Apart from the CityLab Action Guide (2018), all ratios are calculated based on the number of jobs / household.

Two of the most common broad categories of methodologies for calculating jobs-housing balance involve either calculating the number of jobs to residents/households within the boundaries of a given spatial area (such as a neighbourhood or census tract), or performing some form of proximity analysis to determine the number of jobs which fall within a certain travel time or distance buffer of a residential location (e.g. Ewing, 1996). The first of these methodologies may provide a simpler and easier to calculate methodology whereas the later potentially provides a more realistic measurement (Hipp et al, 2017), although one with added complexity and which relies on a greater number of assumptions.

Given the potential for a balance between jobs and housing to contribute to desirable resilience outcomes (such as reduced vehicular miles travelled, emissions, fossil fuel usage, and enhanced resident quality of life), jobs-housing provides a useful indication of urban resilience. Jobs-housing balance (or very closely related metrics) have been used as indicators in holistic models such as the Ecological Urbanism model developed by Rueda (2012) (which demarcates jobs-housing balance as the 'self-containment employment rate'), whilst 'jobs proximity' (measured as the number of proposed jobs within 5km of centre of a development) is used as an indicator in the holistic sustainability framework developed by the Design Centre for Sustainability at the University of British Columbia (DCS, 2009). The CityLab Action Guide (Sweden Green Building Council, 2018) also advocates for a balance of housing and business spaces within an urban area, and suggests a benchmark of 70:30 (of total housing area / service and workplace area). For these reasons, jobs-housing balance is used as a resilience indicator in the RNDT, with a job / dwelling ration threshold of target of 1.5.

References

Armstrong, M., and Sears, B. (2001, April). The New Economy and Jobs/ Housing Balance in Southern California. Retrieved from http://www.scag.ca.gov/Documents/NewEconomyJobsHousingBalance.pdf

Cervero, R. (1996). Jobs-housing balance revisited: trends and impacts in the San Francisco Bay Area. Journal of the American Planning Association, 62(4), 492-511.

Cervero, R., & Duncan, M. (2006). 'Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing?. Journal of the American planning association, 72(4), 475-490.

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Ewing, R., M. DeAnna, et al. (1996). "Best development practices: Doing the right thing and making money at the same time " Urban Land Institute; Florida. Dept. of Community Affair.

Frank, L., Pivo, G. (1994) Relationships between Land Use and Travel Behavior in the Puget Sound Region. 397 Seattle: Washington State Transportation Center.

Giuliano, G. (1991). Is jobs-housing balance a transportation issue? Retrieved from https://cloudfront.escholarship.org/dist/prd/content/qt4874r4hg/qt4874r4hg.pdf

Hibberd, R. E., & Nelson, A. C. (2018). Longitudinal Cluster Analysis of Jobs–Housing Balance in Transit Neighborhoods(No. 18-03557).

Hipp, J.R., Kane, K., and Kim, J.H. (2017). Jobs-Housing balance in Egohoods in Southern California, MFI Quarterly Report: 2017_1. Irvine, CA: Metropolitan Futures Initiative (MFI), University of California Irvine. Retrieved rom https://mfi.soceco.uci.edu/files/2017/01/UCi16_MFI_Report4_Jobs-Housing-Balance.pdf

Peng, Z. R. (1997). The jobs-housing balance and urban commuting. Urban studies, 34(8), 1215-1235.

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

Sweden Green Building Council. (2018). CityLab Action Guide – Version 2.0. Retrieved from http://www.decodeprojektet.se/media/1167/eng-citylabactionguide-180516-webb_com.pdf

Weitz, J., A. P. Association, et al. (2003). "Jobs-housing balance." American Planning Association Chicago, IL.

Wu, Q., Zhang, M., & Yang, D. (2015). Jobs-housing balance: the right ratio for the right place. In Recent Developments in Chinese Urban Planning (pp. 311-333). Springer, Cham.

Pedestrian Connectivity

Pedestrian connectivity is a core component of walkable urban environments, which themselves enhance urban resilience by encouraging physical activity and boosting overall health amongst community members (Lovasi et al, 2011), augmenting community social capital (Leyden, 2003), and improving economic resilience through reduced public health spending and increased land-use efficiency (Litman, 2018). 'Connectivity' refers to the "directness of links and the density of connections in a transport network" (Planning Institute of Australia, 2009, pg.1). Pedestrian connectivity then, refers to the directness of pedestrian links and density of pedestrian connections within a given walking network. This is distinct from 'street connectivity' which corresponds to the connectivity of street networks, although there is overlap between these two phenomenon in that greater street connectivity can facilitate greater pedestrian connectivity and increase pedestrian volumes (Hajrasouliha & Yin, 2015).

Pedestrian connectivity (combined with increased residential density, quality urban design, and mixed land use planning) can increase walkability (thereby contributing to urban resilience) by improving accessibility to key destinations for pedestrians and by making pedestrian trips easier and more pleasant than other forms of mobility such as automobile travel (Planning Institute of Australia, 2009). Intersection density (calculated as the number of intersections per unit area) is a widely used measure of connectivity within the planning literature (Dill, 2004; Stangl & Guinn, 2011), and applying this metric to pedestrian intersection density gives a useful indication of pedestrian connectivity (Osama & Sayed, 2017). The rationale here is that a greater number of pedestrian intersections signifies shorter block length and distances between pedestrian connecting nodes, which in turn creates more direct pathways to pedestrian destinations (Frank et al, 2010) and enhances overall pedestrian network connectivity (Shashank, 2017). Positive correlations between greater intersection densities and pedestrian volumes have been identified by the likes of Hess et al (1999) and Hajrasouliha and Yin (2015), whilst an association between intersections per kilometer length of road km and reduced VKT (vehicle kilometers traveled) has been identified by those such as Pushkar et al (2000). In their 2010 meta-analysis of travel and the built environment, Ewing and Cervero (2010) found that reduced VMT (vehicle miles travelled) were strongly related to intersection density, and that intersection density was also associated with increased likelihood of walk-trips amongst neighbourhood residents and greater accessibility and shorter routes to transit options. In other words, there is considerable literature support for a positive relationship between intersection density and walkability (Ewing and Cervero, 2010).

For this reason, studies such as Frank et al (2010) use intersection density as an indicator of walkable neighbourhood design, and 'pedestrian route connectivity' (measured as the number of pedestrian route intersections per unit area) is used as an indicator in the holistic sustainability framework developed by the Design Centre for Sustainability at the University of British Columbia (DCS, 2009). Similarly, the LEED guide for Neighbourhood Development (2009) recommends that projects with internal streets have an "internal connectivity of at least 140 intersections per square mile (54 intersections square kilometer)" (pg.47), and projects without internal streets should be located in an area where the connectivity of the existing streets within 400m of the project boundary is at least 90 intersections per square mile (35 intersections/ square kilometer). A 2013 working paper by UN-Habitat recommends an intersection density benchmark target of around 100 intersections per square kilometer, which is "considered walkable and appropriate in many cities in order to generate street life and for moving goods and services productively and effectively" (pg.5).

The importance of pedestrian connectivity to urban resilience more broadly is firmly established within the literature, with those such as Sharifi and Yamagata (2014) explicitly referencing 'pedestrian route connectivity' as a useful candidate indicator for holistically assessing urban resilience. Consequently, the RNDT has adopted pedestrian connectivity as a resilience indicator. Given the widespread usage of 'intersection density' as a reliable measurement of pedestrian connectivity (Shashank, 2017; Frank et al, 2010; Dill, 2004) within the literature, the RNDT uses the number of pedestrian intersections per acre as a metric for pedestrian connectivity. Table 4 gives an overview of some of the thresholds for pedestrian connectivity adopted within the literature. For the sake of equal comparison, all thresholds values have been converted to the number of intersections per square mile.

Source	**Indicator**	**Metric**	**Indicator explanation**	**Threshold (intersections per sq. mile)**	**Ideal target (intersections per sq. mile)**
LEED (200x9)	Internal street connectivity	Intersection density	*If a project has internal streets, then these must have a connectivity of at least 140 intersections per quare mile.*	140	140<
	Nearby street connectivity	Intersection density	*If a project does not have internal streets, it should be located within 400m of an area where the existing street typology has a connectivity of at least 90 intersections per square mile.*	90	90<
DCS (2009)	Pedestrian route connectivity	Pedestrian route intersection density	*The number of pedestrian-specific route connections per area unit. The threshold specified is 310 intersections, although the ideal target is 647 intersections / sq. mile.*	310	647
UN-Habitat (2013)		Intersection density	*A threshold of around 259 crossings per sq. mile is deemed necessary for walkability, street activity, and efficient moving of goods and services.*	259	259 <
TransLink (2012)	Fine-grained street networks	Intersection density	*Neighbourhoods should plan for an intersection density of 104 – 155 intersections or more around transit stations to enhance walkability and access to transit.*	104 – 155	155 <
Aurbach (2005)	Street connectivity	Intersection density	*An acceptable intersection density threshold for a well-designed and neighbourhood with good connectivity is between 250-290 intersections per sq. mile. Ideally however, neighbourhoods should aim for an intersection density of greater than 330 intersections per sq. mile.*	250 – 290	330 <
Ontario Ministry of Transportation (2012)	Local Street and Block Pattern	Intersection density	*Achieving an intersection density of at least 155 intersections per sq. mile contributes to a walkable neighbourhood and a well-connected street system that can accommodate a diverse range of transportation modes such as walking, cycling, and transit.*	155	155 <

Table 4 depicts some of the recommended intersection density thresholds for pedestrian connectivity used within the literature. Most sources recommend at least 100 intersections per sq. mile in order to facilitate a well-connected and walkable street environment.

References

Aurbach, L. (2005). TND Design Rating Standards Version 2.2. Retrieved from https://www.epa.gov/sites/production/files/2014-02/documents/tnd_design_rating_standards_2.2.pdf

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Dill, J. (2004, January). Measuring network connectivity for bicycling and walking. In 83rd Annual Meeting of the Transportation Research Board, Washington, DC (pp. 11-15).

Ewing, R., & Cervero, R. (2010). Travel and the built environment: A meta-analysis. Journal of the American planning association, 76(3), 265-294.

Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). The development of a walkability index: application to the Neighborhood Quality of Life Study. British journal of sports medicine, 44(13), 924-933.

Hajrasouliha, A., & Yin, L. (2015). The impact of street network connectivity on pedestrian volume. Urban Studies, 52(13), 2483-2497.

Hess, P. M., Vernez Moudon, A., Catherine Snyder, M., & Stanilov, K. (1999). Site design and pedestrian travel. Transportation research record, 1674(1), 9-19.

Leyden, K. M. (2003). Social capital and the built environment: the importance of walkable neighborhoods. American journal of public health, 93(9), 1546-1551.

Lovasi, G. S., Grady, S., & Rundle, A. (2011). Steps forward: review and recommendations for research on walkability, physical activity and cardiovascular health. Public health reviews, 33(2), 484.

Ontario Ministry of Transportation. (2012). Transit Supportive Guidelines. Retrieved from http://www.mto.gov.on.ca/english/transit/pdfs/transit-supportive-guidelines.pdf

Osama, A., & Sayed, T. (2017). Evaluating the impact of connectivity, continuity, and topography of sidewalk network on pedestrian safety. Accident Analysis & Prevention, 107, 117-125.

Planning Institute of Australia. (2009, June 10). Connectivity and Permeability. Healthy Spaces & Places. Retrieved from https://www.healthyplaces.org.au/userfiles/file/Connectivity%20June09.pdf

Pushkar, A. O., Hollingworth, B. J., & Miller, E. J. (2000). A multivariate regression model for estimating greenhouse gas emissions from alternative neighborhood designs. In 79th annual meeting of the Transportation Research Board, Washington, DC.

Sharifi, A., & Yamagata, Y. (2014). Resilient urban planning: Major principles and criteria. Energy Procedia, 61, 1491-1495.

Shashank, A. (2017). Walking and connectivity: unpacking measures of the built environment. Retrieved from https://pdfs.semanticscholar.org/b710/ad9ef205ea95a4e3a21ef1bab4327ab2b473.pdf

Stangl, P., & Guinn, J. M. (2011). Neighborhood design, connectivity assessment and obstruction. URBAN DESIGN International, 16(4), 285-296. doi:10.1057/udi.2011.14

US Green Building Council. (2009). LEED 2009 for Neighbourhood Development.

TransLink. (2012). Transit-Orientated Communities Design Guidelines: Creating more livable places around transit in Metro Vancouver. Retrieved from https://www.translink.ca/~/media/documents/plans_and_projects/transit_oriented_communities/transit_oriented_communities_design_guidelines.ashx

UN-Habitat. (2013). The relevance of street patterns and public space in urban areas. UN-Habitat Working Paper April 2013. Retrieved from http://mirror.unhabitat.org/downloads/docs/StreetPatterns.pdf

Proximity to Daily Needs

'Proximity to daily needs' refers to how close different key facilities and services that constitute a resident's daily needs are to a resident's home address (Evangelopoulos, 2014). Proximity between urban destinations typically signifies a more compact urban form conducive to walking (Audirac, 1999; Jacobs, 1965), which can have positive implications for reducing vehicular emissions, urban energy consumption, and improving the health of residents (Marquet & Miralles-Guasch, 2015). Reduced vehicular emissions and urban energy consumption can in turn can booster resilience to external stressors such as climate change (Newman et al, 2009), whilst improved community health can reduce public healthcare spending which benefits both the individual physical resilience of residents and the economic resilience of a community (Litman, 2018).

Proximity to daily needs can directly enhance accessibility to important resources and services by shortening travel distances, and by extension reducing trip durations (Proffitt et al, 2019). This accessibility is a crucial element of resilience (Osth et al, 2018). As articulated in the IFRC Framework for Community Resilience (which itself utilizes several indicators of accessibly to key daily needs such as potable water, secure food supplies, and health system resources), "a resilient community has well-maintained and accessible infrastructures and services" (pg.11). This sentiment is echoed by Sharifi and Yamagata (2016), who emphasise the importance of indicators such as 'accessibility to basic needs and services' as important contributors to urban resilience. Holistic assessment tools such as Rueda's (2012) Ecological Urbanism model uses population proximity to basic services as an indicator, with Rueda specifying a <600m proximity threshold for basic facilities (education, healthcare, state assistance), <300m for local commercial activities (groceries, pharmacies, convenience stores), <300 for mobility networks (bus stops, cycling and pedestrian networks), and <200m for greenspaces. A literature review on the 'proximity to daily needs' principle conducted by Evangelopoulos (2014) highlights that most researchers in this field consider a pedestrian shed to extend outwards by 0.25miles (approximately 400m), meaning that for a certain daily need or land use to be considered 'proximate' to a resident, it must typically fall within this 400m buffer.

Due to the importance of living close to a range of key services, the RNDT has adopted a resilience index which assesses the proximity of resident to their different daily needs. For this index, most types of daily needs such as sufficient retail space, job space, frequent transit service (bus), grocery stores, childcare and elementary schools, must be within 400m of residents living spaces to be considered 'proximate'. Skytrain transit and secondary schools have a higher proximity threshold of 800m, whilst public facilities have a proximity threshold of 1200m.

Retail Space

A diversity of retail businesses service the daily material needs of a community, and when paired with residential density, are a primary attribute of a complete walkable community (Leslie et al, 2006). For this reason, residential density (the ratio of residential units to total retail area) and retail floor area ratio (FAR) are used as key indicators of neighbourhood walkability in the Walkability Index developed by Frank et al (2010), where a higher amount of residential density and retail FAR are associated with a more walkable community. Proximity to neighbourhood retail has been positively associated with increased rates of walking in a community, with those living within 200m of a retail establishment having a significantly increased likelihood of making

A diversity of retail businesses service the daily material needs of a community, and when paired with residential density, are a primary attribute of a complete walkable community.

walking trips (Krizek & Johnson, 2006). The positive implications of increased active mobility in terms of reducing automobile dependence are well established within the literature (Newman & Kenworthy, 2015; Newman, 1996), and can contribute to climate change resilience by reducing global emissions associated with transportation (Newman et al, 2009). More generally, the amount of retail sales activity is considered to be a useful indicator of overall economic performance (Frumkin, 2015), which can contribute to the resilience of a local economy.

According to a recent Colliers study, millenials are becoming increasingly more likely to spend their money eating out at restaurants or on unique and boutique

A recent Colliers study on the spending habits of Millennials (those currently aged 23-38) provides some useful insights about the types of retail that will become increasingly important in the near future – especially given that millennials are set to surpass baby-boomers as Canada's largest population cohort within the next 5 years (Colliers, 2019). One of the key findings from the study was that millennials are increasingly likely to spend money on eating out at restaurants, or on unique and boutique experiences and health and fitness, rather than on buying groceries or spending money at large retail stores or malls (Colliers, 2019). Since 2000, spending on restaurants amongst 25-34 year olds has increased by 53%, whereas spending on groceries over this same time period has decreased by 18% (Colliers, 2019). This suggests that there will be a greater demand for smaller, more boutique retail space over the coming decades, where businesses such as healthy restaurants, smoothie bars, and fitness studios can operate, and less demand for large grocery stores and conventional malls. One specific retail arrangement that Colliers sees as having significant potential to grow in Canada based on these changing spending habits is the idea of a 'food hall', described as "a food truck festival under a roof with an attractive communal dining area, licensed to serve alcohol, often paired with live music, art shows, and other public events. They are generally around 10,000 square feet in size with 8-12 local vendors rather than national tenants" (Colliers, 2019, pg.8)". Retail arrangements of this sort provide a combination of fine-dining experiences, entertainment, and opportunities to socialize – all within a concentrated and conveniently located area.

Job Space

As employment is an important daily need for most residents (more than 62% Canadians aged 15 years or older are currently within some form of employment (Statistics Canada, 2019)), higher job density in general will likely improve residents' proximity to their daily needs, thereby increasing urban resilience. Generally, those who work travel greater distances than those who don't, and the ideal commute time is considered to be less than 30minutes. A study by Wachs et al (1993) on the travel patterns of over 1,500 employees for example found that 94% of employees who were traveling 32 minutes or less to work were satisfied or very satisfied with their commute, whereas only 47% of those traveling greater than 32 minutes reported the same level of satisfaction. Expanding on these results, a study on ideal commute times conducted by Redmond & Mokhtarian (2001) found that, from a sample size of over 2,000 people, most survey respondents preferred commute times between 15-19 minutes (with an average of 16 minutes), supporting the notion that commuting can have positive utility and the hypothesis that people "desire to live close to work, but not too close" (pg.182). In 2016, Vancouverites had an average one-way commuting duration of 29.7 minutes (Statistics Canada, 2017). Generally however, people who live close to job spaces and job opportunities are more likely to work, less likely to be jobless, and typically experience shorter job searches (Kneebone & Holmes, 2015). Proximity to jobs is especially important for lower-income socioeconomic groups who may be constrained by the costs associated with longer commute distances (Kneebone & Holmes, 2015). The average distance Canadian commuters travelled to get to work in 2016 was 7.7km, which is an increase of 0.7km since 1996 (although in Vancouver the average commuting distance decreased from 7.7km to 7.4km over this same 20-year time period) (Statistics Canada, 2017).

In terms of preferred mobility type, researchers such as Paez and Whalen (2010) have found that those who engage in active forms of mobility to get to work (such as walking or cycling) tend to be less dissatisfied with their commute than those who travel to work by automobile. These results are comparable to findings elsewhere within the literature, including a recent study of over 3,000 commuters to McGill campus in Montreal conducted by St-Louis et al (2014) which found that the most satisfied commuters were pedestrians (84.98% satisfaction rate), followed by train commuters (84.15%), cyclists (81.85%), drivers (77.42%), metro users (75.62%), and bus users (75.47%). The findings of these studies suggest that overall, those who engage in active mobility for their commute (walking and cycling) are more likely to be satisfied with their commute than those using non-active transport modes (Merle, 2017; St-Louis et al, 2014; Paez & Whalen, 2010). Despite this, active transportation makes up a relatively overall small share of commuting modes: in the 2016 Census, only 6.9% of Canadian commuters cycled or walked to work (Statistics Canada, 2017).

People who live close to job spaces and job opportunities are more likely to work, less likely to be jobless, and typically experience shorter job searches.

Healthy Food

Proximity to nutritious food is a necessary and fundamental daily need for human functioning, development, and good health (Health Canada, n.d.).

Improving access to affordable, appropriate, and healthy food has been identified as a key way in which cities like Vancouver can improve resilience against external stressors such as food insecurity (City of Vancouver, 2019). Food security will likely continue to become an increasingly important issue over the coming decades, as food availability, accessibility, and food systems stability become more and more compromised by the effects of anthropogenic accelerated climate change (FAO, 2008). Generally within the literature, supermarkets and grocery stores are used as a proxy for healthy food, with proximity to grocery stores (either in terms of distance or travel time) being used as an indicator of access to healthy food (Li & Kim, 2018; Burns & Inglis, 2007). Due to their size, supermarkets (especially chain-supermarkets) may be more likely to sell a range of healthy foods at lower prices compared to smaller grocery or convenience stores, and are therefore an especially useful indicator of healthy food accessibility (Powell et al, 2007).

Childcare

Day-to-day social assets such as adequate and proximate childcare programs have been identified by the Resilient Vancouver Strategy as key societal needs which can help “enable more people to participate in the economy, be active in the communities and cope with shocks and stresses” (City of Vancouver, 2019, pg.62). Quality early childcare has been associated with an improvement in child socio-emotional development (Felfe & Lalive, 2018) and is commonly perceived within the literature as a key way to promote important social and academic skills prior to formal schooling (Vandell et al, 2010). Where possible, Vancouver Coastal Health (2018) recommends locating childcare in close proximity to other daily needs and community facilities, including schools, libraries, parks and community centres, and away from main roads where noise and air pollution could be detrimental to the wellbeing of young children. Locating childcare in close proximity to residential neighbourhoods is also recommended (Vancouver Coastal Health, 2018), and the distance of a household to daycare or preschool facilities has been demonstrated to influence the attendance of children to these facilities, with closer proximity contributing to a greater likelihood of attendance (Dussaillant, 2016). Family proximity to child care options has also been shown to positively contribute to women participation in the workforce (Compton & Pollak, 2014), which may have positive implications for economic resilience.

Childcare has been identified in the recent Resilient Vancouver Strategy as an important social asset that can “enable more people to participate in the economy, be active in the communities and cope with shocks and stresses” (City of Vancouver, 2019, pg.62). Image by Vancouver Community College.

Schools

Increasing levels of education within a community are associated with numerous benefits for the overall resilience and wellbeing of community members, including reduced levels of poverty, increased lifetime earnings, reduced incarceration rates, increased rates of volunteering, increased rates of democratic participation, and increased rates of perceived health and wellbeing (Baum & Payea, 2005). In a study of the costs and benefits of education for American children it is estimated that if the annual national number of high school dropouts was reduced by half then the government would reap a lifetime public benefit of $45 billion through additional tax revenues and reduced costs of welfare payments, crime and justice, and public health (Levin et al, 2007). Perhaps more importantly at the individual level, "high school graduation captures both the cognitive and non-cognitive attributes that are important for success in adulthood" (Levin et al, 2007, pg.2).The innumerable benefits of education highlight the important social and economic resilience implications of providing schools proximate to communities.

The education level of a population is frequently used as an indicator of urban resilience in the post-occupancy stage. Cutter et al (2010) for example, uses 'education equity' (measured as the ratio of the percentage of population with a college education to the percentage of population with no high school diploma) as an indicator of social resilience, whilst 'education level' and 'literacy rates' are used as resilience indicators by the likes of Normandin et al (2009). As improved accessibility to education has been associated with better educational outcomes (Asahi, 2014), measuring the proximity of children to schools provides a useful metric for quantifying resilience in the design phase. One study by Burde and Linden (2009) for instance which analyzed over 1,500 children in rural Afghanistan found that distance to the nearest school had a significant impact on both enrollment rates and test scores: for every additional mile that children must travel to school, enrollment decreased by 16% and test scores fell by 0.19 standard deviations. Likewise, a 2018 study on academic performance in higher education conducted by Vieira et al identified a negative relationship between distance from place of residence and place of study, with the academic performance of students being negatively impacted by decreased proximity to their place of study (Vieira et al, 2018).

The level of education within a population is frequently used as an indicator of urban resilience i
can help improve education levels and contribute to resilience. Image by the High School Transiti

These results highlight the value of providing a range of quality educational facilities proximate to communities.

Despite the increasing trend towards consolidating school districts to create larger supersized schools as a means to improve the efficiency of providing educational services (Hayes, 2018; Boser, 2013; Hlyden, 2005; Lightfoot, 2015), there is a growing body of literary advocating for the benefits of smaller schools (ILSR, 2012; Vander Ark, 2002; Howley & Bickel, 2000; Lee & Smith, 1997). French et al (2007) for instance argue that smaller schools have the potential to produce better academic achievement results amongst students, whilst Howley and Bickel (2000) found that "as schools become larger, the negative effect of poverty on student achievement increases" (pg.10). Similarly, Hylden (2005) argues that "students in small schools perform better academically, graduate at higher levels, are more likely to attend college, and earn higher salaries later on in life" and "participate more in extracurricular activities, have better rates of attendance, report greater positive attitudes towards learning, and are less likely to face school-related crime and violence" (pg.3). These claims are supported by a breadth of empirical support: a 1995 study by Lee and Smith looking at academic performance in over 11,000 students from 800 American high schools found that overall smaller schools were associated with improved academic performance, whilst a 1998 study of 133 schools in New York conducted by Stiefel et al found that small academic schools (<600 students) had much lower drop-out rates than smaller-medium (600-1,200), larger-medium (1,200-2,000), and large academic schools (>2,000) (dropout rates were 4.8%, 13.4%, 13.5%, and 11.9% for each of the four schools sizes respectively), as well as greater graduation rates (64% for small schools, versus 50%, 51%, and 56% for each of the other school sizes in ascending order respectively). These results suggest that there may be a number of reasons to encourage increasing the number and distribution of smaller schools. Increasing the number of schools and the geographical dispersal of these may also have the added benefit of increasing the overall proximity of residents to different schools, which can enhance community proximity to a n important daily need.

n holistic resilience assesment frameworks. Schools are an important daily need for communities which
ions study conducted by the University of British Columbia

Public facilities

Public facilities such as public libraries, community centres, and healthcare services are critical pieces of urban infrastructure that are both necessary for urban resilience and a fundamental daily need for residents (Varheim, 2016; LaMondia et al, 2010).

The importance of proximity to public facilities is emphasized extensively within the resilience literature (U.S. Green Building Council, 2019; Sharifi & Yamagata, 2016; Rueda, 2012; Cutter et al, 2010;

DCS, 2009). 'Provision of public facilities' and 'proximity to public facilities' for instance are both used as indicators in the holistic Ecological Urbanism model developed by Rueda (2012), and the provision of social infrastructure facilities (such as libraries, museums, sports centres, health care centres, and educational facilities) are a prerequisite for cities and neighbourhoods seeking LEED certification (U.S. Green Building Council, 2019). Public facilities have also received attention in holistic disaster resilience models such as that developed by Cutter et al (2010), where 'number of public schools per square mile' and 'number of hospital beds per 10,000 population' are both used as indicators of overall disaster resilience. Similarly, the sustainability framework developed by the Design Centre for Sustainability at the University of British Columbia uses an indicator on 'civic amenity', which measures the percentage of dwellings within 400m of a civic amenity (including public facilities such as schools, community centres, libraries, places of worship, and childcare centres) (DCS, 2009). Optimizing the spatial distribution of key public facilities and services will increase accessibility to these facilities (Ngui & Apparico, 2011) and enhance residents' proximity to their daily needs. Allowing for redundancy in public facilities to enable residents to have choice about which facilities they use (and provide a backup should some facilities fail in the case of a natural disaster or other external stress) is seen to be an importance component of resilience in city infrastructure (O'Rourke, 2007).

Overall, proximity to a range of different public facilities is considered to be an importance goal for creating sustainable, equitable, and resilient communities (U.S. Green Building Council, 2019; Sharifi & Yamagata, 2016; Rueda, 2012; DCS, 2009).

Parks

Access to parks and greenspace is an important daily need for urban dwelling residents (Yin & Xu, 2009). Parks provide a space for physical activity, and are associated with numerous physical, mental, and psychosocial benefits (Liu et al, 2017). For instance, proximity to green parks has been associated with higher levels of physical activity, especially amongst young adults (Kaczynski et al, 2008), which in turn has innumerable human health benefits including reducing the risk of cardiovascular disease, certain types of cancer, obesity, and hypertension (Warburton et al, 2006). This is turn has the potential to reduce public health spending associated with inactivity, which is a significant burden for the Canadian economy. For example, a study by Katzmarzyk et al (2000) estimates that approximately two-thirds of Canadians are physically inactive and that a 10% reduction in inactivity nationally could reduce direct health care expenditures by $150 million annually. As such, proximity to green parks is able to contribute to useful co-benefits, including reducing economic vulnerability through a reduction in public health spending, and improving the physical wellbeing and resilience of individuals within a community. Exposure to greenspace has also been shown to have numerous mental health benefits, such as lowering levels of perceived stress and physiological stress amongst residents, which in turn can booster psychological resilience (Roe et al, 2013). Nearby greenspace can provide a forum for informal social interaction and improved sense of community (Kuo et al, 1998), which has positive implications for psychological wellbeing (Kawachi & Berkman, 2001) and the resilience of a community more generally (Beatley & Newman, 2013). Proximity to greenspace is especially important for children, who are not able to travel to travel as easily or as far as their adult counterparts (ARUP, 2017).

Increasing the number of parks and optimizing the spatial distribution of these will increase accessibility and proximity to a crucial and often overlooked daily need. A core prerequisite for communities and cities seeking LEED certification is that a community/city must have a minimum of 121 square feet per person of greenspace, and that 90% of dwelling units must have a greenspace within 800m of walkable distance, highlighting the importance of greenspace proximity as a key design element of sustainable and resilient communities (U.S. Green Building Council, 2019). Other studies have adopted smaller walking distance buffers as a threshold of proximity to greenspace, including Sturm and Cohen (2014) who use a 400m walking distance threshold in order for greenspace to be considered as within a proximate "short walking distance". This shorter walk distance coincides with the 0.25mile (approximately 400m) pedestrian walkshed radius that is generally considered within the literature to indicate 'proximity' for a walker (Evangelopoulos, 2014), and is emphasised in the public open space health and wellbeing guidelines developed by Villanueva et al (2015), which recommend that at least 95% of dwellings should have access to a small (0.3-0.5ha) and medium (0.5-1.5ha) neighbourhood park within a 400m distance.

Access to parks and greenspace is considered within the literature to be an important daily need that can boost individuals' mental and physical wellbeing. 'Proximate greenspace' is typically considered to be greenspace that is within 400m of a resident's home. Image by Romakoma via Lonely Planet.

References

ARUP. (2017). Cities Alive: Designing for urban childhoods. Retrieved from https://www.arup.com/perspectives/publications/research/section/cities-alive-designing-for-urban-childhoods

Asahi, K. (2014). The impact of better school accessibility on student outcomes.

Audirac, I. (1999). Stated preference for pedestrian proximity: an assessment of new urbanist sense of community. Journal of Planning Education and Research, 19(1), 53-66.

Baum, S., & Payea, K. (2005). The Benefits of Higher Education for Individuals and Society. Retrieved from https://trends.collegeboard.org/sites/default/files/education-pays-2004-full-report.pdf

Boser, U. (2013). Size Matters: A Look at School-District Consolidation. Center for American Progress.

Burns, C. M., & Inglis, A. D. (2007). Measuring food access in Melbourne: access to healthy and fast foods by car, bus and foot in an urban municipality in Melbourne. Health & place, 13(4), 877-885.

City of Vancouver. (2019). Resilient Vancouver Strategy. Retrieved from https://vancouver.ca/files/cov/resilient-vancouver-strategy.pdf

Colliers International. (2019). Millennials, then and now. Retrieved from http://www.collierscanada.com/en/commercial-property-research/2019/spark-report-millennials-then-and-now#.XVRKdehKg2w

Compton, J., & Pollak, R. A. (2014). Family proximity, childcare, and women's labor force attachment. Journal of Urban Economics, 79, 72-90.

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1).

Dussaillant, F. (2016). Usage of child care and education centers: The proximity factor. SAGE Open, 6(2), 2158244016652668.

Evangelopoulos, E. (2014). Neighborhoods, Proximity to Daily Needs, & Walkability in Form-Based Codes.

Felfe, C., & Lalive, R. (2018). Does early child care affect children's development?. Journal of Public Economics, 159, 33-53.

Food and Agricultural Organization of the United Nations (FAO). (2008). Climate Change and Food Security: A Framework Document. Retrieved from http://www.fao.org/3/k2595e/k2595e00.pdf

Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). The development of a walkability index: application to the Neighborhood Quality of Life Study. British journal of sports medicine, 44(13), 924-933.

French, D., Atkinson, M., & Rugen, L. (2007). Creating small schools: A handbook for Raising Equity and Achievement. Thousand Oaks, CA: Corwin and Center for Collaborative Education.

Frumkin, N. (2015). Guide to economic indicators. Routledge.

Hayes, J. L., III. (2018). Realizing the ideal school district size: How district size affects achievement and expenditure.

Health Canada. (n.d.). Nutrition and Healthy Eating. Retrieved from https://www.canada.ca/en/health-canada/services/food-nutrition/healthy-eating.html

Howley, C. B., & Bickel, R. (2000). When It Comes to Schooling... Small Works: School Size, Poverty, and Student Achievement.

Hylden, J. (2005). What's So Big about Small Schools? The Case for Small Schools: Nationwide and in North Dakota. PEPG 05-05. Program on Education Policy and Governance.

IFRC. (2014). IFRC Framework for community resilience. International Federation or Red Cross and Red Crescent Societies, Geneva, Switzerland.

Institute for Local Self Reliance (ILSR). (2012, March 19). Small Schools vs. Big Schools. Retrieved from https://ilsr.org/rule/small-schools-vs-big-schools/

Katzmarzyk, P. T., Gledhill, N., & Shephard, R. J. (2000). The economic burden of physical inactivity in Canada. Cmaj, 163(11), 1435-1440.

Kawachi, I., & Berkman, L. F. (2001). Social ties and mental health. Journal of Urban health, 78(3), 458-467.

Kneebone, E. & Holmes, N. (2015). The growing distance between people and jobs in metropolitan America. Metropolitan Policy Program at Brookings. Retrieved from https://www.brookings.edu/wp-content/uploads/2016/07/Srvy_JobsProximity.pdf

Krizek, K. J., & Johnson, P. J. (2006). Proximity to trails and retail: effects on urban cycling and walking. Journal of the American Planning Association, 72(1), 33-42.

Kuo, F. E., Sullivan, W. C., Coley, R. L., & Brunson, L. (1998). Fertile ground for community: Inner-city neighborhood common spaces. American Journal of Community Psychology, 26(6), 823-851.

LaMondia, J. J., Blackmar, C. E., & Bhat, C. R. (2010, August). Comparing transit accessibility measures: A case study of access to healthcare facilities. In Proceedings of the 89rd Annual Meeting of Transportation Research Board, Washington, DC, USA.

Lee, V. E., & Smith, J. B. (1997). High school size: Which works best and for whom?. Educational Evaluation and Policy Analysis, 19(3), 205-227.

Leslie, E., Butterworth, I., & Edwards, M. (2006, October). Measuring the walkability of local communities using Geographic Information Systems data. In Walk21-VII,"The Next Steps", The 7th International Conference on Walking and Liveable Communities. Melbourne. http://www. walk21. com/papers/m (Vol. 6).

Levin, M., Belfield, C., Muennig, P., & Cecilia, R. (2007, January). The Costs and Benefits of an Excellent Education for All of Americas Children. Retrieved from https://pdfs.semanticscholar.org/af57/1f8380a94ed03875dc7adc5b907e8b47707c.pdf

Li, J., & Kim, C. (2018). Measuring Individuals' Spatial Access to Healthy Foods by Incorporating Mobility, Time, and Mode: Activity Space Measures. The Professional Geographer, 70(2), 198-208.

Lightfoot, L. (2015, October 27). Supersize schools: how big is too big…2,000? Or 4,000? The Guardian. Retrieved from https://www.theguardian.com/education/2015/oct/27/supersize-schools-too-big-add-places-pupils

References

Litman, T. (2018, November 16). Evaluating Transportation Diversity. Victoria Transport Policy Institute.

Liu, H., Li, F., Li, J., & Zhang, Y. (2017). The relationships between urban parks, residents' physical activity, and mental health benefits: A case study from Beijing, China. Journal of environmental management, 190, 223-230.

Marquet, O., & Miralles-Guasch, C. (2015). The Walkable city and the importance of the proximity environments for Barcelona's everyday mobility. Cities, 42, 258-266.

Merle, A. (2017, November 9). The Ideal Work Commute Will Make you Happier and Healthier. Huffpost. Retrieved from https://www.huffpost.com/entry/the-ideal-work-commute-will-make-you-happier-and-healthier_b_59b6ca67e4b0bb893fffffd9

Newman, P. (1996). Reducing automobile dependence. Environment and urbanization, 8(1), 67-92.

Newman, P., & Kenworthy, J. (2015). The end of automobile dependence. In The End of Automobile Dependence (pp. 201-226). Island Press, Washington, DC

Newman, P., Beatley, T., & Boyer, H. (2009). Resilient cities: responding to peak oil and climate change. Island Press.

Ngui, A. N., & Apparicio, P. (2011). Optimizing the two-step floating catchment area method for measuring spatial accessibility to medical clinics in Montreal. BMC health services research, 11(1), 166.

Normandin, J. M., Therrien, M. C., & Tanguay, G. A. (2009, June). City strength in times of turbulence: strategic resilience indicators. In Proc. of the Joint Conference on City Futures, Madrid (pp. 4-6).

O'Rourke, T. D. (2007). Critical infrastructure, interdependencies, and resilience. BRIDGE-Washington-National Academy of Engineering-, 37(1), 22.

Östh, J., Dolciotti, M., Reggiani, A., & Nijkamp, P. (2018). Social capital, resilience and accessibility in urban systems: a study on Sweden. Networks and Spatial Economics, 18(2), 313-336.

Páez, A., & Whalen, K. (2010). Enjoyment of commute: A comparison of different transportation modes. Transportation Research Part A: Policy and Practice, 44(7), 537-549.

Powell, L. M., Slater, S., Mirtcheva, D., Bao, Y., & Chaloupka, F. J. (2007). Food store availability and neighborhood characteristics in the United States. Preventive medicine, 44(3), 189-195.

Proffitt, D. G., Bartholomew, K., Ewing, R., & Miller, H. J. (2019). Accessibility planning in American metropolitan areas: Are we there yet?. Urban Studies, 56(1), 167-192.

Redmond, L. S., & Mokhtarian, P. L. (2001). The positive utility of the commute: modeling ideal commute time and relative desired commute amount. Transportation, 28(2), 179-205.

Roe, J., Thompson, C., Aspinall, P., Brewer, M., Duff, E., Miller, D., ... & Clow, A. (2013). Green space and stress: evidence from cortisol measures in deprived urban communities. International journal of environmental research and public health, 10(9), 4086-4103.

Sharifi, A., & Yamagata, Y. (2016). Urban Resilience Assessment: Multiple Dimensions, Criteria, and Indicators. In Urban Resilience (pp. 259-276). Springer, Cham.

Statistics Canada. (2017). Journey to work: Key results from the 2016 Census. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/171129/dq171129c-eng.htm#targetText=Commuters%20spent%20an%20average%20of,minutes%20for%20public%20transit%20commuters.

Statistics Canada. (2019). Labour force characteristics by province, monthly, seasonally adjusted. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1410028703

Stiefel, L., Iatarola, P., Fruchter, N., & Berne, R. (1998). The Effects of Size of Student Body on School Costs and Performance in New York City High Schools.

St-Louis, E., Manaugh, K., van Lierop, D., & El-Geneidy, A. (2014). The happy commuter: A comparison of commuter satisfaction across modes. Transportation research part F: traffic psychology and behaviour, 26, 160-170.

Sturm, R., & Cohen, D. (2014). Proximity to urban parks and mental health. The journal of mental health policy and economics, 17(1), 19.

U.S. Green Building Council. (2019). LEED v4.1 Cities and Communities: Plan and Design. Retrieved from https://new.usgbc.org/leed-v41#cities-and-communities

Vancouver Coastal Health. (2018). Design Resource for Child Care Facilities. Retrieved from http://www.vch.ca/Documents/Design-resource-for-Child-care-facilities.pdf#targetText=Adjacent%20Uses%20%2D%20Where%20possible%2C%20it,%2C%20schools%2C%20libraries%20and%20parks.

Vandell, D. L., Belsky, J., Burchinal, M., Steinberg, L., Vandergrift, N., & NICHD Early Child Care Research Network. (2010). Do effects of early child care extend to age 15 years? Results from the NICHD study of early child care and youth development. Child development, 81(3), 737-756.

Vander Ark, T. (2002). The case for small high schools. Educational Leadership, 59(5), 55-59.

Vårheim, A. (2016). A note on resilience perspectives in public library research: Paths towards research agendas. Proceedings from the Document Academy, 3(2), 12.

Villanueva, K., Badland, H., Hooper, P., Koohsari, M. J., Mavoa, S., Davern, M., ... & Giles-Corti, B. (2015). Developing indicators of public open space to promote health and wellbeing in communities. Applied geography, 57, 112-119.

Wachs, M., Taylor, B. D., Levine, N., & Ong, P. (1993). The changing commute: A case-study of the jobs-housing relationship over time. Urban studies, 30(10), 1711-1729.

Warburton, D. E., Nicol, C. W., & Bredin, S. S. (2006). Health benefits of physical activity: the evidence. Cmaj, 174(6), 801-809.

Yin, H., & Xu, J. G. (2009). Spatial accessibility and equity of parks in Shanghai. Urban Studies, 16(6), 71-76.

DESIGN

Open Space Design

Open space can be designed to contribute to urban resilience in numerous ways (Siavash, 2016; Monfared & Hashemnejad, 2015; De Vries et al, 2013; Mitchell & Popham, 2008). For example, public open space that is attractive, comfortable, accessible, functional, and safe can play an important role in facilitating social interaction amongst community members (Monfared & Hashemnejad, 2015; Sullivan et al, 2004), which in turn can enhance social ties and contribute to the overall resilience of a neighborhood. Similarly, open greenspace can provide a therapeutic environment which residents can exercise in and enjoy, and which positively benefits their mental and physical wellbeing (Finlay et al, 2015; De Vries et al, 2013; Sugiyama et al, 2008; Maas et al, 2006). Exposure to green open space and public areas with green design features has been associated with lower levels of health inequalities (Mitchell & Popham, 2008), reduced stress, reduced mental fatigue (Aspinall et al, 2015), and improvements in overall mood (Kondo et al, 2018), and cognitive development (Dadvand et al, 2015). Each of these benefits contributes to the overall physical and psychological resiliency of individual community members, as well as enhancing the economic resilience of a city through reduced spending on public health associated with inactivity (Katzmarzyk et al, 2000).

In addition to the directly positive implications of quality open space design for the human user experience, the way urban spaces are designed can also benefit non-human users and foster city-wide resilience to larger scale stressors. Open space designed to maximize ecological connectivity and habitat area for instance can positively impact the resiliency of non-human ecological communities and enhance biodiversity (City of New Westminster, 2016). Similarly, open space design that increases vegetation and pervious surface in an urban area can mitigate the effects of Urban Heat Island (UHI) and the risk of flooding and stormwater pollution, improving resilience against such hazards (Beatley & Newman, 2013), and open space design which creates urban ventilation and urban porosity can utilize prevailing breezes as a passive cooling system to regulate the thermal environment and improve urban air quality (Raven, 2011). Open space can also be designed in ways that produce multiple co-benefits in terms of resilience. The seawall in Vancouver for example "expertly blends hard resilience with everyday recreational use" by providing an attractive amenity space for people to walk, run, cycle, and socialise, whilst simultaneously acting as a flood protection mechanism for Stanley Park (Peinhardt, 2019).

These pathways highlight the numerous pathways through which open space design can positively impact urban resilience, and the ways in which effective open space design can contribute to resilience are well explored within the literature (Peinhardt, 2019; Pickett et al, 2013; Rueda, 2012). 'Public space quality' for instance (a product of effective design) is a central theme in the holistic Ecological Urbanism model developed by Rueda (2012), and 'thermic comfort', 'street space accessibility', 'street proportion', 'visual perception of urban vegetation', 'acoustic comfort', and 'corrected compactness' are all indicators of open space design quality which come under this theme.

For these reasons, the RNDT uses an open space design index as an indicator of resiliency. This index is comprised of several metrics which our research has highlighted as integral to quality open space design and positive user experience, including traffic volumes (Curran et al, 2013; Miranda-Moreno et al, 2011; Litman, 1999), activity generators (Mehta, 2007; Gehl, 1987), active edges (Montgomery, 2013; Jacobs, 1965), public edges, solar access, tree canopy coverage, softscape features, sense of enclosure, flexible design (Whyte, 1980), weather protection, seating and furniture, and materiality. A discussion of each of these components is provided below.

Traffic Volumes

Traffic volume may detrimentally impact pedestrian experience of a public space, by increasing air and noise pollution (Litman, 1999). Decreasing automobile volumes has been demonstrated to positively impact pedestrian comfort levels (Ovstedal & Ryeng, 2002; Litman, 1999) by reducing automobile-related noise and air pollution which is detrimental to human wellbeing (Curran et al, 2013). This in turn makes it more likely that pedestrians will use and stay in a given location for a longer duration, which has positive implications for the liveliness of a public space (Gehl, 1987). Decreasing traffic volumes can also reduce the risk of collision between vehicles and pedestrians (Miranda-Moreno et al, 2011), benefiting the actual and perceived safety of pedestrians.

This improved safety has positive implications for pedestrian comfort and level of service, which again will make pedestrians more likely to use a space and stay for a longer durations. This is particularly important for creating public spaces that are safe and playable for children, given that "children are more vulnerable to being hit by cars due to their smaller size, their undeveloped ability to judge speed and their lack of experience and understanding of traffic danger" (ARUP, 2017, pg.32).

The air and noise pollution assosciated with increased traffic volumes can detrimentally impact on pedestrian experience in open spaces. Image by Mark van Manen via Postmedia news.

Activity Generators

The liveliness of a public space is a product of both the number of people in an area and the duration of their stay (Mehta, 2007; Gehl, 1987). Activity generators such as bars, restaurants, and stores, can enliven a space by attracting people and enticing them to stay (Jacobs, 1965). This creates a positive feedback loop, whereby other pedestrians are attracted to a space based on its 'busyness' and 'liveliness', which itself is a product of activity generators (Jacobs, 1965). Other more temporary types of activity generators include dancers, street theatre musicians, food trucks or open air cafes, and exhibitors (City of Vancouver, 1992).

Active edges (entrances)

Active mixed-use edges enhance opportunities for social interaction and increase the liveliness of an urban area (Gehl, 2013; Montgomery, 2013; Jacobs, 1965). Fine-grained mixed use urban edges adjacent to open spaces can enhance pedestrian impressions of an area and their overall comfort levels (Montgomery, 2013), and the frequency of bars, restaurants, stores, and other non-residential activities along the edge of a public spaces may also provide a means of passive surveillance that can enhance actual and perceived safety of pedestrians (Perkins et al, 1993; Jacobs, 1965). Active ground-level edges (such as retail entrances) are considered to be an effective strategy to animate plazas (City of Vancouver, 2018), and activating park edges by intentionally creating edge zones where specific activities can take place (such as play, meandering/strolling, viewing, gathering, and eating or drinking) has been identified as a way to enhance the performance and functionality of urban parks (Cooper, 2018).

Public edges

Privatization of open urban space leads to increased control over use, access, and behaviour, which can have negative implications for the experience of some users (Nemeth & Schmidt, 2011; Low, 2006). Whilst this is especially true of privately-owned open spaces accessible to the public, privatization can also occur in situations where the design of an open space, including its edges, limits access or use (Wood, 2018; Low, 2006). One way this can occur is if public spaces are bordered by private edges that discourage certain users, uses or activities. For example, public space that is enclosed by private edges which reduce permeability (either visually or physically) may create a potential barrier to the use of that space (Kumari, 2011). Conversely, creating physically and visually porous public edges around a public space may increase perceived feelings of connection between that space and the wider neighbourhood (Goffin, 2015), which may benefit user experience and accessibility (Andrade et al, 2018). A recent study looking at human behaviour in public spaces, 'Field Guide to Life in Urban Plazas: A Study of New York City', found that plazas with wide, open entrances and edges adjacent to other public spaces such as crossings or pathways facilitated greater flows of pedestrians (SWA, 2019). For this reason, design guidelines for public space (including public space that is privately owned) typically encourage porous public edges that are "well-connected to surrounding public parks, plazas, and streets" (City of Waterloo, 2019, pg.1). Clearly demarcating the edges of open space as 'public' in a way that is legible to pedestrians is considered to be an important way to encourage public usage of that space (City of Toronto, 2014).

Solar access

Solar access in public spaces is crucial for creating a thermally comfortable environment that is usable year-round (Capeluto et al, 2006; Nikolopoulou et al, 2001; City of Vancouver, 1992), especially in cooler seasons and northern climates such as Vancouver. Solar access is related to user enjoyment of a public space, and is likely to become an increasingly important urban policy issue as cities continue to densify (Altman & Zube, 2012). Because of this, adequate solar access is considered a key priority for open space design, and many municipalities globally, including New York and San Francisco, have adopted strict regulations to protect solar access in public spaces accordingly (Capeluto et al, 2006).

Whilst solar access in public spaces is generally perceived to have a positive impact on user experience and comfort levels, it is equally important to provide shade and shelter to maximize comfort levels in different seasons and weather conditions (Mehta & Bosson, 2010; Whyte, 1980). This is especially true for cities in warmer climates (MAV, 2015). Deciduous trees are a useful design feature in this respect, as they provide passive cooling and shading during summer, whilst enhancing solar insolation during winter months (Capeluto et al, 2006). This is in contrast to buildings, which cast shade year-round – including during winter months where such shade may be detrimental to pedestrian comfort.

Solar access in public spaces is crucial for creating a thermally comfortable environment th (USA), by the author.

Tree canopy

Tree canopy coverage can regulate the thermal environment of an open public space (Lin et al, 2008), which has positive benefits for human comfort and the overall user experience - a key component of good design (Brown & Katz, 2011). This is achieved through processes of evapotranspiration which cools the near-ground atmosphere, and through the shading provided directly by the tree canopy itself (Kong et al, 2017; Klemm et al, 2015; Lin et al, 2008). Trees with denser canopy coverage provide a greater amount of shade, which has a greater cooling effect on the surrounding atmospheric environment and the thermal comfort of pedestrians (Bruse, 2007). In addition to the functional value of trees in open space, the aesthetic value of urban trees is well documented within the literature (Schroeder, 2011) and is reflected in the ability of urban trees to increase the value of nearby properties (Donovan & Burtry, 2010). Well-placed tree planting more generally is considered to be a salient component of urban open space design (Marcus & Francis, 1997), and an important public amenity (Altman & Zube, 2010).


at is usable year-round. Picture taken in Pioneer Courthouse Square, Portland

The presence of large trees may have a positive impact on crime reduction: a recent study in Portland for instance found that large mature trees in public right of ways is generally associated with lower rates of criminal activity in surrounding areas (Donovan & Prestemon, 2012). The authors suggest that this relationship may be partially explained by the fact that trees make public spaces more desirable which increases the chances of a criminal being observed, and also because trees indicate to potential criminals that a neighbourhood is more cared for (and is therefore more likely to be observed by an authority), both of which disincentivise criminal activity (Donovan & Prestemon, 2012). Such potential explanations are supported by the likes of Kuo and Sullivan (2001), who suggest that well maintained trees and vegetation outside a house act as a cue to potential criminals “that the inhabitants actively care about their home territory and potentially implying that an intruder would be noticed and confronted” (pg.347).

Exposure to greenery and neighbourhood tree canopy has also been associated with a plethora of human health benefits (Kuo, 2015), including reduced stress (De Vries et al, 2013), improved mental health (Sugiyama et al, 2008), lower rates of obesity and increased social cohesion (Ulmer et al, 2016), and lower rates of cardiovascular and respiratory illness (Donovan et al, 2013). Exposure to nature and the stress reduction this prompts can also help shift individuals towards a state of deep relaxation that is conducive to improve sleep quality (Kuo, 2015). Overall, increased neighbourhood tree coverage in urban areas is positively related to improved human wellbeing and experience (Ulmer et al, 2016).

In addition to the human health benefits of tree canopy, connecting street greenery to urban parks and squares through continuous urban foliage creates a connected ecological habitat that can boost biodiversity and enhance ecological health (Rueda, 2012). Larger patches of urban trees and taller tree canopies have been shown to be associated with species richness (Stewart et al, 2009), and protecting and enhancing urban forests has been identified as a key way to promote biodiversity (Alvey, 2006).

Softscape

'Soft' landscape features refer to natural design elements such as vegetation, water, and topography (London Borough of Croydon, 2009). The amount of softscape design features within an urban open space can positively impact pedestrian comfort levels by providing shade and through processes of evapotranspiration which regulate the thermal environment (Kong et al, 2017; Klemm et al, 2015; Lin et al, 2008). In their study of visual perceptions of public open spaces in Niksic, Montenegro, Perovic and Folic (2012) noted that softscape design features appeared to have a calming effect on users, which was beneficial for overall user experience. This calming effect may also have positive implications for crime reduction. Kuo and Sullivan (2001) for instance found that apartment buildings with greater levels of nearby vegetation tended to experience lower rates of crime even after accounting for factors such as building height, vacancy rate, the number of apartments per building, and the number of occupied units per building, whilst a study of minor crimes in Californian public spaces found that 90% of graffiti or vandalism incidences occurred in areas without plantings, with only 10% of these crimes occurring in public spaces with softscape design features (Stamen, 1993).

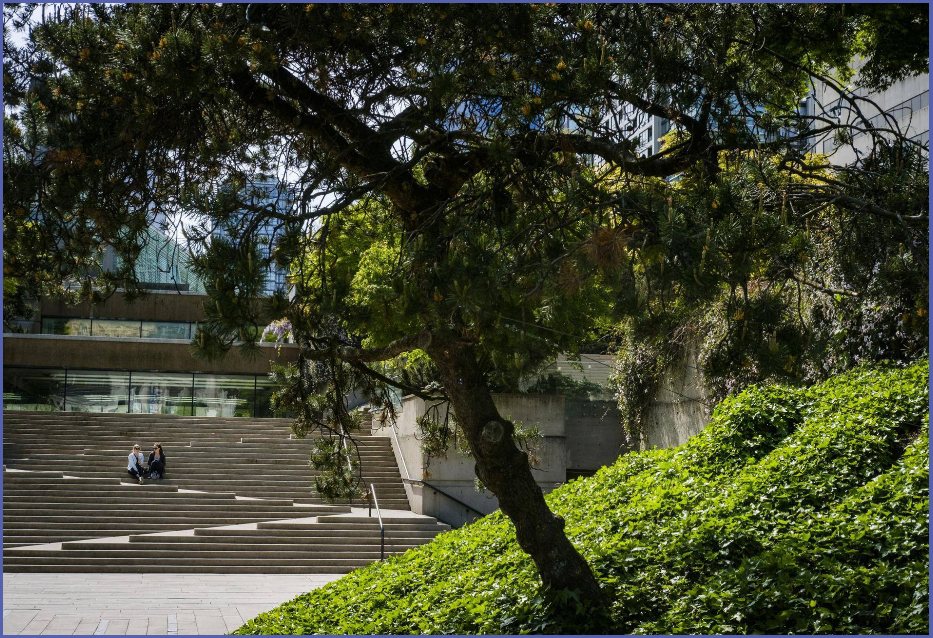
Sense of Enclosure

Successful public spaces require an easily identifiable demarcation from their surrounding environment – something that is often achieved through a sense of enclosure (Carmona, 2019; Whyte, 1980). That is, where building landscape features contain space in a visually obvious way in order to create a distinctive and recognizable place (Carmona, 2019). Continuous building façade adjacent to open space can contribute to a strong sense of enclosure (Thwaites et al, 2005), as well as building heights that are proportional to the size and width of the public open space (London Canada, 2010). The ideal ratio of the width of a public space (W) to the height of surrounding buildings (H) for an optimal sense of enclosure will be contingent on the size of the public open space (Kim & Kim, 2019; London Canada, 2010), although theorists such as Lynch et al (1984) have proposed ideal H/W ratios of around 1:3 to 1:2, with others such as Moughtin (1992) proposing slightly more enclosed ideal H/W ratios of 1:2 to 1:1. More recent research by Carmona et al (2003) suggests an even greater ideal H/W ratio of 2:1 to 2.5:1, and a maximum H/W ratio of 4:1 has been offered by Nelessen (1993). Depending on the public space then, an ideal H/W ratio for a desirable sense of enclosure can be considered to vary from a minimum of 1:3 to a maximum of 4:1 (Nelessen, 1993; Lynch et al, 1984). Despite this variation, the literature on sense of enclosure is generally in agreement that there is an inverted U-shaped relationship between sense of enclosure and user comfort, where "extreme high values of enclosure evoke claustrophobia and confinement, while extreme low values of enclosure evoke discomfort because of physiological shelter" (Alkhresheh, 2007, pg.22).

Flexible Design

Flexible urban design is necessary to deal with the complexity and flux of urban life (Beirao & Duarte, 2005). One example of flexible urban design in open spaces is the use of movable furniture, such as seats, benches, and tables, which allow pedestrians to tailor a public space to suit their own unique needs and preferences (Mohsen et al, 2018; Whyte, 1980). In his seminal 1980 study of people in public spaces, William Whyte observed that given the option, people will almost always move chairs before they sit in them – even if this appears to have little functional utility. In other words, people enjoy the very act of exercising choice over where they sit in public spaces – a freedom movable furniture permits (Whyte, 1980).

In addition to movable seating, other examples of flexible urban design features that can enhance the quality and user enjoyment of a public open space include mobile canopies and ceilings for different weather conditions, mobile urban furniture such as tables, and mobile activities such as temporary volleyball nets or giant chess sets (Mohsen et al, 2018). In addition to the benefits for user experience,



Exposure to greenery in the form of softscape design features or tree canopy can have a calming and relaxing effect on users of public space.

Image top left: Robson Square, Vancouver. Image by John Lehmann via the The Globe and Mail.

Middle: Bute Street public plaza, Vancouver. Image by Jennifer Gauthier via Vancouver Courier.

Bottom left: Downtown Portland, Orgegon, public waterfront promenade.Photo by the author.

flexibility in urban design can also directly enhance disaster resilience in urban spaces by allowing a space to adapt and dynamically respond to external stressors whilst still remaining functional (Fallah et al, 2014). Furthermore, 'flexibility' is perceived to be a fundamental and essential characteristic of any urban system (Tyler & Moench, 2012).

Movable furniture, such as the chairs in Bryant Park (NYC) shown above, provide a flexible seating option which users can arrange to suit their needs. Photo by Brent Toderian.

Seating + Furniture

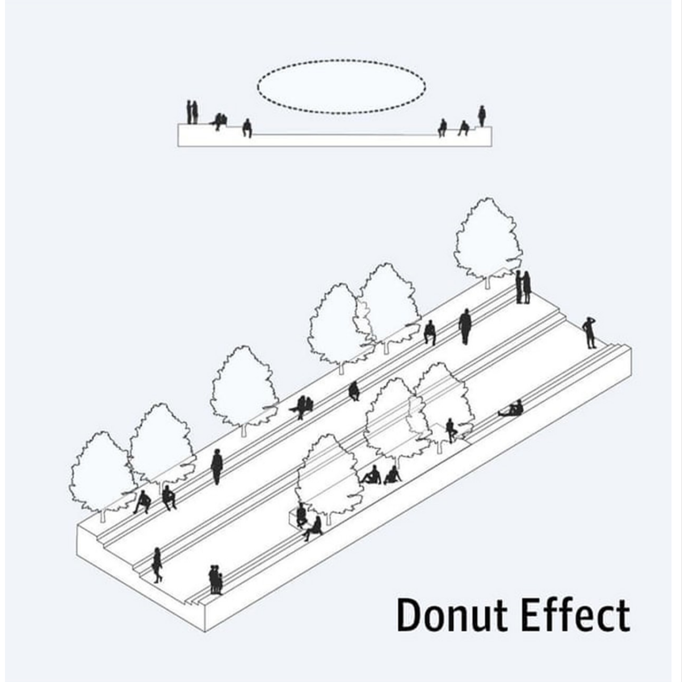
Flexible and diverse seating options are a crucial design feature of successful public space (Whyte, 1980). Generally, people are more likely to use and linger in public spaces such as a plaza if there is a diverse range of seating options (SWA, 2019; Whyte, 1980). As pioneering American Urbanist William Whyte (1980) succinctly describes, "people tend to sit most where there are places to sit" (pg.28). Grass is particularly useful in this respect, as it provides a flexible and comfortable surface for people to play, relax, and socialize on (Carmona, 2019) Other types of movable furniture, such as seats, benches, and tables, are also effective as they allow pedestrians to tailor a public space to suit their own unique needs and preferences (SWA, 2019; Mohsen et al, 2018; Whyte, 1980). Seating with some form of backing and shelter (such as in the form of shade from trees) immediately adjacent to more open and exposed public spaces are particularly popular amongst pedestrians (SWA, 2019). People in public spaces are also more likely to fill the seating around the edges of public spaces before they will sit in the middle – a phenomenon known as the "donut effect" (SWA, 2019). This suggests that providing movable seating with some form of backing around the edge of public spaces such as a plaza has the potential to enhance user enjoyment of public open space – especially if paired with some activation of the centre of the public space with some form of temporary entertainment or food option (SWA, 2019).

Weather protection

Although public spaces should generally be orientated to receive maximum sunlight in order to enhance pedestrian thermal comfort, it is equally important to provide shade and shelter from wind and rain to maximize comfort levels in different seasons and weather conditions (Mehta & Bosson, 2010; Whyte, 1980). Design features that achieve this will make an open space more attractive, and increase the likelihood that it will be utilized and enjoyed by the public.

Materiality

Public spaces should ideally utilize a diverse range of sustainable materials that are robust, require minimal levels of ongoing maintenance where possible, and have a reasonable life span and durability (City of New Westminster, 2016). Using permeable materials or planting vegetation where possible is also preferable, and can provide valuable biodiversity corridor and ecosystem services (such as shading and passive cooling) whilst simultaneously increasing resilience against flood hazards (City of New Westminster, 2016). Choosing materials which create regular smooth surfaces for walking is also crucial for enhancing pedestrian priority and accessibility for all users (Gehl, 2013; Otak, 2013).



The Donut Effect: People tend to fill up the seating on the edges of public spaces before filling the middle. Diagram sourced from SWA (2019).

> “
>
> ***People tend to sit most where there are places to sit.***
>
> ”
>
> **- William Whyte**

Reference

Alkhresheh, M. M. (2007). Enclosure as a function of height-to-width ratio and scale: its influence on user's sense of comfort and safety in urban street space (Doctoral dissertation, University of Florida).

Altman, I., & Zube, E. H. (Eds.). (2012). Public places and spaces (Vol. 10). Springer Science & Business Media.

Alvey, A. A. (2006). Promoting and preserving biodiversity in the urban forest. Urban Forestry & Urban Greening, 5(4), 195-201.

ARUP. (2017). Cities Alive: Designing for urban childhoods. Retrieved from https://www.arup.com/perspectives/publications/research/section/cities-alive-designing-for-urban-childhoods

Aspinall, P., Mavros, P., Coyne, R., & Roe, J. (2015). The urban brain: analysing outdoor physical activity with mobile EEG. Br J Sports Med, 49(4), 272-276.

Beatley, T., & Newman, P. (2013). Biophilic cities are sustainable, resilient cities. Sustainability, 5(8), 3328-3345.

Beirão, J., & Duarte, J. (2005). Urban grammars: towards flexible urban design.

Bruse, M. (2007, November). Simulating human thermal comfort and resulting usage patterns of urban open spaces with a multi-agent system. In Proceedings of the 24th International Conference on Passive and Low Energy Architecture PLEA (Vol. 24, pp. 699-706).

Capeluto, I. G., Yezioro, A., Bleiberg, T., & Shaviv, E. (2006, September). Solar rights in the design of urban spaces. In Comunicación presentada en la 23rd Conference on Passive and Low Energy Architecture, Ginebra.

Carmona, M. (2019). Principles for public space design, planning to do better. Urban Design International, 24(1), 47-59.

Carmona, M., Heath, T. & Tiesdell, S. (2003). Public Places, Urban Spaces: The Dimensions of Urban Design. Burlington, Ma: Architectural Press

City of New Westminster. (2016, July). Downtown Building and Public Realm Design Guidelines and Master Plan. Retrieved from https://www.newwestcity.ca/database/files/library/Final_Version___NW_Downtown_Building_and_Public_Realm_Design_Guidelines_and_Master_Plan.pdf

City of Toronto. (2014, June). Privately-owned publically accessible spaces (POPS), creative place making to enhance urban life. Retrieved from https://www.toronto.ca/wp-content/uploads/2017/08/8527-draft-design-guidelines-for-privately-owned-publicly-accessible-space-Di....pdf

City of Vancouver. (1992). Plaza Design Guidelines. Retrieved from https://vancouver.ca/docs/planning/plaza-design-guidelines-1992-november-17.pdf

City of Vancouver. (2018). Cambie Corridor Public Realm Plan. Retrieved from https://vancouver.ca/images/web/cambie-corridor/cambie-corridor-public-realm-plan.pdf

City of Waterloo. (2019). Guidelines for Privately Owned Publically Accessible Spaces (POPS). Retrieved from https://www.waterloo.ca/en/government/resources/Documents/Cityadministration/Uptown-Public-Realm-Strategy/Guideline-for-Privately-Owned-Publicly-Accessible-Spaces-POPS.pdf

Cooper, M. (2018). Urban Park Street Edges: Enhancing Functionality for the Performance of the 21st Century City. Retrieved from https://atrium.lib.uoguelph.ca/xmlui/handle/10214/13547

Dadvand, P., Nieuwenhuijsen, M. J., Esnaola, M., Forns, J., Basagaña, X., Alvarez-Pedrerol, M., ... & Jerrett, M. (2015). Green spaces and cognitive development in primary schoolchildren. Proceedings of the National Academy of Sciences, 112(26), 7937-7942.

De Vries, S., Van Dillen, S. M., Groenewegen, P. P., & Spreeuwenberg, P. (2013). Streetscape greenery and health: stress, social cohesion and physical activity as mediators. Social Science & Medicine, 94, 26-33.

Donovan, G. H., Butry, D. T., Michael, Y. L., Prestemon, J. P., Liebhold, A. M., Gatziolis, D., & Mao, M. Y. (2013). The relationship between trees and human health: evidence from the spread of the emerald ash borer. American journal of preventive medicine, 44(2), 139-145.

Fallah, M., Masoud, M., & Navaie, A. (2014). Role of resilient and flexible urban space in disaster management. Bulletin of Environment, Pharmacology and Life Sciences, 3(3), 1-6.

Finlay, J., Franke, T., McKay, H., & Sims-Gould, J. (2015). Therapeutic landscapes and wellbeing in later life: Impacts of blue and green spaces for older adults. Health & Place, 34, 97-106.

Gehl, J. (1987). Life between Buildings: Using Public Space,[trans by Jo Koch, Van Nostrand] Reinhold: New York.

Gehl, J. (2013). Cities for people. Island press.

Goffin, P. (2015). Public Works: How to Make Parks More Accessible. Retrieved from https://torontoist.com/2015/11/public-works-how-to-make-parks-more-accessible/

Jacobs, J. (1965). The death and life of great American cities. Harmondsworth, UK: Penguin.

Klemm, W., Heusinkveld, B. G., Lenzholzer, S., & van Hove, B. (2015). Street greenery and its physical and psychological impact on thermal comfort. Landscape and Urban Planning, 138, 87-98.

Kondo, M., Fluehr, J., McKeon, T., & Branas, C. (2018). Urban green space and its impact on human health. International journal of environmental research and public health, 15(3), 445.

Kong, L., Lau, K. K. L., Yuan, C., Chen, Y., Xu, Y., Ren, C., & Ng, E. (2017). Regulation of outdoor thermal comfort by trees in Hong Kong. Sustainable Cities and Society, 31, 12-25.

Kumari, N. (2011). Urban Edge as a Responsive Urban Space: Examination of the impact on the city with special reference to the city of Colombo. Retrieved from http://dl.lib.mrt.ac.lk/bitstream/handle/123/1443/chapter%202.pdf?sequence=6&isAllowed=y

Kuo, F. E., & Sullivan, W. C. (2001). Environment and crime in the inner city: Does vegetation reduce crime?. Environment and behavior,

Reference

33(3), 343-367.

Kuo, M. (2015). How might contact with nature promote human health? Promising mechanisms and a possible central pathway. Frontiers in psychology, 6, 1093.

Lin, B., Li, X., Zhu, Y., & Qin, Y. (2008). Numerical simulation studies of the different vegetation patterns' effects on outdoor pedestrian thermal comfort. Journal of Wind Engineering and Industrial Aerodynamics, 96(10-11), 1707-1718.

Litman, T. (1999). Traffic calming: benefits, costs and equity impacts. Victoria, BC,, Canada: Victoria Transport Policy Institute.

London Borough of Croydon. (2009). Landscape Design; Supplementary Planning Guidance No. 12.

London Canada. (2010). Illustrated Urban Design Principles. Retrieved from https://www.london.ca/business/Planning-Development/urban-design/Documents/Illustrated-Urban-Design-Principles.pdf

Low, S. M. (2006). The erosion of public space and the public realm: paranoia, surveillance and privatization in New York City. City & Society, 18(1), 43-49.

Lynch, K., Lynch, K. R., & Hack, G. (1984). Site planning. MIT press.

Maas, J., Verheij, R. A., Groenewegen, P. P., De Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity, and health: how strong is the relation?. Journal of Epidemiology & Community Health, 60(7), 587-592.

Marcus, C. C., & Francis, C. (Eds.). (1997). People places: design guidlines for urban open space. John Wiley & Sons.

Miranda-Moreno, L. F., Morency, P., & El-Geneidy, A. M. (2011). The link between built environment, pedestrian activity and pedestrian–vehicle collision occurrence at signalized intersections. Accident Analysis & Prevention, 43(5), 1624-1634.

Mitchell, R., & Popham, F. (2008). Effect of exposure to natural environment on health inequalities: an observational population study. The lancet, 372(9650), 1655-1660.

Mehta, V., & Bosson, J. K. (2010). Third places and the social life of streets. Environment and Behavior, 42(6), 779-805.

Monfared, N. S. S., Hashemnejad, H., & Yazdanfar, S. A. (2015). Design principles in sustainable local community with security and socialization approach (Case study: Chizar). Procedia-Social and Behavioral Sciences, 201, 62-70.

Montgomery, C. (2013). Happy city: Transforming our lives through urban design. Macmillan.

Moughtin, C. (1992). Urban Design: Street and Square (Oxford, Butterworth).

Mohsen, S., Khodadad, S., and Khodadad, M. (2018). Flexible Urban Public Spaces and their Designing Principles. Journal of Civil Engineering and Urbanism, 8(4), 39-43. Retrieved from http://www.ojceu.ir/main/attachments/article/65/J.%20Civil%20Eng.%20Urban.%208%20(4)%2039-43,%202018.pdf

Municipal Association of Victoria (MAV). (2015). Shade Design for Public Places. Retrieved from http://www.mav.asn.au/__data/assets/pdf_file/0018/7326/Shade-design-for-public-places.pdf

Nelessen, A. (1993). Visions for a New American Dream. Chicago, IL: Planners Press.

Németh, J., & Schmidt, S. (2011). The privatization of public space: modeling and measuring publicness. Environment and Planning B: Planning and Design, 38(1), 5-23.

Nikolopoulou, M., Baker, N., & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: understanding the human parameter. Solar energy, 70(3), 227-235.

Otak, Inc. (2013, May). Hawaii Pedestrian Toolbox, A Guide for Planning, Design, Operations, and Education to Enhance Pedestrian Travel in Hawaii. Retrieved from https://hidot.hawaii.gov/highways/files/2013/07/Pedest-Tbox-Hawaii-Pedestrian-Toolbox-Low-Res.pdf

Ovstedal, L., & Ryeng, E. (2002, September). Understanding pedestrian comfort in European cities: How to improve walking conditions. In European Transport Conference, Cambridge, UK (Vol. 6).

Peinhardt, K. (2019). Resilience roundup: public spaces fighting climate change. Project for Public Spaces. Retrieved from https://www.pps.org/article/resilience-roundup-public-spaces-fighting-climate-change

Perovic, S., & Folic, N. K. (2012). Visual perception of public open spaces in Niksic. Procedia-Social and Behavioral Sciences, 68, 921-933.

Pickett, S. T., Cadenasso, M. L., & McGrath, B. (Eds.). (2013). Resilience in ecology and urban design: linking theory and practice for sustainable cities (Vol. 3). Springer Science & Business Media.

Raven, J. (2011). Cooling the public realm: climate-resilient urban design. In Resilient Cities (pp. 451-463). Springer, Dordrecht.

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

Schroeder, H. W. (2011). Does beauty still matter? Experiential and utilitarian values of urban trees. In In: Trees, people and the built environment. Proceedings of the Urban Trees Research Conference; 2011 April 13-14; Edgbaston, Birmingham, UK. Institute of Chartered Foresters: 159-165.(pp. 159-165).

Siavash, Y. S. (2016). Achieving Urban Resilience: Through Urban Design and Planning Principles (Doctoral dissertation, Oxford Brookes University).

Stamen, T. (1993). Graffiti deterrent proposed by horticulturalist [Press release]. Riverside: University of California, Riverside.

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2008). Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships?. Journal of Epidemiology & Community Health, 62(5), e9-e9.

Stewart, G. H., Meurk, C. D., Ignatieva, M. E., Buckley, H. L., Magueur, A., Case, B. S., ... & Parker, M. (2009). Urban biotopes of Aotearoa New Zealand (URBANZ) II: floristics, biodiversity and conservation values of urban residential and public woodlands, Christchurch. Urban Forestry & Urban Greening, 8(3), 149-162.

Sullivan, W. C., Kuo, F. E., & Depooter, S. F. (2004). The fruit of urban nature: Vital neighborhood spaces. Environment and behavior, 36(5), 678-700.

SWA. (2019). Field Guide to Life in Urban Plazas: A Study of New York City. Retrieved from https://live-swa-2019.pantheonsite.io/wp-content/uploads/2019/08/Field-Guide-to-Life-in-Urban-Plazas_digital1.pdf

Thwaites, K., Helleur, E., & Simkins, I. M. (2005). Restorative urban open space: Exploring the spatial configuration of human emotional fulfilment in urban open space. Landscape Research, 30(4), 525-547.

Toderian, B. (2015, October 21). There aren't many #placemaking tools that are as cheap, simple & effective as #movablechairs. #BryantPark #SummitNYC. Retrieved from https://twitter.com/BrentToderian/status/658751071720837120

Tyler, S., & Moench, M. (2012). A framework for urban climate resilience. Climate and development, 4(4), 311-326.

Ulmer, J. M., Wolf, K. L., Backman, D. R., Tretheway, R. L., Blain, C. J., O'Neil-Dunne, J. P., & Frank, L. D. (2016). Multiple health benefits of urban tree canopy: The mounting evidence for a green prescription. Health & Place, 42, 54-62.

Whyte, W. H. (1980). The social life of small urban spaces.

Wood, N. (2018). Planning for Privately Owned Public Space in the Greater Toronto Area. Retrieved from https://yorkspace.library.yorku.ca/xmlui/bitstream/handle/10315/34832/MESMP02839.pdf?sequence=1&isAllowed=y

People-First Streets

Pedestrian orientated streets have the potential to enhance urban resilience in multiple ways. For example, pedestrian streets reduce automobile dependency, which in turn reduces transport related carbon emissions, traffic congestion, and urban sprawl, making cities more resilient to external stressors such as climate change (Galderisi & Ferrara, 2012), less resource intensive, and more efficient (Woodcock et al, 2007). Pedestrian friendly streets also enhance public health by encouraging active forms of mobility (Litman, 2018), improving street level air quality, and reducing transport-related mortalities (Woodcock et al, 2007), as well as increasing social connectedness - something which has been demonstrated to strengthen communities and enhance resiliency in the face of disaster (Chandra et al, 2011). Although 'pedestrian first streets' does not appear to be explicitly used in other holistic resilience frameworks, the components contributing to a pedestrian friendly street environment discussed in the following subsections are commonly linked to urban resilience. For these reasons, the extent to which a neighbourhood's streets are friendly and accommodating to pedestrians is used an indicator for the RNDT. A key way to measure pedestrian friendliness is assessing how comfortable a given street is for non-automobile users. The following section discusses design features germane to pedestrian comfort levels at street level.

Active Edges

A diversity of active entrances and mixed uses can and make people feel more trusting and comfortable (Leyden, 2003; Montgomery, 2013). This increases the likelihood that people will walk slower, stop to rest, and engage in social interaction with one another at a street level, which can in turn increase the sense of community and social capital of a community, thereby positively contributing to social resilience. Active edges with many street orientated windows and doors also enhance feelings of 'eyes on the street' (Jacobs, 1965) which can increase the perception of safety and comfort of those on the sidewalks, thereby encouraging leisurely walking and increasing the likelihood of chance social interaction. Such feelings of safety and passive surveillance are enhanced by building edges that articulate individual ground-floor units (Macdonald, 2005).

Traffic Volume

Decreasing automobile traffic volume positively impacts pedestrian comfort levels (Ovstedal & Ryeng, 2002; Litman, 1999). This is primarily achieved by reducing automobile-related noise and air pollution which is detrimental to human wellbeing (Curran et al, 2013), as well as creating a greater balance between pedestrian and vehicle prioritization in a streetscape environment (Kim et al, 2011). Reducing traffic volume has significant potential to improve pedestrian safety, with one study conducted by Miranda-Moreno et al (2011) in Montreal finding that a 30% reduction in traffic volume would reduce the total number of pedestrians injured by vehicles by 35% and reduce the risk of a pedestrian collision by 50%.

Traffic Design Speed

Slower automobile traffic speeds typically increase pedestrian comfort levels, and improve pedestrian safety (Litman, 1999). Interventions to reduce traffic speeds have been shown to lower rates of vehicular-pedestrian collisions (Leaf & Preusser, 1999). As pedestrian injury severity increases exponentially in relation to vehicular speed (Litman, 1999), reduced car speeds also lowers the probability of collision-related pedestrian fatalities (Anderson et al, 1997; Leaf & Preusser, 1999). Given safety (both perceived and actual) is a key component of pedestrian comfort and level of service, such factors play an important role in improving overall pedestrian comfort. Reducing traffic speeds and encouraging a regular traffic flow to minimize rapid acceleration or deceleration has also been shown to be an effective mitigation strategy for reducing traffic related noise pollution (Curran et al, 2013), which can likewise enhance pedestrian experience and comfort levels. Lower traffic speeds are especially crucial for enhancing the safety and playability of streets for children, who are particularly vulnerable to being hit by cars due to their small size and lack of ability and experience in judging traffic speed and danger (ARUP, 2017).

Curb-to-Curb Width

Reduced street curb-to-curb width can improve pedestrian comfort (Kim et al, 2011), and is commonly used as a traffic calming measure (U.S. Department of Transportation, 2015). This is achieved in part by restricting the volume of traffic, which reduces traffic related noise and air pollution (Curran et al, 2013), thereby making the street environment more comfortable for pedestrian travel (Sarkar, 2003). Reducing street curb-to-curb width also creates a greater balance between pedestrian and vehicle prioritisation in the streetscape, which in turn can improve pedestrian level of service (Kim et at, 2011).

Narrower streets slow down traffic, which creates a more safe and enjoyable environment for pedestrians. Image by GRIDS Vancouver via Twitter.

Sidewalk Width

Increasing sidewalk width is associated with gradual improvements in pedestrian safety and pedestrian comfort levels (Dandan et al, 2007). 5 feet of space is the bare minimum width needed to accommodate two people walking side-by-side: wider sidewalks permit a more comfortable amount of space between walkers, as well as providing greater opportunity for pedestrians to walk alongside each other and socialize (FHWA, n.d.). Wide sidewalks are especially imperative along streets with frequent pedestrian activities, and make movement easier and more comfortable for those using mobility assisted devices such as wheelchairs or strollers (City of Toronto, 2017). Widening sidewalks by extending the sidewalk curb into the existing roadway (thereby simultaneously narrowing the road) has also been demonstrated to be an effective traffic calming measure which has positive benefits for improved pedestrian safety and reducing overall rates of pedestrian-automobile collisions (Mead et al, 2014). Sidewalk widths that are too narrow have been identified as a key reason why potential pedestrians may favour car usage over walking on a given street (Kim et al, 2011). Wider sidewalks also foster opportunities for children to play and explore in the public real, and contributes to a child-friendly urban environment (ARUP, 2017).

Pedestrian Priority (physical design)

Separating pedestrians from automobile lanes significantly improves pedestrian and cyclist comfort levels (Kang & Fricker, 2016; Li et al, 2012). Pedestrian priority at intersections (in terms of crossing signal time intervals) can improve pedestrian experience and comfort by reducing pedestrian waiting times (Levelt, 1992). Pedestrian bridges and underpasses should only be used as a last resort (Gehl, 2013). Direct lines of walking for pedestrian pathways without unnecessary obstacles or detour

Increasing footpath width creates a more comfortable amount space for pedestrians to pass one another and walk side-by-side. Sidewalk trees can also serve to improve pedestrian experience by providing shade and some degree of weather protections, as well as providing a partial screen from adjacent traffic. Image by Michigan Municipal League via BetterBurb.

can improve the pedestrian experience (Gehl, 2013). Reducing the number of driveways to minimize potential disruptions to pedestrian travel on a sidewalk and providing on-street parking where feasible can also prioritize pedestrians first and contributes to a pedestrian friendly streetscape (Otak, 2013). Regular pedestrian information signs, maps, and curb extensions at intersections and mid-block crossings are also helpful in this respect, as is implementing traffic calming measures which reduce traffic volume and speed (Otak, 2013). Pedestrian ramps, curb-cuts, and regular smooth surfaces for sidewalks are also crucial for enhancing pedestrian priority and accessibility for all users (Gehl, 2013; Otak, 2013). Building design which accentuates vertical façade lines and expressions can make pedestrian walks seem shorter, whereas horizontal façade patterns can reinforce pedestrian feelings of distance (Gehl, 2013).

Cycling Infrastructure

Continuous, separated, and purpose built cycle infrastructure positively impacts cyclist comfort levels (Hull & O'Holleran, 2014). The presence of dedicated cycling cycle infrastructure has also been shown to improve actual and perceived safety, and increase the likelihood that community members may choose to cycle (Schultheiss et al, 2018). Off-street cycleways or those physically separated from automobile traffic by some form of barrier are the preferred type of infrastructure amongst the vast majority of current and potential cyclists (Schultheiss et al, 2018).

Shared pedestrian and bicycles sidewalks may negatively impact pedestrian comfort levels, but these negative impacts may be alleviated by widening the sidewalk and regulating cyclist speeds (Kang & Fricker, 2016). Other strategies and design features to mitigate the potential for negative cylist-pedestrian interactions include developing educational campaigns about respectful and safe cyclist and pedestrian behaviour in shared spaces; establishing regular signage to encourage shared space norms; creating pedestrian harbours; and demarcating cyclist 'dismount zones' in areas of particularly heavy pedestrian activity (McGill Cycling Working Group, 2014).

On-Street Parking

On-street parking arguably has the potential to both benefit and detriment the pedestrian street experience. Some researchers for instance purport that on-street parking acts as a traffic calming tool which can lower the traffic speed along a street and act as a buffer between pedestrians and moving vehicles – both of which can positively impact pedestrian safety and comfort (Peprah, 2014; Dumbaugh & Gattis, 2005). However, the benefits of on-street parking apply predominantly to parallel parking only rather than angled on-street parking, the latter of which has been shown to have an overall negative effect on pedestrian and road-user safety (Biswas et al, 2017). For instance, angled parking has been associated with more than double the number of crashes per unit distance compared to parallel parking by some researchers (Box, 2004), predominantly due to the difficult maneuver involved with both entering and exciting an angled on-street park (Biswas et al, 2017).

The benefits of on-street parking however are also predominately limited to lower speed minor streets (Biswas et al, 2017), and when used in conjunction with other traffic calming design interventions such as raised curbs, sidewalks, small building setbacks, and vegetated buffers between the road and pedestrian traffic (Marshell et al, 2008). On high-speed roads, on-street parking is associated with higher crash rates and an increase in pedestrian fatalities and severe injuries (Marshell et al, 2008). For this reason, pedestrian safety and street design guidelines tend to actively discourage on-street parking in high-speed areas (Wisconsin State, 2010; ITE, 2006), although the threshold for 'high speed' is not unanimously agreed upon. The Wisconsin State Department of Transportation (2010) for example recommends prohibiting on-street parking in areas where the speed limit exceeds 45mph (~72km/h), whilst the ITE proposed guidelines for walkable communities recommend a maximum of 35mph (~56km/h) for on-street parking (ITE, 2006).

Given the potential for on-street parking to obstruct the view of drivers leading to a greater number of pedestrian-vehicular collisions (especially amongst children), researchers recommend that on-street parking (if implemented) should be prohibited

Generally, there appears to be an emerging consensus within the literature that parallel o
streets has the potential to be an effective traffic calming measure which can positively be
street in East Vancouver.

near pedestrian intersections and crossings (Biswas et al, 2017). For instance, the Wisconsin Guide to Pedestrian Best Practices (2010) recommends that for streets with speed limits between 35-45mph (~56-64km/h), a no-parking zone should extent 50 feet from any intersection. In the case of a roundabout or uncontrolled intersection, Biswas et al (2017) recommends an even greater setback of at least 75 feet from the intersection/roundabout yield line.

Generally, there appears to be an emerging consensus within the literature that parallel on-street parking (set back from intersections and roundabouts) on low-speed minor streets has the potential to be an effective traffic calming measure which can positively benefit the safety and comfort of pedestrians.

n-street parking (set back from intersections and roundabouts) on low-speed minor
nefit the safety and comfort of pedestrians. Photo taken by the author along a residential

Softscape (%)

The amount of greenery and softscape design features within an urban environment can positively impact pedestrian comfort levels by providing shade and through processes of evapotranspiration which regulate the thermal environment (Kong et al, 2017; Klemm et al, 2015; Lin et al, 2008). A number of studies conducted by Gehl Architects highlight the importance of "soft edges" in enhancing pedestrian comfort and livability along streets in residential neighborhoods (Gehl, 1986), and a study conducted by Wolfe and Mennis (2012) found a significant association between the amount of greenery in Philadelphia neighbourhoods and decreased rates of assault, robbery, and burglary. These results are supported by the likes of Kuo and Sullivan, who found that buildings with greater levels of nearby vegetation tended to experience lower rates of crime (2001). A study by Happy City (2017) found that streets and laneways with vegetated softscape features were associated with a greater sense of attachment, perception of trust, sociability, and overall sense of wellbeing amongst residence in comparison to a street or laneway with only hardscape design features. Interestingly, this same study found that incorporating colorful paint into pedestrian intersection design was also associated with greater levels of trust and subjective wellbeing as compared to a standard intersection (Happy City). In addition to the human user benefits of streets which incorporate soft design features, softscape design can also help create natural corridors for wildlife, which can have positive implications for local biodiversity (City of New Westminster, 2016).

Tree Canopy (%)

Tree canopy coverage and vegetation has positive

Tree canopy and green street design features can improve pedestrian comfort by providing shade and protection from the elements. Green design features also have the potential to reduce surface water runoff by increasing the amount of effective pervious area, as well as mitigating the urban heat island effect common to many cities. Image by Paul Krueger via flickr.

effects on outdoor pedestrian comfort levels (Lin et al, 2008). Key reasons for this include the ability of trees to block wind, provide shade from the sun, and regulate the thermal environment and atmospheric humidity levels - especially during summer (Kong et al, 2017; Lin et al, 2008). Generally, the these positive functions of urban tree canopy are proportional to the tree size, meaning that the more mature and older a tree is the better it is able to provide useful ecosystem services to enhance the pedestrian experience (Nordic Forest Research, n.d.). Urban trees can provide an important aesthetic amenity for humans to enjoy, as well as providing habitat for different types of wildlife (Nordic Forest Research, n.d.). A greater diversity of urban trees will be more resilient to stressors and disturbances (such as disease), and facilitate a greater range of biodiversity (Nordic Forest Research, n.d.). The presence of streetscape greenery and urban tree canopy has also been associated with reduced stress (De Vries et al, 2013) and improved mental health (Sugiyama et al, 2008). Overall, more neighbourhood tree coverage in urban areas is positively related to improved pedestrian wellbeing and experience (Ulmer et al, 2016).

Effective Pervious Area

Effective pervious area (EPA) refers to the pervious surface that infiltrates water into the ground without impacting a natural hydrological system as a percentage of a total given area (Condon, 2010). For example, if all surface runoff filters into the surrounding ground, then EPA will be 100% as there has been no effect on the natural watershed hydrology (Condon, 2010). Increasing EPA can help increase urban resilience against flood hazards, by reducing the volume and intensity of surface runoff through natural infiltration of stormwater (Alley & Veenhuis, 1983). Increasing EPA and vegetation can also reduce the urban heat island effect, which has positive implications for the outdoor thermal comfort level and wellbeing of urban pedestrians (Wu et al, 2016; Lin et al, 2008).

Weather Protection

Urban design that provides protection from the elements can elevate pedestrian comfort levels (Ovstedal & Ryeng, 2002). Shade, shelter, and flexible design features that offer weather protection in different seasons and don't impede pedestrians' visual outlook are considered to be important contributors to overall pedestrian comfort (Whyte, 1980).

Solar Access

Increased solar access generally corresponds to increased human thermal comfort levels (Nikolopoulou et al, 2001), especially in cooler seasons and climates (Whyte, 1980). However, it is equally important to provide shade and shelter to maximize comfort levels in different seasons and weather conditions (Mehta & Bosson, 2010; Whyte, 1980). Deciduous trees are a useful design feature in this respect, as they provide passive cooling and shading during summer, whilst enhancing solar insolation during winter months (Capeluto et al, 2003).

Access to sunshine can improve pedestrian comfort levels in a street environment - especially in cooler seasons and climates. Picture by Ryhor Bruyeu via Picfair.

Reference

Alley, W. M., & Veenhuis, J. E. (1983). Effective impervious area in urban runoff modeling. Journal of Hydraulic Engineering, 109(2), 313-319.

Anderson, R. W., McLean, A. J., Farmer, M. J. B., Lee, B. H., & Brooks, C. G. (1997). Vehicle travel speeds and the incidence of fatal pedestrian crashes. Accident Analysis & Prevention, 29(5), 667-674.

Biswas, S., Chandra, S., & Ghosh, I. (2017). Effects of on-street parking in urban context: A critical review. Transportation in developing economies, 3(1), 10.

Box, P. C. (2004). Curb-parking problems: Overview. Journal of Transportation Engineering, 130(1), 1-5.

Capeluto, I. G., Yezioro, A. B. R. A. H. A. M., & Shaviv, E. D. N. A. (2003). Climatic aspects in urban design—a case study. Building and environment, 38(6), 827-835.

Chandra, A., Acosta, J., Howard, S., Uscher-Pines, L., Williams, M., Yeung, D., ... & Meredith, L. S. (2011). Building community resilience to disasters: A way forward to enhance national health security. Rand health quarterly, 1(1).

City of New Westminster. (2016, July). Downtown Building and Public Realm Design Guidelines and Master Plan. Retrieved from https://www.newwestcity.ca/database/files/library/Final_Version___NW_Downtown_Building_and_Public_Realm_Design_Guidelines_and_Master_Plan.pdf

City of Toronto. (2017). Complete Streets Guidelines. Retrieved from https://www.toronto.ca/services-payments/streets-parking-transportation/enhancing-our-streets-and-public-realm/complete-streets/complete-streets-guidelines/

Condon, P. M. (2012). Seven rules for sustainable communities: design strategies for the post carbon world. Island Press.

Curran, J. H., Ward, H. D., Shum, M., & Davies, H. W. (2013). Reducing cardiovascular health impacts from traffic-related noise and air pollution: intervention strategies. Environmental Health Review, 56(02), 31-38.

De Vries, S., Van Dillen, S. M., Groenewegen, P. P., & Spreeuwenberg, P. (2013). Streetscape greenery and health: stress, social cohesion and physical activity as mediators. Social Science & Medicine, 94, 26-33.

FHWA. (n.d.). Walkways, Sidewalks, and Public Space. FHWA course on bicycle and pedestrian transportation. Retrieved from https://safety.fhwa.dot.gov/ped_bike/univcourse/pdf/swless13.pdf

Galderisi, A., & Ferrara, F. F. (2012). Enhancing urban resilience in face of climate change: a methodological approach. Tema. Journal of Land Use, Mobility and Environment, 5(2), 69-88.

Gehl, J. (1986). "Soft edges" in residential streets. Scandinavian housing and planning research, 3(2), 89-102.

Gehl, J. (2013). Cities for people. Island press.

Happy City. (2017, July). Happy Streets Living Lab. Retrieved from https://thehappycity.com/wp-content/uploads/2017/07/Happy-Streets-Living-Lab-Report-Final_0710_web.pdf

Hull, A., & O'Holleran, C. (2014). Bicycle infrastructure: can good design encourage cycling?. Urban, Planning and Transport Research, 2(1), 369-406.

ITE (Institute of Transportation Engineers). (2006). Context Sensitive Solutions in Designing Major Urban Thoroughfares for Walkable Communities, an ITE Proposed Recommended Practice. Retrieved from https://www.epa.gov/sites/production/files/2015-11/documents/rp036.pdf

Kang, L., & Fricker, J. D. (2016). Sharing urban sidewalks with bicyclists? An exploratory analysis of pedestrian perceptions and attitudes. Transport Policy, 49, 216-225.

Klemm, W., Heusinkveld, B. G., Lenzholzer, S., & van Hove, B. (2015). Street greenery and its physical and psychological impact on thermal comfort. Landscape and Urban Planning, 138, 87-98.

Kim, S., Choi, J., & Kim, Y. (2011). Determining the sidewalk pavement width by using pedestrian discomfort levels and movement characteristics. KSCE Journal of Civil Engineering, 15(5), 883.

Kong, L., Lau, K. K. L., Yuan, C., Chen, Y., Xu, Y., Ren, C., & Ng, E. (2017). Regulation of outdoor thermal comfort by trees in Hong Kong. Sustainable Cities and Society, 31, 12-25.

Kuo, F. E., & Sullivan, W. C. (2001). Environment and crime in the inner city: Does vegetation reduce crime?. Environment and behavior, 33(3), 343-367.

Leaf, W. A., & Preusser, D. F. (1999). Literature review on vehicle travel speeds and pedestrian injuries. US Department of Transportation, National Highway Traffic Safety Administration.

Levelt, P. B. M. (1992). Improvement of Pedestrian Safety and Comfort at Traffic Lights: Results from French, British and Dutch Field Tests (Vol. 92, No. 56). SWOV Institute for Road Safety.

Lin, B., Li, X., Zhu, Y., & Qin, Y. (2008). Numerical simulation studies of the different vegetation patterns' effects on outdoor pedestrian thermal comfort. Journal of Wind Engineering and Industrial Aerodynamics, 96(10-11), 1707-1718.

Litman, T. (1999). Traffic calming: benefits, costs and equity impacts.

Reference

Victoria, BC,, Canada: Victoria Transport Policy Institute.

McGill Cycling Working Group. (2014, July). Recommendations. Retrieved from https://www.mcgill.ca/campusplanning/files/campusplanning/pedestrian_cycling_co-existence_final_report.pdf

Mead, J., Zegeer, C., Bushell, M. (2014, April). Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research. Retrieved from http://www.pedbikeinfo.org/cms/downloads/PedestrianLitReview_April2014.pdf#page=10&zoom=100,69,326

Mehta, V., & Bosson, J. K. (2010). Third places and the social life of streets. Environment and Behavior, 42(6), 779-805.

Miranda-Moreno, L. F., Morency, P., & El-Geneidy, A. M. (2011). The link between built environment, pedestrian activity and pedestrian–vehicle collision occurrence at signalized intersections. Accident Analysis & Prevention, 43(5), 1624-1634.

Macdonald, E. (2005). Street-facing dwelling units and livability: The impacts of emerging building types in Vancouver's new high-density residential neighbourhoods. Journal of Urban Design, 10(1), 13-38.

Montgomery, C. (2013). Happy city: Transforming our lives through urban design. Macmillan.

Nikolopoulou, M., Baker, N., & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: understanding the human parameter. Solar energy, 70(3), 227-235.

Nordic Forest Research. (n.d.). Urban Tree Diversity for Sustainable Cities, Policy Brief. Retrieved from https://nordicforestresearch.org/wp-content/uploads/2017/09/URBAN-TREE-DIVERSITY3.pdf

Otak, Inc. (2013, May). Hawaii Pedestrian Toolbox, A Guide for Planning, Design, Operations, and Education to Enhance Pedestrian Travel in Hawaii. Retrieved from https://hidot.hawaii.gov/highways/files/2013/07/Pedest-Tbox-Hawaii-Pedestrian-Toolbox-Low-Res.pdf

Ovstedal, L., & Ryeng, E. (2002, September). Understanding pedestrian comfort in European cities: How to improve walking conditions. In European Transport Conference, Cambridge, UK (Vol. 6).

Peprah, C., Oduro, C. Y., & Afi Ocloo, K. (2014). On-street parking and pedestrian safety in the Kumasi metropolis: issues of culture and attitude. Dev Country Stud, 4(20), 85-94.

Sarkar, S. (2003). Qualitative evaluation of comfort needs in urban walkways in major activity centers. Transportation Quarterly, 57(4), 39-59.

Schultheiss, B., Sanders, R., Judelman, B., Boudart, J., Blackburn, L., Brookshire, K., … & Embry, M. (2018). Literature Review: Resource Guide for Separating Bicyclists from Traffic. Retrieved from https://safety.fhwa.dot.gov/ped_bike/tools_solve/docs/fhwasa18030.pdf

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2008). Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships?. Journal of Epidemiology & Community Health, 62(5), e9-e9.

U.S. Department of Transportation. (2015). Traffic Calming to Slow Vehicle Speeds. https://www.transportation.gov/mission/health/Traffic-Calming-to-Slow-Vehicle-Speeds

Ulmer, J. M., Wolf, K. L., Backman, D. R., Tretheway, R. L., Blain, C. J., O'Neil-Dunne, J. P., & Frank, L. D. (2016). Multiple health benefits of urban tree canopy: The mounting evidence for a green prescription. Health & Place, 42, 54-62.

Whyte, W. H. (1980). The social life of small urban spaces.

Wisconsin Department of Transportation. (2010). Wisconsin Guide to Pedestrian Best Practices. Retrieved from https://wisconsindot.gov/Pages/projects/multimodal/ped.aspx

Woodcock, J., Banister, D., Edwards, P., Prentice, A. M., & Roberts, I. (2007). Energy and transport. The Lancet, 370(9592), 1078-1088.

Wu, Z., Kong, F., Wang, Y., Sun, R., & Chen, L. (2016). The impact of greenspace on thermal comfort in a residential quarter of Beijing, China. International journal of environmental research and public health, 13(12), 1217.

Neighbourhoods with higher rates of sociability are more resilient, both at an individual and community level.

Top photo by the Project for Public Spaces via Public Square. Bottom image by by Alice via Playing Out.

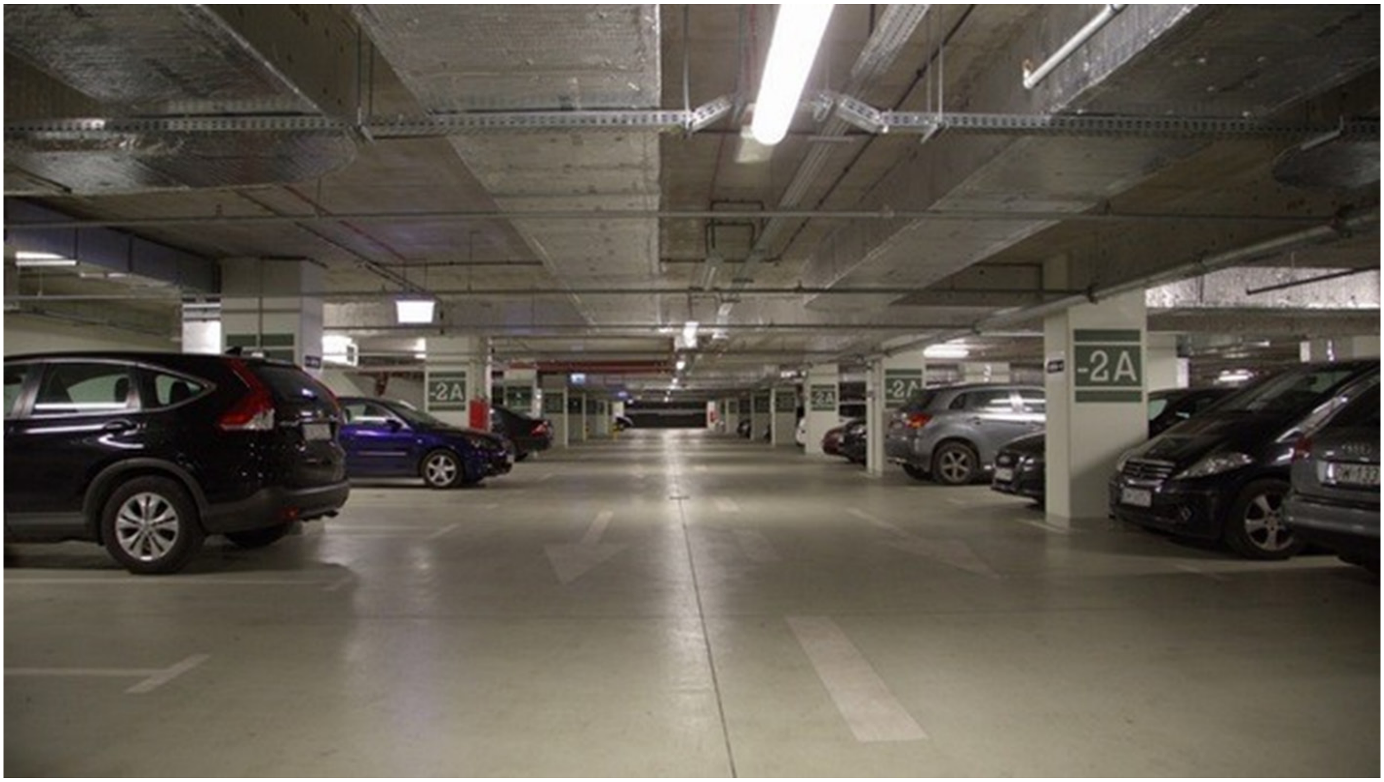
Sociable Built Form

The power of social capital to enhance resilience at an urban scale has been widely discussed within the literature (Aldrich & Meyer, 2015; Aldrich, 2012; Ledogar & Fleming, 2008). That is to say neighbourhoods with higher rates of sociability are more resilient, both at an individual and community level (Aldrich & Meyer, 2015; Murphy, 2007). One study conducted by Murphy (2007) for example found that communities with greater social capital resources showed greater resiliency in the face of urban emergencies such as the 2003 prolonged electricity power outage in eastern North America, and the 2000 E.coli crisis in Ontario. Because of the strong relationship between social capital and urban resilience established within the literature, numerous holistic urban resilience models have incorporating indicators which aim to measure social capital. The Disaster Resilience Index developed by Cutter et al (2010) for example adopts three explicit 'social capital' indicators (religion, civic involvement, and advocacy), whilst the Community Disaster Resilience model developed by the Torrens Resilience Institute also adopts a number of indicators which seek to quantify the level of social connectedness amongst community members (including the proportion of a community engaged with organizations such as sports teams and service groups; the level of communication between the community and local government; and the degree of connectedness across different demographic groups (age, ethnicity, new/old residents) within a community) (Arbon et al, 2012). Similarly, the City Resilience Index developed by ARUP and The Rockfeller Foundation (2014) uses indicators for 'cohesive communities' and 'local community support' as measurements of urban resilience, and in their analysis of over 30 holistic frameworks for measuring resilience Sharifi and Yamagata (2016) emphasis the recurrence of indicators which relate to social capital, including indicators such as 'place attachment and sense of community', 'shared assets', 'volunteerism and civic engagement in social networks', and the 'degree of connectedness across community groups' (pg.255).

Due to the heavily emphasized relationship between social capital and urban resilience and the widespread usage of indicators relating to social capital within the resilience literature, 'sociable built form' (the extent to which the built environment facilitates and encourages social interaction and enhances social capital) is used as a key indicator of the RNDT. Our research has shown that several underlying design elements can contribute to sociability in the built environment, including building massing (MacDonald, 2005), height (Kearnes et al, 2012), parking provision (Williams, 2005), building orientation (Jacobs, 1965), and communal spaces (City of Vancouver, 2018b).

Parking Provision

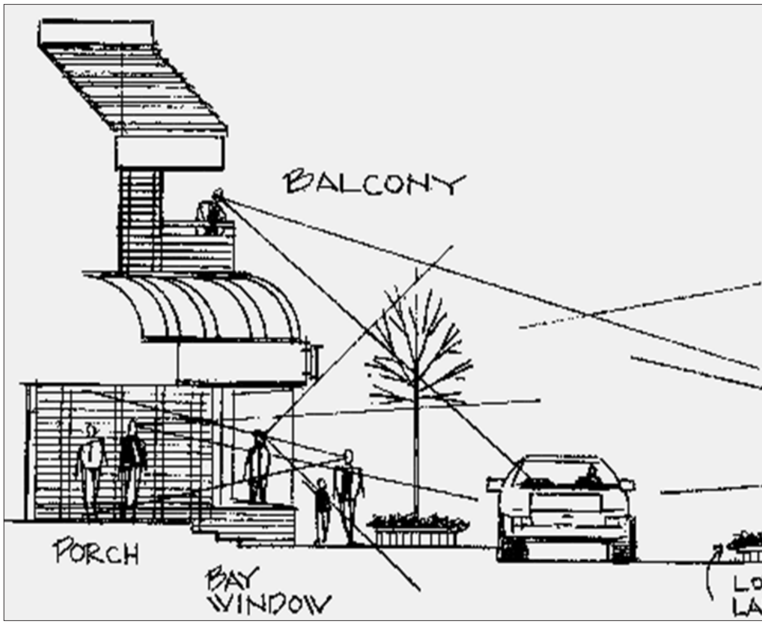
Underground parking gives people a direct, private entry point to their dwelling, thereby minimizing street presence and opportunities for social interaction (Atkinson, 2016). Conversely, ground-floor access points to buildings (rather than from an internal entry from an underground parking unit) contribute to increased opportunity for social interaction (MacDonald, 2005). On-street parking also allows car-focused activity to take place directly in front of groundfloor units, thereby enhances socialization opportunities (MacDonald, 2005). Car parking on the periphery of residential communities prevents residents from walking straight from their private unit to their cars (Williams, 2005) thereby increasing the likelihood of chance social interactions and the overall livability of an area.



Underground parking provides a direct private entry to residential dwellings which can minimize street presence and restrict opportunities for social interaction. Image by Wroclaw.

Building Orientation

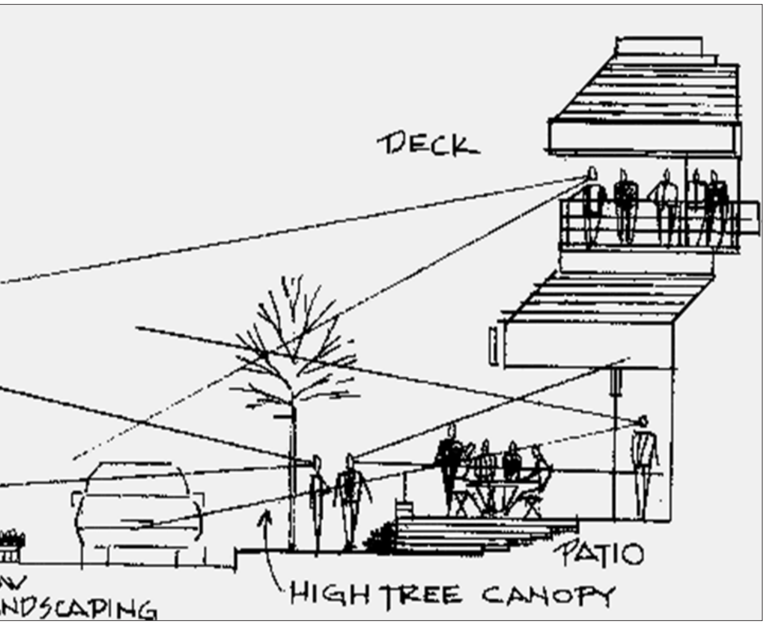
Street-facing building orientation with strong articulation of individual groundfloor units contribute to opportunities for social interaction (Gehl, 2011). A distance of at least 6 feet between buildings and the street is key for maintaining a comfortable transition zone between the public and private realms (MacDonald, 2005). Such a transition space allows for features such as front patios, covered balconies, front entry porches, external porch stairs, and front yard gardens – all of which encourage interaction for dwelling residents and those on the sidewalk (City of Vancouver, 2018a). Street facing dwellings with street orientated windows and doors also enhance feelings of 'eyes on the street' (Jacobs, 1965) which can increase the perception of safety and comfort of those on the sidewalks, thereby encouraging leisurely walking and increasing the likelihood of chance social interaction. Elevating groundfloor units slightly is preferable to enhance the privacy of residents and delineate a clear transition from the public realm of the street (City of New Westminster, 2017).



Street-facing dwellings with street-orientated windows provide additional opport
'eyes on the street', which can increase the perception of safety and comfort for those
create a clear transition from the public and private realms. Image source: Taylorsvi

Communal Space

Higher quality communal spaces that are functional and appealing to use attract more people and encourage greater social interaction (Willliams, 2005). Such spaces can enhance feelings of place attachment, sense of community, and social connectedness (Francis et al, 2012). Communal spaces that are permeable and visible are more likely to be perceived as 'safe', meaning people are more likely to spend a greater amount of time there. This increases the opportunity for social interaction (Monfared & Hashemnejad, 2015), which in turn can enhance social capital and contribute to community resilience. Design features which enhance the quality of outdoor communal amenity space (thereby increasing the likelihood of social interaction, and by extension, community resilience) include the presence of vegetation (Sullivan et al, 2004), appropriate seating and resting options (Carmona, 2019), solar access (Capeluto et al, 2006), and appropriate shade and shelter from wind and rain during different seasons and weather conditions (Mehta & Bosson, 2010; Whyte, 1980).



unities for social interaction, as well as providing passive surveillance and feelings of using the sidewalk. Groundfloor units which are slightly elevated above street level lle City (2019).

Communal spaces in residential buildings, such as this rooftop garden, can create opportunities for social interaction amongst residents and contribute to social capital and community resilience. Image sourced from mit24h.

In residential developments, communal gardens, workshops, amenity party rooms, shared kitchens, courtyards, playgrounds, balconies, and rooftop patios have been identified as effective design features that encourage social interaction and increase neighbourly connection, all of which contribute to social resiliency (City of Vancouver, 2018b). Building massing which creates a central protected space where interaction can occur (such as an outdoor courtyard predominantly enclosed by building massing) has also been demonstrated to contribute to more sociable neighbourhoods (Abu-Ghazzeh, 1999). The Happy City Happy Homes toolkit recommends creating sub-clusters within residential developments where no more than 12 households share a semi-private amenity space, and limiting the number of households per entrance to less than 8 in order to facilitate social interaction and build trust and social capital amongst neighbours (Happy City, 2017). The justification for this is that residential sub-clusters which facilitate smaller group sizes can reduce feelings of over-crowdedness and anonymity and increase opportunities for regular contact between neighbours (Happy City, 2017). In office buildings smaller building floor-plates have been demonstrated to be more conducive to greater social interaction amongst employees (Sailer & McCulloh, 2012).

Massing which positions ground-floor building levels close to the street encourages social interaction. Photo taken in Northwest Portland, Oregon, by the author.

Synergies + Trade-offs:

Active Edges

Active mixed-use street frontages encourage walking and pedestrian activity, which in turn enhances opportunities for social interaction and increases the liveliness of an area (Gehl, 2013; Montgomery, 2013; Jacobs, 1965).The presence of active, soft urban edges is strongly associated with improved livability (Gehl, 2013). Permeability of the street frontage (i.e. visual connection between the activities occurring within buildings and those at street level) is also important for promoting social behaviour (Mehta & Bossom, 2010).

Building Massing

Massing that articulates individual ground-floor units within a building enhances the impression of 'eyes on the street' (Macdonald, 2005), which can in turn improve opportunities for social interaction, sense of community, and feelings of safety (Jacobs, 1965; Brown et al, 2009). Massing which positions ground-floor building levels close to the street encourages social interaction (Montgomery, 2013; Harvey, 2004). Building massing which enhances urban ventilation and urban porosity can also utilize prevailing breezes as a passive cooling system to regulate the thermal environment, thereby minimizing the urban heat island effect and improving urban air quality (Raven, 2011) – all of which are beneficial to pedestrian comfort levels and urban resilience more generally.

Building Height

Social and psychosocial outcomes in high-rise residential buildings (greater than 12-storeys tall

(City of Vancouver, 2018b)) tend to be worse than for other housing typologies (Kearns et al, 2012; Evans et al, 2003; Zaff & Devlin, 1998).Overall, individuals living in high rise residential buildings have more mental health problems than those in other residential building typologies, and are more likely to experience social isolation (Evans, 2003; Evans et al, 2003). The social isolation experienced by high rise residents is likely causally linked to the worse psychosocial outcomes amongst these people (Evans, 2003). That is to say, increased social isolation within high rise buildings likely contributes to worse mental health outcomes amongst residents. This pattern is especially evident in vulnerable social groups and low income families (Kearns et al, 2012).

There are several key reasons as to why high rise buildings may be conducive to greater rates of loneliness and social isolation. Perhaps most importantly is that the architecture and urban design of high rise buildings tends to "support individualization and anonymity" (Musterd & van Kempen, 2005, p.21), which in turn leads to social withdrawal. For example, in a typical high rise building underground parking is connected to an elevator that whisks residents directly to their floor of residence. Each floor may contain a shared hallway onto which each private dwelling opens. However, this shared hallway will likely lack any amenities, seating, facilities, or design features that may encourage residents to linger and socialize. Consequently, residents may feel inclined to quickly transition from the elevator or staircase to their private dwelling, severely limiting opportunities for social interaction with neighbours and other residents to impersonal spaces such as elevators, lobbies, and hallways (Gifford, 2007). Closely related to this point is that highrise buildings typically lack quality defensible public space where social interaction can occur, and which residents can feel some sense of shared ownership over (Kearnes et al, 2012; Lowry, 1990). High-rise building typologies typically provide limited child-friendly areas, which has been shown to reduce overall child playtime compared to children living in more horizontal building typologies and can negatively impact on child development and wellbeing (Modi, 2018).

Individuals living in high-rise buildings are also more likely to feel a weaker sense of privacy and control in their living environment (McCarthy & Saegert, 1978). Such findings suggest that, although there is a strong relationship between the height of a building and sociability, this may in large be attributable to the design characteristics typical of high rise buildings, rather than being an inherent by-product of buildings themselves. That is to say, design interventions which increase defensible public space within high rise towers or which facilitate more opportunities for social interaction may be able to mitigate the relationship between building height and social outcomes.

A substantial body of literature has associated high-rise living with reduced sociability and worse psychosocial outcomes. Whilst this does not mean that tall buildings cannot be designed in a way that fosters social interaction, it suggests that conventionally, the i architecture and urban design of high-rise buildings has tended to "support individualization and anonymity" (Musterd & van Kempen, 2005, p.21). Image of the Vancouver House by Nicolas Blachette.

Low and midrise residential building typologies (generally considered to be around 2-4 storeys and 5-12 storeys respectively (City of Vancouver, 2018b)) are typically more likely to encourage sociability and foster a sense of community compared to high rise buildings (Tavakoli, 2017; Gifford, 2007; Jacobs, 1965; Dominguez, n.d.). Part of the reason for this is that lower building typologies engage more with the built environment at a street level, which enhances opportunities for social interaction between residents and those on the sidewalk or street (Macdonald, 2005). Given that a lack of social connectedness and support is likely a key driver behind the worse psychosocial outcomes amongst high-rise dwellers (Evans, 2003) this street-level engagement can have important implications for mental health. Such street-level engagement can also enhance passive surveillance and impressions of 'eyes on the street '(Jacobs, 1965), which can have positive implications for residents feelings of safety and their willingness to engage in social interaction. In low-rise developments, most movement is on the horizontal plane (rather than up vertical elevators) providing additional opportunity for social interaction with neighbours (Modi, 2014; Tavakoli, 2017). Low-rise building typologies are also more likely to provide easy access to family-friendly amenities where children can play with one another, which increases social opportunities amongst young residents (Modi, 2018).

Reference

Atkinson, R. (2016). Limited exposure: Social concealment, mobility and engagement with public space by the super-rich in London. Environment and Planning A: Economy and Space, 48(7), 1302-1317.

Abu-Ghazzeh, T. M. (1999). Housing layout, social interaction, and the place of contact in Abu-Nuseir, Jordan. Journal of environmental psychology, 19(1), 41-73.

Aldrich, D. P. (2012). Building resilience: Social capital in post-disaster recovery. University of Chicago Press.

Aldrich, D. P., & Meyer, M. A. (2015). Social capital and community resilience. American behavioral scientist, 59(2), 254-269.

Arbon, P., Gebbie, K., Cusack, L., Perera, S., & Verdonk, S. (2012). Developing a model and tool to measure community disaster resilience: Final report. Australia: Torrens Resilience Institute.

Capeluto, I. G., Yezioro, A., Bleiberg, T., & Shaviv, E. (2006, September). Solar rights in the design of urban spaces. In Comunicación presentada en la 23rd Conference on Passive and Low Energy Architecture, Ginebra.

Carmona, M. (2019). Principles for public space design, planning to do better. Urban Design International, 24(1), 47-59.

City of New Westminster. (2017). Our City New Westminster, Official Community Plan Development Permit Areas. Retrieved from https://www.newwestcity.ca/council_minutes/0710_17/DPA%20Guidelines%20Aug%2028%202017.pdf

City of Vancouver. (2018a). RM-8A and RM-8AN Guidelines. Land Use and Development Policies and Guidelines. Retrieved from https://guidelines.vancouver.ca/R031.pdf

City of Vancouver. (2018b). Hey Neighbour! Exploring sociability in multi-unit buildings across Vancouver. Retrieved from https://vancouver.ca/files/cov/hey-neighbour-case-study-booklet.pdf

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1).

Dominguez, S. (n.d.). Living Up, Or Living Apart? Addressing the Social Consequences of High-Rise Living. Retrieved from https://vancouver.ca/files/cov/living-up-or-living-apart.pdf

Evans, G. W., Wells, N. M., & Moch, A. (2003). Housing and mental health: a review of the evidence and a methodological and conceptual critique. Journal of social issues, 59(3), 475-500.

Evans, G. 2003. The built environment and mental health. Journal of Urban Health, 80(4): 536–555.

Gehl, J. (2011). Life between buildings: using public space. Island press.

Gehl, J. (2013). Cities for people. Island press.

Gifford, R. (2007). The consequences of living in high-rise buildings. Architectural science review, 50(1), 2-17.

Happy City. (2017). Happy Homes toolkit. Retrieved from https://thehappycity.com/project/happy-homes/

Jacobs, J. (1965). The death and life of great American cities.

Harmondsworth, UK: Penguin.

Kearns, A., Whitley, E., Mason, P., & Bond, L. (2012). 'Living the high life'? Residential, social and psychosocial outcomes for high-rise occupants in a deprived context. Housing Studies, 27(1), 97-126.

Ledogar, R. J., & Fleming, J. (2008). Social capital and resilience: A review of concepts and selected literature relevant to Aboriginal youth resilience research. Pimatisiwin, 6(2), 25.

Lowry, S. (1990). Housing and health: Families and flats. BMJ: British Medical Journal, 300(6719), 245.

Macdonald, E. (2005). Street-facing dwelling units and livability: The impacts of emerging building types in Vancouver's new high-density residential neighbourhoods. Journal of Urban Design, 10(1), 13-38.

McCarthy, D., & Saegert, S. (1978). Residential density, social overload, and social withdrawal. Human Ecology, 6(3), 253-272.

Mehta, V., & Bosson, J. K. (2010). Third places and the social life of streets. Environment and Behavior, 42(6), 779-805.

Modi, S. (2014). Improving the Social Sustainability of High-rises. Council on Tall Buildings and Urban Habitat Journal, (1). Retrieved from http://global.ctbuh.org/resources/papers/download/828-improving-the-social-sustainability-of-high-rises.pdf

Modi, S. (2018). An analysis of high-rise living in terms of provision of appropriate social spaces for children. Journal of Urban Design and Health, 5(4). Retrieved from https://www.urbandesignmentalhealth.com/journal-5---high-rise.html

Monfared, N. S. S., Hashemnejad, H., & Yazdanfar, S. A. (2015). Design principles in sustainable local community with security and socialization approach (Case study: Chizar). Procedia-Social and Behavioral Sciences, 201, 62-70.

Murphy, B. L. (2007). Locating social capital in resilient community-level emergency management. Natural Hazards, 41(2), 297-315.

Musterd, S., & Van Kempen, R. (2005). Large-scale Housing Estates in European Cities: opinions of residents on recent developments.

Raven, J. (2011). Cooling the public realm: climate-resilient urban design. In Resilient Cities (pp. 451-463). Springer, Dordrecht.

Sailer, K., & McCulloh, I. (2012). Social networks and spatial configuration—How office layouts drive social interaction. Social networks, 34(1), 47-58.

Sharifi, A., & Yamagata, Y. (2016). Urban Resilience Assessment: Multiple Dimensions, Criteria, and Indicators. In Urban Resilience (pp. 259-276). Springer, Cham.

Tavakoli, A. (2017). Supporting friendlier, more neighbourly multi-unit buildings in Vancouver. Retrieved from https://sustain.ubc.ca/sites/sustain.ubc.ca/files/GCS/2017_GCS/Final_Reports/Supporting%20friendlier%20more%20neighbourly%20multi-unit%20buildings%20

Taylorsville City, Utah. (2019). Chapter 13.12: Traditional Neighbourhood Development Overlay Zone. In Taylorsville, Utah: City Code. Retrieved from https://www.sterlingcodifiers.com/codebook/m_index.php?book_id=540

Williams, J. (2005). Designing neighbourhoods for social interaction: The case of cohousing. Journal of Urban Design, 10(2), 195-227. doi:10.1080/13574800500086998

Wroclaw. (2016, February 10). NMF underground parking fees from Feb 15. Retrieved from https://www.wroclaw.pl/en/nmf-underground-parking-fees-from-feb-15-prices

Zaff, J., & Devlin, A. S. (1998). Sense of community in housing for the elderly. Journal of community psychology, 26(4), 381-398.

ENERGY + GHG

Transit Accessibility

Transit accessibility is considered within the literature to be conducive to urban resilience goals (Pendall et al, 2012; Forth et al, 2013; Newman et al, 2009). For example, transit accessibility encourages active transportation such as walking, and can contribute to a reduction in vehicle ownership and use (Liu & Cirillo, 2015). This in turn can reduce GHG emissions and improve the public health outcomes of a community through reduced exposure to air pollution and reduced physical inactivity (Sallis et al, 2004; Litman, 2003). Transit accessibility can also contribute to social equity by providing easier access to key essential services such as healthcare, food, and education – an especially important matter for low-income groups who may be unable to afford car ownership (Golub & Martens, 2014).

Transit accessibility can generally be understood as "the ease of travel for an individual to reach a desired destination via public transit" (Fayyaz et al, 2017, pg.2). Most attempts to measure transit accessibility can generally either be categorized as those which do not consider travel time (and instead focus on indicators such service coverage, comfort, and frequency of service) and those which do (Fayyaz et al, 2017). Due to the fundamental importance of travel time in influencing mobility choices and the tendency of simple non-time based metrics such as service coverage exaggerate the accessibility of transit (Polzin et al, 2002), the latter category has received greater attention within the literature over recent years (Fayyaz et al, 2017). For this reason, the RNDT has adopted a travel-time based metric for calculating transit accessibility, which measures the amount of access provided by transit to a region's land use (in terms of total jobs and population) from a particular location within 40 minutes travel time, where a balance of land use (jobs and residents) within this travel time indicates good transit accessibility.

Transit Stations

Increasing transit stations and optimizing the location of these can improve residential accessibility and proximity to transit, which heavily influences the usage and performance of transit services (Chien & Qin, 2004). This has positive implications for reducing auto-dependence and auto-related costs and energy usage (Holtzclaw, 1994). In turn, such reductions in automobile usage have positive implications for improving urban air quality, traffic congestion (Beaudoin et al, 2015), and livable built form (Lewis-Workman & Brod, 1997). To enhance accessibility, transit stations will ideally be located on flat (or almost-flat) ground in a visible location with universal access, and a suitable range of amenities. For rapid transit bus stops in British Columbia for example, bus stop poles and strip signs, system icons, route/schedule information, lighting, passenger landing pads, wheelchair pads, garbage bins, seating, and shelter are mandatory amenities, with additional amenities such

Transit accessibility can contribute to social equity by providing easier access to key essential services such as healthcare, food, and education – an especially important matter for low-income groups who may be unable to afford car ownership.

as real-time bus information and bicycle storage being highly desirable (BC Transit, 2010).

Synergies + Trade-offs:

Transit Proximity

In addition to travel time, proximity is commonly perceived to be an important component of transport accessibility (Albacete et al, 2017). Several studies have shown a strong association between transit proximity and transit ridership (Hess, 2009). A recent study of Jan Jose, California, for example found that self-reported walking distance had a statistically significant influence on ridership numbers, and that for each additional five minutes in perceived walking time to transit there was a corresponding 5% decrease in transit usage amongst non-drivers (Hess, 2009). Although conventionally a 0.5-mile (roughly 800m) distance buffer has been used to show the area that a transit station may service, recent research indicates that a much smaller buffer of 0.25-mile (roughly 400m) is more powerful for predicting station-level transit ridership in relation to jobs (Guerra et al, 2012). Due to its relevance to urban resilience, 'Transit proximity' (measured as the percentage of people and jobs within 400m of a convenient transit corridor) is used as an indicator in the holistic sustainability

Access to transit can reduce household spending on transportation, thereby freeing up a greater proportion of household budget which can be used to cover other expenses such as food and accommodation. Photo of the Vancouver SkyTrain by John Lee via Lonely Planet.

framework developed by the Design Centre for Sustainability at the University of British Columbia (DCS, 2009), and the holistic CityLab Action Guide recommends that "the greatest distance to a public transportation stop should not exceed 400 meters" (Sweden Green Building Council, 2018, pg,41).

Jobs-housing balance

A jobs-housing balance can have positive benefits for urban resilience goals by compressing travel distances and converting motorized trips to transit use, cycling, or walking (Cervero & Duncan, 2006). Conversely, an imbalance of jobs and housing can contribute to longer commute times and an increased vehicle miles traveled (VMT) (Sultana, 2002). Sultana (2002) for example found that areas with a imbalanced jobs/housing ratio in Atlanta had on average commute time of 3.5 minutes longer than areas with a balanced jobs/housing ratio, whilst Ewing et al (1996) suggests that a jobs-housing balance can reduce a regions VMT by over 15%. Other benefits of a jobs-housing balance include lowering public expenditures on facilities and services and contributing to a higher quality of life and greater family stability amongst many residents (Armstrong & Sears, 2001).

The average Canadian household paid $12,707 for transportation in 2017, and of this an average of $11,433 was spent on private transportation Canada.

Affordable Housing

Although much of the focus on residential affordability is centered on the cost of housing, it is important to note that housing affordability is influenced by a range of factors. One particularly salient factor is household income spent on transportation, which is in turn influenced by mobility choices and accessibility to public transit. In a national survey of household spending during 2017, Statistics Canada identified the largest portions on household budget go to shelter and transportation, with 29.2% and 19.9% of household spending being attributed to these two areas respectively (Statistics Canada, 2018). Most of this spending on transportation can be attributed to private transportation costs, such as the purchase and operation of cars. For instance, the average Canadian household paid $12,707 for transportation in 2017, and of this an average of $11,433 was spent on private transportation (Statistics Canada, 2018).

Such numbers highlight the importance of the availability and accessibility of public transportation in reducing household spending. Accessibility to rapid transit for example has the potential to significantly lower household spending on transport (Renne et al, 2016). This frees up a greater proportion of household budget able to be spent on accommodation, thereby making a broader range of housing options 'affordable' to residents relative to overall household spending. This relationship between transit accessibility and affordable housing is also bidirectional. For example, low-income households that need highly affordable housing options are less likely to own cars and more likely to use transit which can improve transit ridership (Tumlin & Millard-Ball, 2003).

It should be acknowledged that although accessibility to transit has the potential to improve social equity and urban resilience, the development that typically accompanies accessible transit has the potential to increase land prices, which may negatively impact residential affordability (Pendall et al, 2012). This is especially true if the demand for housing in areas immediately proximate to transit exceeds the supply of housing options (Renne et al, 2016). In Burnaby (British Columbia) for example, Jones and Ley (2016) found that the development next to transit stations led to a loss of affordable housing. However, the increased cost of housing close to transit is more than often offset by the significantly lower spending on transportation that accompanies this type of development, which means that the total housing and transportation costs for residents near transit is still less than for households far away from transit. A study by Renne et al (2016) for instance found that the combined housing and transportation costs within a Transit Orientated Development area were 4% lower than in adjacent developments.

Reference

Albacete, X., Olaru, D., Paül, V., & Biermann, S. (2017). Measuring the accessibility of public transport: A critical comparison between methods in Helsinki. Applied Spatial Analysis and Policy, 10(2), 161-188.

Armstrong, M., and Sears, B. (2001, April). The New Economy and Jobs/Housing Balance in Southern California. Retrieved from http://www.scag.ca.gov/Documents/NewEconomyJobsHousingBalance.pdf

BC Transit. (2010). Infrastructure Design Guidelines. Retrieved from https://www.bctransit.com/documents/1507213417526

Beaudoin, J., Farzin, Y. H., & Lawell, C. Y. C. L. (2015). Public transit investment and sustainable transportation: A review of studies of transit's impact on traffic congestion and air quality. Research in Transportation Economics, 52, 15-22.

Cervero, R., & Duncan, M. (2006). 'Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing?. Journal of the American planning association, 72(4), 475-490.

Chien, S. I., & Qin, Z. (2004). Optimization of bus stop locations for improving transit accessibility. Transportation planning and Technology, 27(3), 211-227.

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Ewing, R., DeAnna, M., Heflin, C. C., & Porter, D. R. (1996). Best development practices.

Fayyaz S, S. K., Liu, X. C., & Zhang, G. (2017). An efficient General Transit Feed Specification (GTFS) enabled algorithm for dynamic transit accessibility analysis. PloS one, 12(10), e0185333.

Foth, N., Manaugh, K., & El-Geneidy, A. M. (2013). Towards equitable transit: examining transit accessibility and social need in Toronto, Canada, 1996–2006. Journal of transport geography, 29, 1-10.

Golub, A., & Martens, K. (2014). Using principles of justice to assess the modal equity of regional transportation plans. Journal of Transport Geography, 41, 10-20.

Guerra, E., Cervero, R., & Tischler, D. (2012). Half-mile circle: Does it best represent transit station catchments?. Transportation Research Record, 2276(1), 101-109.

Hess, D. B. (2009). Access to public transit and its influence on ridership for older adults in two US cities. Journal of Transport and Land Use, 2(1), 3-27.

Holtzclaw, J. (1994). Using residential patterns and transit to decrease auto dependence and costs (Vol. 11). San Francisco, CA: Natural Resources Defense Council.

Jones, C. E., & Ley, D. (2016). Transit-oriented development and gentrification along Metro Vancouver's low-income SkyTrain corridor. The Canadian Geographer/Le Géographe Canadien, 60(1), 9-22.

Lewis-Workman, S., & Brod, D. (1997). Measuring the neighborhood benefits of rail transit accessibility. Transportation Research Record, 1576(1), 147-153.

Litman, T. (2003). Integrating public health objectives in transportation decision-making. American Journal of Health Promotion, 18(1), 103-108.

Liu, Y., & Cirillo, C. (2015). Measuring transit service impacts on vehicle ownership and use. Public transport, 7(2), 203-222.

Newman, P., Beatley, T., & Boyer, H. (2009). Resilient cities: responding to peak oil and climate change. Island Press.

Pendall, R., Gainsborough, J., Lowe, K., & Nguyen, M. (2012). Bringing equity to transit-oriented development: Stations, systems, and regional resilience. Building Resilient Regions: Urban and Regional Policy and its Effects, 4, 148-92.

Pendall, R., Gainsborough, J., Lowe, K., & Nguyen, M. (2012). Bringing equity to transit-oriented development: Stations, systems, and regional resilience. Building Resilient Regions: Urban and Regional Policy and its Effects, 4, 148-92.

Polzin, S. E., Pendyala, R. M., & Navari, S. (2002). Development of time-of-day–based transit accessibility analysis tool. Transportation Research Record, 1799(1), 35-41.

Renne, J. L., Tolford, T., Hamidi, S., & Ewing, R. (2016). The cost and affordability paradox of transit-oriented development: A comparison of housing and transportation costs across transit-oriented development, hybrid and transit-adjacent development station typologies. Housing Policy Debate, 26(4-5), 819-834.

Sallis, J. F., Frank, L. D., Saelens, B. E., & Kraft, M. K. (2004). Active transportation and physical activity: opportunities for collaboration on transportation and public health research. Transportation Research Part A: Policy and Practice, 38(4), 249-268.

Statistics Canada. (2018). Survey of Household Spending, 2017. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/181212/dq181212a-eng.htm

Sweden Green Building Council. (2018). CityLab Action Guide – Version 2.0. Retrieved from http://www.decodeprojektet.se/media/1167/eng-citylabactionguide-180516-webb_com.pdf

Tumlin, J., & Millard-Ball, A. (2003). How to make transit-oriented development work. PLANNING-CHICAGO-, 69(5), 14-19.

Cycling Infrastructure

Infrastructure which favors active forms of mobility such as cycling over automobile usage contributes to urban resilience in numerous ways (Newman, 2010). For example, infrastructure of this sort is conducive to a more compact and dense urban form, which improves the efficiency of urban transportation networks and reduces the amount of energy used by the transportation sector (Litman, 2018), enhancing the resilience of urban energy systems. Simultaneously, increasing cycling infrastructure increases the likelihood that individuals will cycle to the different destinations that comprise their daily needs (Cervero et al, 2013). This reduces automobile usage, which in turn reduces the amount of GHG emissions produced by a city and decreases automobile related air and noise pollution – increasing the livability and climate resilience of an urban area (Newman et al, 2009). For example, a recent study conducted by the Institute for Transportation and Development Policy estimates that in a hypothetical future scenario where 14% of travel in the world's cities is by bicycle, the total global carbon emissions from urban transportation (which itself is a huge emitter) could be reduced by 11% (Mason et al, 2015).

The increased active forms of mobility encouraged by increasing cycling infrastructure can have positive implications for the health of individuals, including increased fitness, and lower rates of obesity and respiratory disease (Oja et al, 2011). This enhances the physical resilience of individuals within a community and lowers spending on public health (Litman, 2018; Katzmarzyk et al, 2000), which boosters the social and economic resilience of a city respectively. A study conducted in China reported a statistically significant relationship between mortality and cycling for transportation, with those who cycled as their predominant form of mobility having a 35% reduction in risk for all—cause mortality (Matthews et al, 2007), whilst a Danish study (Andersen et al, 2000) found that bicycling to work decreased risk of mortality by 39% after adjusting for other factors such as leisure time physical activity. Cycling infrastructure also has the potential to enhance the resilience of

Cycling infrastructure can increase the likelihood that individuals will choose to bike to the difference destinations that comprise their daily needs, which can have numerous resilience benefits including improved public health outcomes and a reduction in carbon emissions caused by automobile trips. Image by HUB Cycling via Daily Hive.

urban transportation networks by increasing diversity of mobility forms. Diversity has been identified as a fundamental characteristic of a resilient system (Godschalk, 2003) and an important contributor to resilience in urban transportation systems more generally (Litman, 2017; Murray-Tuite, 2006).

For these reasons, cities or communities seeking LEED certification are encouraged to design "exclusive and protected bike lines" for at least 90% of the total urban street length where the speed limit is greater than 30km per hour (U.S. Green Building Council, 2019, pg.37). Similarly, Gillis et al (2016) uses 'opportunity for active mobility' (for which cycling infrastructure can act as a proxy) as an indicator of sustainable urban mobility – a core component of urban resilience (Newman et al, 2009; Newman, 2010). The presence of 'bicycle parking', 'bicycle facilities', and 'bike share facilities' are used as measures of success in the EcoDistrict Toolkit developed by the Portland Sustainability Index, and the holistic Community Wellbeing Framework developed by Markovich et al (2018) uses several indicators which seek to measure the extent to which a "project prioritizes and celebrates active modes of transportation and connections to transit, rather than single-occupancy vehicles", including an indicator on whether a project "provides secure, covered bicycle storage adjacent to public areas" and "has access within walking distance to a cycling path" (pg.56).

Because of the strong relationship between the provision of quality cycling infrastructure, the number of people engaging in active forms of mobility, and a host of resilience outcomes such as improved public health and reduced automobile dependence, the RNDT utilizes 'cycling infrastructure' (which measures the percentage of GFA in a development that meets a set of specific cycling criteria) as an indicator of urban resilience.

Reference

Andersen, L. B., Schnohr, P., Schroll, M., & Hein, H. O. (2000). All-cause mortality associated with physical activity during leisure time, work, sports, and cycling to work. Archives of internal medicine, 160(11), 1621-1628.

Cervero, R., Caldwell, B., & Cuellar, J. (2013). Bike-and-ride: build it and they will come. Journal of Public Transportation, 16(4), 5.

Gillis, D., Semanjski, I., & Lauwers, D. (2016). How to monitor sustainable mobility in cities? Literature review in the frame of creating a set of sustainable mobility indicators. Sustainability, 8(1), 29.

Godschalk, D. R. (2003). Urban hazard mitigation: Creating resilient cities. Natural Hazards Review, 4(3), 136-143. doi:10.1061/(ASCE)1527-6988(2003)4:3(136)

Katzmarzyk, P. T., Gledhill, N., & Shephard, R. J. (2000). The economic burden of physical inactivity in Canada. Cmaj, 163(11), 1435-1440.

Litman, T. (2017). Evaluating Transportation Diversity. Victoria Transport Policy Institute.

Litman, T. (2018). Economic Value of Walkability. Retrieved from https://www.vtpi.org/walkability.pdf

Markovich, J., Slovinec, D., & Dinh, T. (2018). Community Wellbeing: A Framework for the Design Professionals. Ottawa: The Conference Board of Canada.

Mason, J., Fulton, L., & McDonal, Z. (2015, November). A Global High Shift Cycling Scenario: The Potential For Dramatically Increasing Bicycle and E-bike Use in Cities Around the World with Estimated Energy, C02, and Cost Impacts. Retrieved from https://itdpdotorg.wpengine.com/wp-content/uploads/2015/11/A-Global-High-Shift-Cycling-Scenario_Nov-2015.pdf

Matthews, C. E., Jurj, A. L., Shu, X. O., Li, H. L., Yang, G., Li, Q., ... & Zheng, W. (2007). Influence of exercise, walking, cycling, and overall nonexercise physical activity on mortality in Chinese women. American journal of epidemiology, 165(12), 1343-1350.

Murray-Tuite, P. M. (2006, December). A comparison of transportation network resilience under simulated system optimum and user equilibrium conditions. In Proceedings of the 2006 Winter Simulation Conference (pp. 1398-1405). IEEE.

Newman, P. (2010). Resilient infrastructure cities. Developing Living Cities: From Analysis to Action; Kallidaikurichi, S., Yuen, B., Eds, 77-106.

Newman, P., Beatley, T., & Boyer, H. (2009). Resilient cities. Responding to peak oil and climate change. Washington DC.

Oja, P., Titze, S., Bauman, A., De Geus, B., Krenn, P., Reger-Nash, B., & Kohlberger, T. (2011). Health benefits of cycling: a systematic review. Scandinavian journal of medicine & science in sports, 21(4), 496-509.

Portland Sustainability Institute. (2011). EcoDistricts Toolkit: Assessment.

U.S. Green Building Council. (2019). LEED v4.1 Cities and Communities: Plan and Design. Retrieved from https://new.usgbc.org/leed-v41#cities-and-communities

Parking Provision

Parking provision is related to resilience through several different pathways. One such pathway is that of affordability (Litman, 2019; Jia & Wachs, 1999). Residential buildings that provide off-street parking are typically less affordable overall than those that don't (Jia & Wachs, 1999). An analysis of San Francisco for example found that single-detached houses and condominiums which include off-street parking are more than 10% more costly than those that do not (Jia & Wachs, 1999). The Victoria Transport Policy Institute estimates that for typical affordable housing development, one parking space per unit will increase costs by 12.5%, whilst two parking spaces per unit can increase costs by up to 25% (Litman, 2019). Given that affordability housing / shelter is an often used indicator in holistic resilience models including the City Resilience Index developed by ARUP and The Rockfeller Foundation (2014), the WILUTE model of urban sustainability developed by Zhao et al (2013), and the IFRC (International Federation of Red Cross) Framework for Community Resilience (2014), a reduction in affordability associated with parking provision in residential developments can be seen to be detrimental to neighbourhood resiliency.

Another pathway through which parking provision relates to urban resilience is the energy usage and embodied carbon associated with constructing and maintaining car parking infrastructure. Both underground and surface parking increases the amount of concrete and cement used in construction, which has a high embodied carbon content (Hammond & Jones, 2008). Such resource intensive construction reduces resiliency against climate change by contributing significantly to global GHG emissions, as well as facilitating a form of transportation (cars) which also produce a significant amount of GHG emissions and degrade urban air quality (Kodransky & Hermann, 2010). Parking provision also directly increases the amount of impervious urban surface, which has been demonstrated to increase vulnerability to flood-related hazards (Brody et al, 2012) and contribute to UHI (Forinash et al, 2003).

A final pathway through which parking provision

The Victoria Transport Policy Institute estimates that for typical affordable housing development, one parking space per unit will increase costs by 12.5%, whilst two parking spaces per unit can increase costs by up to 25%. Image by Transport for Wales.

relates to urban resilience is by creating or restricting opportunities for social interaction which can contribute to social capital and community resilience (Aldrich & Meyer, 2015). For instance, underground parking gives people a direct, private entry point to their dwelling, thereby minimizing street presence and opportunities for social interaction (Atkinson, 2016). Conversely, ground-floor access-points to buildings (rather than an internal entrance from an underground parking unit) contribute to increased opportunities for social interaction (MacDonald, 2005). On-street parking also allows car-focused activity to take place directly in front of groundfloor units, thereby enhancing the opportunity for socialising with other residents and those passing on the street (MacDonald, 2005). Car parking on the periphery of residential communities can prevent residents from walking straight from their private unit to their cars (Williams, 2005) thereby increasing the likelihood of chance social interactions and the overall livability of an area.

In summary, an increased provision of car parking can generally be perceived to act counter to urban resilience goals. If parking must be including within a residential community however, then surface street-level parking on the edge of a community may be preferable over underground parking, both in terms of embodied carbon and social capital. Due to the pertinence of parking provision to urban resilience, the RNDT has adopted this metric as an indicator of resiliency, where a reduction in parking provision is generally seen to be conducive to resilience.

Reference

Hammond, G. P., & Jones, C. I. (2008). Embodied energy and carbon in construction materials. Proceedings of the Institution of Civil Engineers-Energy, 161(2), 87-98.

Litman, T. (2019). Parking Requirements Impacts on Housing Affordability. Retrieved from http://vtpi.org/park-hou.pdf

Atkinson, R. (2016). Limited exposure: Social concealment, mobility and engagement with public space by the super-rich in London. Environment and Planning A: Economy and Space, 48(7), 1302-1317.

Macdonald, E. (2005). Street-facing dwelling units and livability: The impacts of emerging building types in Vancouver's new high-density residential neighbourhoods. Journal of Urban Design, 10(1), 13-38.

Forinash, C. V., Millard-Ball, A., Dougherty, C., & Tumlin, J. (2003, July). Smart growth alternatives to minimum parking requirements. In 2nd Urban Street Symposium: Uptown, Downtown or Small Town: Designing Urban Streets That Work, Anaheim, California: Transportation Research Board: Washington, DC.

Aldrich, D. P., & Meyer, M. A. (2015). Social capital and community resilience. American behavioral scientist, 59(2), 254-269.

ARUP and The Rockfeller Foundation. (2014). City Resilience Index; understanding and measuring city resilience.

Zhao, P., Chapman, R., Randal, E., & Howden-Chapman, P. (2013). Understanding resilient urban futures: a systemic modelling approach. Sustainability, 5(7), 3202-3223.

IFRC. (2014). IFRC Framework for community resilience. International Federation or Red Cross and Red Crescent Societies, Geneva, Switzerland.

Jia, W., & Wachs, M. (1999). Parking requirements and housing affordability: Case study of San Francisco. Transportation Research Record, 1685(1), 156-160.

Kodransky, M., & Hermann, G. (2010). Europe's parking u-turn: from accomodation to regulation. Institute for Transportation and Development Policy.

Williams, J. (2005). Designing neighbourhoods for social interaction: The case of cohousing. Journal of Urban Design, 10(2), 195-227. doi:10.1080/13574800500086998

Embodied Carbon

Reducing the amount of emissions from infrastructure and buildings has been identified as an important part of addressing external global stressors such as climate change (Zizzo et al, 2017). Given that roughly 20% of total global GHG emissions are embodied in the construction phase of buildings and infrastructure (Oka et al, 2013), targeting the construction sector will be an important component of this process, and a salient opportunity to increase resilience at the urban scale. For this reason the City of Vancouver has outlined a set of targets which aim to reduce the embodied emissions in new buildings by 40% (relative to a 2018 baseline) by 2030, with a primary emphasis on using lower carbon construction materials and designs (City of Vancouver, 2019). Reducing construction waste and improving the recycling of materials used in construction will also be an important component of reducing embodied carbon in buildings (U.S. Green Building Council, 2019).

Reducing total urban GHG emissions (of which embodied carbon is a significant contributor) is frequently discussed within the resilience literature (Galderisi & Ferrara, 2012) and is a key focus of numerous models for assessing urban resilience such as the WILUTE model developed by Zhao et al (2013). Accordingly, the RNDT has adopted embodied carbon as an indicator of resilience. Our research has shown that building height, parking provision, and construction type are key elements that influence the embodied carbon within the built environment. A brief exploration of each of these elements is provided below.

Construction Type

The embodied carbon of a building is influenced by the types of materials used in construction (Cabeza et al, 2013). Although there is a wide variety of methodologies used within the literature for computing embodied carbon and no universal consensus on which approach is most accurate and reliable (Cabeza et al, 2013), wooden building materials are generally perceived as having a lower embodied carbon than other building materials such as steel, brick, aluminium, and concrete (Teshnizi, 2019; Buchanan & Levine, 1999). This is primarily a consequence of the lower fossil fuel requirements involved with manufacturing wood (Cabeza et al, 2013).

A study of the New Zealand building industry for example, found that a 17% increase in wood usage could result in a 20% reduction in carbon emissions from the manufacturing of building materials, which would reduce national carbon emissions by approximately 1.5% (Buchanan & Levine, 1999). Modern wood framed buildings have typically been found to have a lower embodied carbon than concrete buildings (Hsu, 2010), especially where carbon capture and storage technologies are used (Nassen et al, 2012). It is estimated that every 100 cubic feet of wood used in construction has the potential to store an average of 0.65 metric tons of carbon (ReThink Wood, 2015).

In one study Buchanan and Levine (1999) found that for several common building typologies (residential, office, industrial), wooden buildings had an overall lower total processing energy amount, and a consistently lower amount of released carbon per m^2 of construction compared to concrete (and steel where applicable). In a recent study on reducing the embodied emissions of new buildings in Vancouver (Teshnizi, 2019), the author found strong positive relationships between the quantities of concrete and metal and metal in a building, and Global Warming Potential (GWP) – defined here as “the embodied carbon emissions from production, use, and end of life phases of a building lifetime reported in Kg CO_2” (pg.5). Conversely, a strong negative correlation was identified between the quantity of wooden materials used in construction and GWP, meaning that substituting concrete and metal for wooden materials in construction can be effective in reducing overall embodied carbon (Teshnizi, 2019). Wood is also a significantly more lightweight than other construction materials such as concrete or different metals, meaning that wooden construction can reduce overall building weight and decreases the amount of foundation materials needed during construction (and the embodied carbon that accompanies these additional materials) (Teshnizi, 2019). This is especially pertinent given that the foundations of a building typically account for a large share of overall embodied emissions (Teshnizi, 2019).

The overall embodied carbon and energy of steel versus concrete buildings however is less clear cut (Hsu, 2010). Johnson et al (1998) for example investigated several different building typologies (office and dwelling) with either concrete and/or steel frames and found no clear winner in terms of embodied carbon. This is consistent with a lifecycle analysis (LCA) conducted by Guggemos & Horvath (2005), which found the embodied energy and carbon within two comparative five-story buildings with concrete and steel framing respectively to be very similar. A study of the Toronto and Vancouver building stock however, found that for a hypothetical three-story office building with no underground parking, steel framing consistently had the highest embodied energy, followed by concrete and wooden options respectively (Cole & Kernan, 1996). In contrast, a lifecycle analysis of two 100,000 SF buildings conducted by Johnson (2006) found that steel and concrete building frames tended to have very similar environmental impacts, albeit with concrete having a slightly higher amount of embodied carbon.

It should be noted that the embodied carbon in concrete can vary significant depending on its cement content (Evan, 2016; Hammond & Jones, 2008) and the type of cement used (Shams et al, 2011) which may partially account for some of the variability in comparisons between steel and concrete framed buildings. One study of the construction industry in

	Summary of key findings	Literature support
Wood versus concrete	Wooden building materials generally considered to have a lower embodied carbon than materials such as steel, brick, aluminium, and concrete. This is partly a consequence of the lower amount of fossil fuels required by wood during processing, the relative lightweight properties of wood relative to other materials, and the carbon storage potential of wood.	Buchanan & Levine (1999) Cabeza et al (2013) Hsu (2010) Teshnizi (2019)
Concrete versus steel	The embodied carbon of steel and concrete framed buildings in many studies appears to be relatively similar.	Guggemos & Horvath (2005) Hsu (2010) Johnson et al (1998)
	However, the embodied carbon in concrete can vary significantly depending on its cement content, and using cement mixes with a lower embodied carbon can significantly reduce the overall embodied carbon of a concrete building.	Evan (2016) Pak (2019) Shams et al, 2011)
Recyclability	Using recycled materials can often reduce the overall embodied carbon of a building. Although most construction materials have the potential to be recycled, the recyclability of specific materials with vary significantly on a project-to-project basis.	Cabeza et al (2013) Tam (2011) Teshnizi (2019) Thormark (2000)

Table 5 above provides a simplified summary of some of the key relationships between construction material and embodied carbon identified within this section.

Dhaka for example found that for replacing type-I cement with type-II or type-III cement in concrete buildings could reduce the embodied carbon of a building by 23-35% and 22-45% respectively (Shams et al, 2011). A more recent study in Vancouver by Pak (2019) found that changing from Portland Cement to Portland Limestone in all concrete has the potential to reduce the overall embodied carbon of a typical concrete Vancouver high rise building (33-storey residential) by 22.6%.

Using recycled materials has the potential to reduce the embodied carbon in construction (Teshnizi, 2019; Cabeza et al, 2013). In a study of Japanese residential buildings for instance, Gao et al (2001) found that using recycling materials for building construction where possible can reduce overall embodied carbon by at least 10%, with the greatest benefits coming from recycling materials with high embodied carbon such as steel and aluminium. Similarly, a study of a family house in Sweden constructed from a high proportion of recycled materials found that the environmental impacts of construction were roughly 50% less than if all construction materials had been new (Thormark, 2000). Most construction materials including wood, concrete, steel, aluminium, and bricks can be recycled (Teshnizi, 2019; Riddell, 2017) although the recyclability of these specific materials will vary significantly from project to project (Tam, 2011).

Generally, wooden construction is considered to have a lower embodied carbon than a comparable sized concrete building. Image by Jimmy Stamp via Smithsonian magazine.

Table 5 provides a simplified summary of some of the key relationships identified in the preceding paragraphs.

Synergies + Trade-offs:

Building Height

Increased building height is associated with increased embodied carbon and energy (Treloar et al, 2001).This can partly be attributed to the increased load effects associated with taller buildings and the need for more energy intensive materials such as steel during construction (Resch et al, 2016).

The relationship between embodied energy and building height is not strictly linear however. Aye et al (1999) for example found that very low building typologies (i.e. single storey buildings) often have a low surface area/volume ratio, which can result in a higher embodied carbon relative to middle density buildings. As this ratio normalizes with increasing height though, increases in embodied carbon begin to become more closely associated with increases in building height (Treloar et al, 2001).

Parking Provision

Increased provision of underground parking increases the amount of concrete used in construction, which ultimately increases the embodied carbon of a building due to the high embodied carbon in concrete (Pak, 2019; Hammond and Jones, 2008). Increased surface parking also increases overall embodied carbon on account of the cement used in construction, but this is likely to be comparatively less than underground parking on account of the quantity of materials used in each parking type (Bionova Ltd, 2018). For example, it is estimated that in a 7000m^2 7-storey building with 2-levels of underground parking, the total embodied carbon of the building could be reduced by approximately 69% if all parking was shifted to above ground (Bionova Ltd, 2018). On average, the CO_2 emissions embodied per unit area of underground parking is estimated to be between 650-680kg- CO_2/ m^2 (Roh & Tae, 2016). Similarly, a recent study of embodied carbon in in Vancouver towers (Pak, 2019) found that reducing allocated parkade space in a typical concrete high rise building by 50% could provide an overall embodied carbon reduction of around 6%. The increased amount of carbon intensive materials used in the construction of underground parking is reflected in the comparatively high construction cost of underground parking relative to surface parking (Atlas Group, 2018).

In summary, any parking option will increase embodied carbon in a buildings construction, although underground parking is likely to have a greater embodied carbon on account of the additional carbon intensive materials used in construction.

> *Although wooden construction is generally considered to have a lower embodied carbon than concrete, the embodied carbon of steel and concrete framed buildings in many studies appears to be relatively similar.*

Reference

Atlas Group (2018). 2018 Canadian Cost Guide. Retrieved from http://creston.ca/DocumentCenter/View/1957/Altus-2018-Construction-Cost-Guide-web-1

Aye, L., Bamford, N., Charters, B., & Robinson, J. (1999). Optimising embodied energy in commercial office development. RICS Foundation, 217-223.

Bionova. (2018). The 10 design commandments for cutting your building's embodied carbon: how to reduce embodied carbon in the built environment. Retrieved from https://www.oneclicklca.com/embodied-carbon-reduction-in-construction/

Buchanan, A. H., & Levine, S. B. (1999). Wood-based building materials and atmospheric carbon emissions. Environmental Science & Policy, 2(6), 427-437.

Cabeza, L. F., Barreneche, C., Miró, L., Morera, J. M., Bartolí, E., & Fernández, A. I. (2013). Low carbon and low embodied energy materials in buildings: A review. Renewable and Sustainable Energy Reviews, 23, 536-542.

City of Vancouver. (2019, April 16). Climate Emergency Response (RTS No. 12978; VanRIMS No. 08-2000-20). Retrieved from https://council.vancouver.ca/20190424/documents/cfsc1.pdf

Cole, R. J., & Kernan, P. C. (1996). Life-cycle energy use in office buildings. Building and environment, 31(4), 307-317.

Evan. (2016, April). What building material has the smallest overall environmental impact? Retrieved from https://blogs.umass.edu/natsci397a-eross/what-building-material-wood-steel-concrete-has-the-smallest-overall-environment-impact/

Galderisi, A., & Ferrara, F. F. (2012). Enhancing urban resilience in face of climate change: a methodological approach. Tema. Journal of Land Use, Mobility and Environment, 5(2), 69-88.

Gao, W., Ariyama, T., Ojima, T., & Meier, A. (2001). Energy impacts of recycling disassembly material in residential buildings. Energy and Buildings, 33(6), 553-562.

Guggemos, A. A., & Horvath, A. (2005). Comparison of environmental effects of steel-and concrete-framed buildings. Journal of infrastructure systems, 11(2), 93-101.

Hammond, G. P., & Jones, C. I. (2008). Embodied energy and carbon in construction materials. Proceedings of the Institution of Civil Engineers-Energy, 161(2), 87-98.

Hsu, S. L. (2010). Life cycle assessment of materials and construction in commercial structures: variability and limitations (Doctoral dissertation, Massachusetts Institute of Technology).

Jeffrey, C. (2011, September). Construction and Demolition Waste Recycling: A Literature Review. Retrieved from https://cdn.dal.ca/content/dam/dalhousie/pdf/dept/sustainability/Final%20C%26D%20literature%20review.pdf

Johnson, T. W. (2006). Comparison of environmental impacts of steel and concrete as building materials using the Life Cycle Assessment method (Doctoral dissertation, Massachusetts Institute of Technology).

Nässén, J., Hedenus, F., Karlsson, S., & Holmberg, J. (2012). Concrete vs. wood in buildings–an energy system approach. Building and environment, 51, 361-369.

Oka, T., & Sawachi, T. (2013). Annex 57–evaluation of embodied energy and carbon dioxide emissions for building construction. In Central Europe Towards Sustainable Building Conference, Prague, Czech Republic (pp. 9-12).

Pak, A. (2019). Concrete high rise LCA study, City of Vancouver. Retrieved from https://vancouver.ca/files/cov/cov-concrete-high-rise-study.pdf

Resch, E., Bohne, R. A., Kvamsdal, T., & Lohne, J. (2016). Impact of urban density and building height on energy use in cities. Energy Procedia, 96, 800-814.

Rethink Wood. (2015, April). Evaluating the Carbon Footprint of Wood Buildings: Reducing greenhouse gases with high-performance structures. Retrieved from https://www.awc.org/pdf/education/gb/ReThinkMag-GB500A-EvaluatingCarbonFootprint-1810.pdf

Riddell, T. (2017, August). Why Recycling Construction Materials is Important for Your Business. Retrieved from https://esub.com/recycling-construction-materials-important-business/

Roh, S., & Tae, S. (2016). Building Simplified Life Cycle CO2 Emissions Assessment Tool (B-SCAT) to Support Low-Carbon Building Design in South Korea. Sustainability, 8(6), 567.

Shams, S., Mahmud, K., & Al-Amin, M. (2011). A comparative analysis of building materials for sustainable construction with emphasis on CO 2 reduction. International Journal of Environment and Sustainable Development, 10(4), 364-374.

Tam, V. W. (2011). Rate of reusable and recyclable waste in construction. Open Waste Management Journal, 4(1), 28-32.

Teshnizi, Z. (2019). Policy Research on Reducing the Embodied Emissions of New Buildings in Vancouver. Retrieved from https://vancouver.ca/files/cov/cov-embodied-carbon-policy-review-report.pdf

Thormark, C. (2000). Environmental analysis of a building with reused building materials. International Journal of Low Energy & Sustainable Building, 1.

Treloar, G. J., Fay, R., Ilozor, B., & Love, P. E. (2001). An analysis of the embodied energy of office buildings by height. Facilities, 19(5/6), 204-214.

U.S. Green Building Council. (2019). LEED v4.1 Cities and Communities: Plan and Design. Retrieved from https://new.usgbc.org/leed-v41#cities-and-communities

Zhao, P., Chapman, R., Randal, E., & Howden-Chapman, P. (2013). Understanding resilient urban futures: a systemic modelling approach. Sustainability, 5(7), 3202-3223.

Zizzo, R., Kyriazis, J. Goodland, H. (2017). Embodied Carbon of Buildings and Infrastructure – International Policy Review. Retrieved from https://www.naturallywood.com/sites/default/files/documents/resources/embodied_carbon_in_construction_and_infrastructure_-_international_policy_review.pdf

Photovoltaic Potential

With a rapidly growing global population and an increasing scarcity of carbon based fossil fuels, slowing urban metabolism by reducing urban energy consumption and adopting more renewable energy technologies is a crucial requirement for enhancing urban resilience (Agudelo-Vera et al, 2012). Renewable electricity generation through photovoltaic technologies can play an important role in this process (Carl, 2014). Solar energy technologies have been shown to have the potential to improve the year-round efficiency of urban energy systems (Wong et al, 2006), which has positive implications for overall urban resilience by creating a more self-sufficient energy system, and facilitating a slower and more sustainable urban metabolism (Bristow & Kennedy, 2013). The importance of increasing renewable energy technologies such as solar energy to improve urban resilience is discussed extensively within the literature (Agudelo-Vera et al, 2012; Galderisi & Ferrara, 2012), and indicators which measure a city's ability to utilize renewable forms of energy, such as solar energy, are seen to be an important criteria for assessing urban energy resilience (Sharifi & Yamagata, 2016). The Toolkit for Resilient Cities developed by Siemens for example uses an indicator which measures the proportion of commercial / residential / institutional buildings that are served by their own energy consumption, with the rationale for this indicator

Studies such as that conducted by Byrd et al (2013) have demonstrated that low building typologies with large roofs (such as those typical of dispersed suburban neighbourhoods) have the greatest potential to harness solar energy, whilst tall inner-city building typologies are less suited to this task. Photo by jandrielombard via realestate.com.au being that greater uptake from a local energy system creates greater resiliency against shocks to the wider electrical grid (Siemens, 2013). Such reasoning is supported by Champagne and Aktas (2016) who highlight 'renewable energy for less reliability on grid power' as a key resilient design principle for buildings.

For these reasons 'photovoltaic potential', which provides an indication of the extent to which a city may be able to harvest renewable solar energy through photovoltaic technologies, is used as an indicator in the RNDT. Through our solar access modelling, building massing and building height were identified as key design features in the built environment that can influence photovoltaic potential.

In an analysis of the different building typologies across the city of Auckland, New Zealand, Byrd et al (2013) found that buildings with a large roof area to floor area ratio have the greatest photovoltaic potential. That is to say low, building typologies with large roofs (such as those typical of dispersed suburban neighbourhoods) have the greatest potential to harness solar energy, whilst tall inner-city building typologies are less suited to this task (although these have potential to be more energy efficient in other ways). These results are consistent with other research which identifies a positive relationship between the building massing typical of dispersed urban neighbourhoods and photovoltaic potential (Mohajeri et al, 2016). Such findings have important implications for the potential to retrofit suburbia (which comprises a large part of the North American urban landscape) with photovoltaic technologies to improve the resiliency of urban energy systems (Byrd et al, 2013).

Reference

Agudelo-Vera, C. M., Leduc, W. R., Mels, A. R., & Rijnaarts, H. H. (2012). Harvesting urban resources towards more resilient cities. Resources, conservation and recycling, 64, 3-12.

Bristow, D. N., & Kennedy, C. A. (2013). Urban metabolism and the energy stored in cities: Implications for resilience. Journal of Industrial Ecology, 17(5), 656-667.

Byrd, H., Ho, A., Sharp, B., & Kumar-Nair, N. (2013). Measuring the solar potential of a city and its implications for energy policy. Energy policy, 61, 944-952.

Carl, C. (2014). Calculating solar photovoltaic potential on residential rooftops in Kailua Kona, Hawaii. University of Southern California.

Champagne, C. L., & Aktas, C. B. (2016). Assessing the resilience of LEED certified green buildings. Procedia Engineering, 145, 380-387.

Galderisi, A., & Ferrara, F. F. (2012). Enhancing urban resilience in face of climate change: a methodological approach. Tema. Journal of Land Use, Mobility and Environment, 5(2), 69-88.

Mohajeri, N., Upadhyay, G., Gudmundsson, A., Assouline, D., Kämpf, J., & Scartezzini, J. L. (2016). Effects of urban compactness on solar energy potential. Renewable Energy, 93, 469-482.

Sharifi, A., & Yamagata, Y. (2016). Principles and criteria for assessing urban energy resilience: A literature review. Renewable and Sustainable Energy Reviews, 60, 1654-1677.

Siemens. (2013). Toolkit for Resilient Cities. Retrieved from https://assets.new.siemens.com/siemens/assets/public.1543066657.641ee2256c5a0d5919d1aa3094a701f6ec9c3f90.toolkit-for-resilient-cities.pdf

Wong, B., Snijders, A., & McClung, L. (2006, May). Recent inter-seasonal underground thermal energy storage applications in Canada. In 2006 IEEE EIC Climate Change Conference (pp. 1-7). IEEE

Building Envelope Efficiency

At a planetary level buildings use approximately 40% of global energy, 40% of global resources, 25% of global water, and contribute roughly 30% of the total global GHG emissions (UNEP, n.d.). Consequently, improving the energy performance of buildings has been identified as a potential avenue to significantly reduce global GHG emissions, thereby enhancing climate resilience and improving the resiliency of urban energy systems (UNIEP, 2017). Furthermore, improving the energy performance of buildings provides opportunities for reduced operational costs (Sozer, 2010), which can benefit the fiscal and social resiliency of communities by improving affordability.

Urban energy performance and efficiency is unanimously perceived to be an important component of resilience within the literature (Sharifi &Yamagata, 2016; Kuznecova et al, 2014; Bristow & Kennedy, 2013; Galderisi & Ferrara, 2012), and is frequently used as an indicator in holistic resilience assessment models (Siemens, 2013; Economist Intelligence Unit, 2012; Rueda, 2012; DCS, 2009). The Toolkit for Resilient Cities developed by Siemens (2013) for instance uses 'total improvements in city-wide energy/water efficiency over the past 5 years' as an indicator of resilience (under the rationale that efficiencies help to increase system capacity which directly contributes to resilience), whilst 'energy consumption by sector' (including the construction sector and in different building types) is an indicator in the Ecological Urbanism model developed by Rueda (2012). Similarly, 'Energy consumption', 'energy intensity', 'renewable energy consumption', and 'clean and efficient energy policies' are all indicators used by the holistic European Green City Index developed by the Economic Intelligence Unit (2012); and 'building energy consumption' is used by as an indicator in the holistic sustainability framework developed by the Design Centre for Sustainability at the University of British Columbia (DCS, 2009).

Simpler, more compact building envelopes tend to be more energy efficient (Pacheco, 2012). This is because the surface exposed to potential unintended heat loss and gains is minimized (Aksoezen et al, 2015), reducing the requirement for energy intensive ongoing heating and cooling.

Transparent envelope design features can increase the solar gain of a building during heating seasons, thereby improving energy efficiency and reducing the costs involved in heating (Parasonis et al, 2012). Optical properties of a building envelope including coefficients of permeability, absorption, and reflectivity of solar radiation can also impact on energy efficiency, depending on climate and season (Bostancioğlu, 2010). Increasing building envelope efficiency is discussed by the New York City Climate Resiliency Guidelines (2019) as a useful design strategy for addressing climate change hazards at the building scale. At the design stage, the building envelope provides a useful metric for assessing the likely overall energy efficiency

Simpler, more compact building envelopes will have less unintended heat loss and gains, and a corrosponding increase in energy efficiency.

of a building (Sozer, 2010).

Due to the widely accepted relevance of building energy performance to urban resilience, the RNDT has incorporated 'building envelope efficiency' (measured as the building surface area to floor area index) as a resilience indicator. Under this metric, a more compact, simple building envelope will give a higher envelope efficiency score, which in turn is associated with greater resiliency. From our research, building massing, height, and parking provision have been identified as key elements of the built environment that can influence building energy performance (Godoy-Shumizu et al, 2018; Aksoezen et al, 2015; Mohareb & Row, 2014; Pacheco, 2012). A brief discussion of each of these elements is provided below.

Building massing

More compact building massing will correspond to less unintended hear loss and gains, and a corresponding increase in energy efficiency (Pacheco, 2012; Aksoezen et al, 2015). This improves the operational energy performance of a building. A study by Lylykangas (2009) looking at heat loss in relation to building shape for example, found that compact building shapes with a smaller surface to volume ratio such as a cube or a short cylinder had less unintended hear loss than other building typologies.

As well as having a greater ongoing energy efficiency, studies by Bostancioglu (2007) and Bathurst and Butler (1982) have demonstrated that building envelopes with a smaller external wall area/floor area ratio (i.e. more compact building envelopes) are more energy efficient to construct, which corresponds to a lower construction cost per square foot (Bostancioglu, 2010). A study by Bostancioglu (2010) for example found that a compact square-shaped building could be up to 6% cheaper to construct per square foot compared to less compact building shapes such as rectangle, star, or H-shaped buildings (as well as producing increased operational energy savings as great as 26.92%). These results make logical sense: if a building increases the amount of wall area needing to be constructed whilst the floor area remains constant, then it follows that additional construction materials will be required for the additional wall area (Stoy & Schalcher, 2007). These additional materials used increase construction costs, which negatively impacts affordability. More compact, efficient building envelopes then not only increase affordability by reducing operational costs over the long term, but also by being cheaper to construct (Bostancioglu, 2010).

Building height

In general, increased building height corresponds to a decrease in energy performance (Godoy-Shumizu et al, 2018; Lam et al, 2004).This relationship is not always linear however. For example, very low building typologies (i.e. single storey) often have a low surface area/volume ratio, which can result in a higher embodied carbon and energy performance relative to middle density buildings (Aye et al, 1999). As this ratio normalizes with increasing height though, increases in embodied carbon and energy begin to become more closely associated with increases in building height (Treloar et al, 2001). This suggests that mid-density multi-story building typologies (such as those from 3-8 storeys high) may have the best energy performance in relation to building height, compared to very low or tall buildings.

Parking provision

The energy performance of a building is detrimentally impacted by the presence of underground parking (Bionova Ltd, 2018; Cole & Kernan, 1996) This is largely a consequence of the increased embodied energy and carbon involved during the construction phase of underground parking (Bionova Ltd, 2018), although is also exacerbated by ongoing electrical costs (such as for lighting) and the often-inefficient ventilation systems found in many underground parking facilities (Chan et al, 1998). In a study analysing the embodied energy in a three-storey office building based on construction material (wood, steel, or concrete), it was found that the inclusion of two stories of concrete underground parking increased the overall embodied energy of the wooden building by 38%, the steel building by 21%, and the concrete building by 25% (Cole & Kernan, 1996).

Reference

Aksoezen, M., Daniel, M., Hassler, U., & Kohler, N. (2015). Building age as an indicator for energy consumption. Energy and Buildings, 87, 74-86.

Aye, L., Bamford, N., Charters, B., & Robinson, J. (1999). Optimising embodied energy in commercial office development. RICS Foundation, 217-223.

Bionova. (2018). The 10 design commandments for cutting your building's embodied carbon: how to reduce embodied carbon in the built environment. Retrieved from https://www.oneclicklca.com/embodied-carbon-reduction-in-construction/

Bostancıoğlu, E. (2007). Factors Affect Residential Buildings Cost in Pre Design Phase

Bostancioğlu, E. (2010). Effect of building shape on a residential building's construction, energy and life cycle costs. Architectural Science Review, 53(4), 441-467.

Bristow, D. N., & Kennedy, C. A. (2013). Urban metabolism and the energy stored in cities: Implications for resilience. Journal of Industrial Ecology, 17(5), 656-667.

Chan, M. Y., Burnett, J., & Chow, W. K. (1998). Energy use for ventilation systems in underground car parks. Building and Environment, 33(5), 303-314.

Cole, R. J., & Kernan, P. C. (1996). Life-cycle energy use in office buildings. Building and environment, 31(4), 307-317

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Economist Intelligence Unit. (2012). The Green City Index, A summary of the Green City Index research series.

Godoy-Shimizu, D., Steadman, P., Hamilton, I., Donn, M., Evans, S., Moreno, G., & Shayesteh, H. (2018). Energy use and height in office buildings. Building Research & Information, 46(8), 845-863.

Kuznecova, T., Romagnoli, F., & Rochas, C. (2014). Energy metabolism for resilient urban environment: a methodological approach. Procedia Economics and Finance, 18, 780-788.

Lam, J. C., Chan, R. Y., Tsang, C. L., & Li, D. H. (2004). Electricity use characteristics of purpose-built office buildings in subtropical climates. Energy Conversion and Management, 45(6), 829-844.

Lylykangas, K. (2009). Shape factor as an indicator of heating energy demand. In Proceedings of the 15th International Wood Construction Conference (IHF).

Mohareb, E., and Row, J. (2014). Improving Energy Efficiency in Alberta's Buildings. Retrieved from https://www.pembina.org/reports/improving-energy-efficiency-in-alberta-buildings.pdf

New York City. (2019, April). Climate Resiliency Design Guidelines. Retrieved from https://www1.nyc.gov/assets/orr/pdf/NYC_Climate_Resiliency_Design_Guidelines_v3-0.pdf

Pacheco, R., Ordóñez, J., & Martínez, G. (2012). Energy efficient design of building: A review. Renewable and Sustainable Energy Reviews, 16(6), 3559-3573.

Parasonis, J., Keizikas, A., & Kalibatiene, D. (2012). The relationship between the shape of a building and its energy performance. Architectural Engineering and Design Management, 8(4), 246-256.

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

Sharifi, A., & Yamagata, Y. (2016). Principles and criteria for assessing urban energy resilience: A literature review. Renewable and Sustainable Energy Reviews, 60, 1654-1677.

Siemens. (2013). Toolkit for Resilient Cities. Retrieved from https://assets.new.siemens.com/siemens/assets/public.1543066657.641ee2256c5a0d5919d1aa3094a701f6ec9c3f90.toolkit-for-resilient-cities.pdf

Sozer, H. (2010). Improving energy efficiency through the design of the building envelope. Building and environment, 45(12), 2581-2593.

Stoy, C., & Schalcher, H. R. (2007). Residential building projects: Building cost indicators and drivers. Journal of construction engineering and management, 133(2), 139-145.

Treloar, G. J., Fay, R., Ilozor, B., & Love, P. E. (2001). An analysis of the embodied energy of office buildings by height. Facilities, 19(5/6), 204-214.

UN Environment and International Energy Agency (UNIEP) .(2017). Towards a zero-emission, efficient, and resilient buildings and construction sector, Global Status Report 2017

United Nations Environment Programme (UNEP). (n.d.). Energy Efficiency For Buildings. Retrieved from http://www.studiocollantin.eu/

Carbon Sequestration

Carbon sequestration refers to the process of capturing and storing atmospheric carbon dioxide. Carbon dioxide is the most commonly produced GHG emission, and is one of the key drivers behind anthropogenic accelerated climate change (Hardy, 2003). Reducing the amount of carbon in the atmosphere through carbon sequestration has been identified as a potential strategy to help mitigate the effects of climate change (Canadell & Raupach, 2008), and thereby contribute to improving urban resilience in the face of this significant growing global stressor. Carbon reduction is highlighted as a key priority in numerous municipal resilience plans. A primary goal of the San Francisco resilience plan for example is to lead the world in greenhouse gas mitigation, and carbon sequestration provides one way to help achieve this goal.

The average annual carbon storage rate per square meter of tree cover in urban areas is estimated to be 0.28kgC/m^2 (Nowak et al, 2013). The size of a tree directly influences its carbon storage and sequestration potential. Large trees greater than 77cm in diameter sequester approximately 90 times more carbon than small trees less than 8cm in diameter (Nowak, 2002).

Large, mature evergreen trees are the most effective carbon sequesters. Photo of Capilano Park sourced from timestravel.

Larger trees also typically have a greater lifespan than smaller trees, which impacts their carbon sequestration ability over a longer timeframe. The carbon uptake of a tree is also related to its leaf longevity, meaning that evergreen trees contribute greater to carbon reduction than comparable sized deciduous trees (Leung et al, 2011). Essentially, large urban trees (especially those which are coniferous) are more effective at carbon sequestration than smaller ones, and the overall percentage of urban tree coverage is positively associated with increased rates of carbon sequestration which can help mitigate the impacts of human atmospheric emissions and climate change.

It should be noted here that the carbon sequestration rates of urban forests is heavily outweighed by the total carbon production of cities. For example, a forest area 30-50 times the size of Singapore would be needed to offset the current carbon produced by this city (Velasco et al, 2016). Tree canopy coverage (and in particular urban tree coverage) can contribute to urban resilience by reducing atmospheric emissions, but the scale of such mitigation strategies should not be overestimated. There are, however, a host of other resilience benefits of urban greenery: carbon sequestration is but one of these. Alongside the carbon sequestration abilities of vegetation features themselves, urban soils (in which these vegetation features are often planted) have also been shown to sequester carbon and reduce atmospheric carbon emissions in an urban area (Pouyat et al, 2006), and at a planetary scale, planting trees (regionally, as well as in urban environments) has the potential to contribute significantly to a reduction in atmospheric carbon levels (Bastin et al, 2019). A recent study looking at the global tree restoration potential to mitigate the effects of climate change for example estimates that a 25% global increase in forested area is possible outside of existing forested, agricultural, or urban land, and that this additional tree coverage has the potential to sequester more than 200 gigatonnes of additional carbon at maturity which would reduce global atmospheric by roughly 25% (Bastin et al, 2019).

Reference

Canadell, J. G., & Raupach, M. R. (2008). Managing forests for climate change mitigation. science, 320(5882), 1456-1457.

Bastin, J. F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., ... & Crowther, T. W. (2019). The global tree restoration potential. Science, 365(6448), 76-79.

Leung, D. Y., Tsui, J. K., Chen, F., Yip, W. K., Vrijmoed, L. L., & Liu, C. H. (2011). Effects of urban vegetation on urban air quality. Landscape research, 36(2), 173-188.

Nowak, D. J., & Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA. Environmental pollution, 116(3), 381-389.

Nowak, D. J., Greenfield, E. J., Hoehn, R. E., & Lapoint, E. (2013). Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental pollution, 178, 229-236.

Hardy, J. T. (2003). Climate change: causes, effects, and solutions. John Wiley & Sons.

Pouyat, R. V., Yesilonis, I. D., & Nowak, D. J. (2006). Carbon storage by urban soils in the United States. Journal of environmental quality, 35(4), 1566-1575.

Velasco, E., Roth, M., Norford, L., & Molina, L. T. (2016). Does urban vegetation enhance carbon sequestration?. Landscape and urban planning, 148, 99-107.

EARTHQUAKES

Seismic Vulnerability – Buildings

The adage 'earthquakes don't kill people; buildings do' is becoming increasingly apparent. In the recent 2015 Gorkha earthquake in Nepal for example, a moment magnitude 7.8 earthquake caused significant damage or destruction to over 600,000 structures in Katmandu and claimed the lives of over 9,000 people (Rafferty, 2015). The majority of fatalities and serious injuries were caused by the collapse of buildings (Petal et al, 2017). The total economic damage caused by this earthquake is estimated to be approximately 10 Billion U.S. dollars which is more than half of Nepal's GDP (CEDIM, 2015). Similarly, in the February 2011 Christchurch earthquake in New Zealand 185 fatalities were recorded, the majority of which (115 deaths) were caused by the collapse of the Canterbury Television (CTV) building (Potter, 2015).

The seismic vulnerability of an urban building stock gives an indication of how well a city will perform in an earthquake, and thus how physically resilient a city is to seismological shocks (Banica et al, 2017). Indicators assessing the seismic vulnerability of buildings have been widely used in different models to assess the urban resilience of cities to earthquakes, such as that developed by Banica et al (2017) which adopts a seismic vulnerability index which takes into account physical indicators (such as the physical characteristics of the built environment) and social indicators (such as the social and economic sensitivity of inhabitants to external stressors) to determine the overall seismic vulnerability in Iasi, Romania. More holistic resilience models, such as that developed by Cutter et al (2010), have also utilized seismic vulnerability indicators. In Cutter's model, building age is used as a proxy for likely building vulnerability based on when certain mandatory building codes were established, with increasing age corresponding to increased seismic vulnerability. More generally, reducing seismic vulnerability in buildings has been seen as strategy to increase urban resilience (D'Amico & Curra, 2014). For these reasons, the RNDT has incorporated an indicator of seismic vulnerability to measure likely physical resilience of the built environment. Our research has identified building height, construction type, and age as characteristics of the built environment that can influence the seismic performance and vulnerability of a given building as summarized below.

Construction Type

Key Design characteristics that improve seismic performance in construction include stable foundations, continuous load paths, adequate stiffness and strength, redundancy, regularity (or uniformity of mass), ductility and toughness, and ruggedness (FEMA, 2010). Compared to other building materials such as brick, masonry, or concrete, wooden structures perform well in earthquakes due to their high strength-to-weight ratio, numerous redundant load paths, and ductility (Karsh, 2014; Canadian Wood Council, 2003). Because of these properties, wooden structures also tend to accrue less damage than other common buildings during a seismic event and therefore have a greater reuse potential than concrete for example (DWR et al, n.d.). As a recent example of this, the Californian government elected to omit wooden schools constructed between 1933-1979 from their 2002 Inventory of Earthquake Worthiness Assessment of Schools. Schools constructed from concrete, steel, or masonry during this same time were included in the inventory. This decision was made on the grounds that "wooden-frame buildings are

The seismic vulnerability of an urban building stock gives an indication of how well a city will perform in an earthquake, and thus how physically resilient a city is to seismological shocks.

known to perform well in earthquakes" (California Department of Government Services, 2002, pg.6), and are therefore less likely to have sustained damage from previous earthquakes.

Building Age

Although dependent on the specific building stock in question, building age is generally considered to be a structural indicator negatively associated with seismic performance (Panahi et al, 2014; Azar et al, 2004). That is, generally the newer a building is the better its seismic performance. Some of the factors contributing to this relationship include the degeneration of structural integrity with building age, technological improvements to the seismic performance design of buildings in recent years, and more rigorous building codes that have evolved over time.

The factors contributing to seismic performance are numerous and complex however, and counter examples to this relationship have been identified within the literature. Several studies of the Turkish building stock for example, found that traditional wooden-frame buildings performed better during seismic events than newer reinforced concrete buildings (Dogangun et al, 2006; Gulkan & Langenbach, 2004). These findings do not so much undermine the general relationship between building age and seismic vulnerability however, but rather emphasize the importance of design features and construction material as key indicators of potential seismic performance, and highlight the interconnectedness of these factors in determining the overall seismic vulnerability (and potential resilience) of an urban area.

Due to its inherent lightweight and ductile properties, there is a growing body of research which suggests wooden construction is better suited to perform well in a seismological event than other common construction materials such as concrete, masonary, or brick. Image sourced from Robert Barnes via Construction Review Online.

Reference

Ali, M. M. (2001). Evolution of concrete skyscrapers: from Ingalls to Jin mao. Electronic Journal of Structural Engineering, 1(1), 2-14.

California Department of Government Services. (2002). Seismic Safety Inventory of California Public Schools.

Azar, H.S., Meskouris, K., & Azar, M.S. (2004). Probabilistic seismic risk and damageability assessment, presented at 13th World Conference on Earthquake Engineering, Vancouver, B.C. Retrieved from http://www.iitk.ac.in/nicee/wcee/article/13_2758.pdf

Banica, A., Rosu, L., Muntele, I., & Grozavu, A. (2017). Towards Urban Resilience: A Multi-Criteria Analysis of Seismic Vulnerability in Iasi City (Romania). Sustainability, 9(2), 270.

D'Amico, A., & Currà, E. (2014). Paper 20: Urban Resilience and Urban Structure: Vulnerability assessment of historical Italian towns. Proceedings ANDROID Residential Doctoral School.

Panahi, M., Rezaie, F., & Meshkani, S. A. (2014). Seismic vulnerability assessment of school buildings in Tehran city based on AHP and GIS. Natural Hazards and Earth System Sciences, 14(4), 969-979.

Centre for Disaster and Risk Reduction Technology (CEDIM). (2015). Nepal Earthquakes – Report #3. Retrieved from https://www.cedim.kit.edu/english/2850.php

Disaster Waste Recovery (DWR), ProAct Network, & Shelter Centre. (n.d.).Planning Centralised Building Waste Management Programmes in Response to Large Disasters. Retrieved form https://postconflict.unep.ch/humanitarianaction/documents/02_03-04_01-03.pdf

Doğangün, A., Tuluk, Ö. İ., Livaoğlu, R., & Acar, R. (2006). Traditional wooden buildings and their damages during earthquakes in Turkey. Engineering Failure Analysis, 13(6), 981-996.

Petal, M., Baral, S., Giri, S, Rajbanshi, S., Gajurel, S., Green, R.P., Pandey, B., & Shoaf, K. (2017, April). Causes of Deaths and Injuries in the 2015 Gorkha (Nepal) Earthquake, Research Report. Retrieved from https://resourcecentre.savethechildren.net/node/14168/pdf/causes_of_deaths_and_injuries_nepal_earthquake_report_eng_2017.pdf

Potter, S. H., Becker, J. S., Johnston, D. M., & Rossiter, K. P. (2015). An overview of the impacts of the 2010-2011 Canterbury earthquakes. International Journal of Disaster Risk Reduction, 14, 6-14.

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1).

Rafferty, J. (2015). Nepal earthquake of 2015. In Enyclopedia Britannica. Retrieved from https://www.britannica.com/topic/Nepal-earthquake-of-2015

Gülkan, P., & Langenbach, R. (2004, August). The earthquake resistance of traditional timber and masonry dwellings in Turkey. In 13th World Conference on Earthquake Engineering (pp. 1-6).

Karsh, E. (2014, February). Wood-frame construction advantageous in areas prone to seismic activity. Civil + Structural Engineer media. Retrieved from https://csengineermag.com/article/wood-frame-construction-advantageous-in-areas-prone-to-seismic-activity/

CLIMATE CHANGE

Urban Heat Island – Buildings

As cities continue to grow and densify over the coming decades, the urban heat island effect (UHI) will likely continue to become more pronounced, creating a significant environmental stressor for cities to navigate. An urban Heat Island occurs when an urban environment is warmer than surrounding rural areas. The UHI effect is a widely recognized and discussed phenomenon within the literature (Stewart, 2011), and is one of the most widely cited examples of anthropogenic modification of the atmospheric environment (EPA, 2014; Voogt, 2004). Due to the UHI effect the annual mean temperature within a city with more than one million inhabitants can be between 1-3˚C higher than surrounding rural areas (Oke, 1997), and on a clear calm night, this number can reach upwards of 10˚C (Oke, 2002). The two primary sources of UHI are: 1) the heat generated from urban structures that absorb and then re-radiate solar energy; and 2) the heat emitted from human activity within cities (Rizwan et al, 2008). Both buildings and the open spaces between buildings can directly contribute to UHI (EPA, 2014).

Alongside fundamentally altering the climate of city, UHI has a number of negative implications for human health and wellbeing. Areas where UHI is significant for example have been shown to a produce a high degree of ozone pollution, which in turn can lead to increased rates of cardiovascular and respiratory disease (Tan et al, 2010). Urban heat islands have also been demonstrated to amplify the frequency and severity of heat waves, and the number of mortalities during these events (Tan et al, 2010). Due to the profound impact of UHI on climate and human health, it is crucial that cities take steps to address this stressor. Reducing the effects of UHI will improve urban resilience in a multitude of ways, including reducing urban energy usage and costs associate with cooling technologies, and reducing human vulnerability to detrimental health impacts of UHI (Leal Filho et al, 2018). In a study of the urban heat island effect in Los Angeles for example, researchers estimate that resurfacing approximately two-thirds of pavements and rooftops with reflective surfaces and planting three trees per house could significantly reduce the urban heat island effect, and lead to cooling energy savings of approximately $5 billion annually (Akbari, 2005).

Buildings constitute a large part of the urban environment contributing to the UHI effect (EPA, 2014).The thermal energy produced by a building is a function of building massing, and changes in building massing corresponding to an increase in the height to floor area ratio will lead to a reduction in the UHI effect (Giridharan, et al, 2004). More compact building massing gives off less unintended thermal heat into the near ground atmospheric environment (Pacheco, 2012), and is therefore likely to contribute less to UHI than other building massings. Some studies have shown that the dispersed urban massing typical of low density residential development produces more excess radiant heat per parcel than high density urban development (Stone & Rogers, 2001), contributing greater to the overall UHI effect. A recent study of the Washington and Baltimore metropolitan areas for example found that decreasing commercial building heights by 8m and residential building heights by 2.5m increased near surface air temperatures by around 0.4˚C (Loughner et al, 2012). However, this same study found that these lower building heights contributed comparatively less to the UHI phenomenon at night relative to taller buildings, due to the reduced longwave radiation trappings in urban street canyons (Loughner et al, 2012). Similarly during the day, tall buildings have the potential to block wind movement and provide a plethora of surfaces from which solar radiation can be reflected, which can also significantly contribute to UHI (Taslim et al, 2015). Such seemingly contradictory findings highlight the importance of building massing in relation to other buildings and the streetscape (rather than the massing of a single building in isolation) in influencing the occurrence and intensity of UHI. For example, Taslim et al (2015) found that increasing the ratio of building height (H) to the width of the adjacent street (W) had positive implications for reducing UHI by providing substantial shade to the street environment. Building massing which enhances wind flow can decrease the impacts of UHI by enhancing passive cooling and air movement (Rajagopalan et al, 2014).

Due to the pertinence of building massing to UHI, the RNDT uses a Non-Solar Heated Façade Area Index (NSHFFAI) as a metric to assess how much a design proposal may contribute to UHI. NSHFFAI refers to the ratio of a building façade area receiving an annual solar irradiation greater than or equal to 364kWh/ m^2 to the net floor area of an urban area, where a high NSHFFAI is preferable for reducing the likelihood of a building overheating and contributing to UHI. This index has been used by others such as Chen and Norford (2017) to quantify in the design phase the potential of a building to overheat (and thereby emit surplus thermal energy into the near-ground atmosphere, contributing to UHI).

The heat given off by buildings is a key contributor to the UHI effect. According to researchers such as Stone and Rogers (2001), the dispersed urban massing typical of low density residential development actually produces more excess radiant heat per parcel than high density urban development characteristic of a city centre. Image by the Science Museum of Virginia.

Reference

Akbari, H. (2005). Energy saving potentials and air quality benefits of urban heat island mitigation (No. LBNL-58285). Ernest Orlando Lawrence Berkeley NationalLaboratory, Berkeley, CA (US).

Chen, K., & Norford, L. (2017). Evaluating urban forms for comparison studies in the massing design stage. Sustainability, 9(6), 987.

EPA. (2014, June). Reducing Urban Heat Islands: Compendium of Strategies. Retrieved from https://www.epa.gov/sites/production/files/2014-06/documents/basicscompendium.pdf

Giridharan, R., Ganesan, S., & Lau, S. S. Y. (2004). Daytime urban heat island effect in high-rise and high-density residential developments in Hong Kong. Energy and buildings, 36(6), 525-534.

Leal Filho, W., Icaza, L. E., Neht, A., Klavins, M., & Morgan, E. A. (2018). Coping with the impacts of urban heat islands. A literature based study on understanding urban heat vulnerability and the need for resilience in cities in a global climate change context. Journal of cleaner production, 171, 1140-1149.

Loughner, C. P., Allen, D. J., Zhang, D. L., Pickering, K. E., Dickerson, R. R., & Landry, L. (2012). Roles of urban tree canopy and buildings in urban heat island effects: Parameterization and preliminary results. Journal of Applied Meteorology and Climatology, 51(10), 1775-1793.

Oke, R. T. (1997). Urban climate and global environmental change. Applied climatology, 273-287.

Oke, T. R. (2002). Boundary layer climates. Routledge.

Pacheco, R., Ordóñez, J., & Martínez, G. (2012). Energy efficient design of building: A review. Renewable and Sustainable Energy Reviews, 16(6), 3559-3573.

Rajagopalan, P., Lim, K. C., & Jamei, E. (2014). Urban heat island and wind flow characteristics of a tropical city. Solar Energy, 107, 159-170.

Rizwan, A. M., Dennis, L. Y., & Chunho, L. I. U. (2008). A review on the generation, determination and mitigation of Urban Heat Island. Journal of Environmental Sciences, 20(1), 120-128.

Stewart, I. D. (2011). A systematic review and scientific critique of methodology in modern urban heat island literature. International Journal of Climatology, 31(2), 200-217.

Stone, J., Brian, & Rodgers, M. O. (2001). Urban form and thermal efficiency. Journal of the American Planning Association, 67(2), 186.

Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., ... & Chen, H. (2010). The urban heat island and its impact on heat waves and human health in Shanghai. International journal of biometeorology, 54(1), 75-84.

Taslim, S., Parapari, D. M., & Shafaghat, A. (2015). Urban Design Guidelines to Mitigate Urban Heat Island (UHI) Effects In Hot-Dry Cities. Jurnal Teknologi, 74(4).

Voogt, J. A. (2004). Urban heat islands: hotter cities.

Urban Heat Island – Landscape

Landscape, and the open spaces between buildings have the potential to either enhance or mitigate UHI (Estoque et al, 2017; Akbari, 2005). Extensive open space which is entirely concreted for example will significantly contribute to UHI by creating a continuous solar-absorbent surface that will reemit solar energy as sensible heat and raise the surrounding atmospheric thermal temperature accordingly (Jusuf et al, 2007). Contrastingly, open space that is heavily vegetating has the potential to mitigate UHI by providing shade and through processes of evapotranspiration that regulate the near-ground thermal environment and reduce the amount of sensible heat being reemitted into the atmosphere (Wang & Akbari, 2016; Feyisa et al, 2014; Taha, 1997; Kurn et al 1994). The potential for landscape features to positively contribute to urban resilience by reducing UHI has received attention in different resilience assessment frameworks. In Sharifi and Yamagata (2016) for example, 'landscape-based passive cooling' is used as a criterion for assessing urban resilience, whilst 'tree canopy intensity' and the ability of this phenomenon to mitigate the effects of UHI through cooling and shading is used as an indicator in the holistic sustainability framework developed by the Design Centre for Sustainability at the University of British Columbia (DCS, 2009).

Due to the importance of landscape to UHI and the opportunity landscape design elements hold for enhancing urban resilience against UHI the RNDT has adopted a resilience indicator which measures the tree canopy/shading of public open spaces on the summer solstice between 10am-2pm. Our research has highlighted the importance of vegetated softscape design features and tree canopy coverage as urban design levers which can be used to reduce the effects of UHI in public open spaces.

Softscape (%)

Vegetation has been demonstrated to be effective at mitigating the effects of an urban heat island through processes of evapotranspiration and by providing shade (Kurn et al, 1994; Taha, 1997). Increasing the amount of vegetation and softscape design features in the urban landscape between buildings then, can help reduce the urban heat island effect in cities (Li et al, 2011). It is likely that interspersing greenspace and vegetation into the built environment regularly will have a greater impact in reducing UHI than creating highly concentrated greenspace areas (Li et al, 2011). For local greenspace to have an impact on UHI, it is recommended to have at least 600-700m^2 of green landscape for every 1000m^2 of open area (Giridharan et al, 2004).

Water features are also able to reduce the effects of UHI by cooling surrounding air through evaporation (Coutts, 2013). This highlights the potential that for blue design features such as urban streams, fountains, and lakes can have for enhancing resilience against UHI – especially when used in conjunction with green design features (Leal Filho et al, 2018).

Tree canopy (%)

Tree canopy coverage can be effective in reducing the effects of an urban heat island by providing shade (which is typically proportional to the volume of

For local greenspace to have a positive impact on reducing the Urban Heat Island effect, some researchers recommend having at least 600-700m^2 of green landscape for every 1000m^2 of open area.

canopy) and through processes of evapotranspiration (Wang & Akbari, 2016; Akbari, 2005; Taha, 1997; Kurn et al, 1994). Increasing the amount of tree canopy coverage in the built environment then can be a key design intervention to reduce the effects of UHI and urban vulnerability to this phenomenon (Aminipouri et al, 2019; Wang & Akbari, 2016). A recent study by Aminipouri et al (2019) for instance estimates that increasing tree coverage in Vancouver by 1% of total plan area can reduce average daytime temperatures by between 3.2 - 6.3°C, with the greatest heat reductions occurring in low-density residential neighbourhoods with limited existing shading.

Increasing tree coverage in Vancouver by 1% of total plan area can reduce average daytime temperatures by between 3.2 - 6.3°C, with the greatest heat reductions occurring in low-density residential neighbourhoods with limited existing shading.

Reference

IPCC. (2001). Climate change 2001; impacts adaption and vulnerability. Report of Working Group II of the Intergovernmental Panel on Climate Change, Hydrology and Water Resources Section.

Akbari, H. (2005). Energy aving potentials and air quality benefits of urban heat island mitigation (No. LBNL-58285). Ernest Orlando Lawrence Berkeley NationalLaboratory, Berkeley, CA (US).

Aminipouri, M., Knudby, A. J., Krayenhoff, E. S., Zickfeld, K., & Middel, A. (2019). Modelling the impact of increased street tree cover on mean radiant temperature across Vancouver's local climate zones. Urban Forestry & Urban Greening, 39, 9-17.

Coutts, A. M., Tapper, N. J., Beringer, J., Loughnan, M., & Demuzere, M. (2013). Watering our cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context. Progress in Physical Geography, 37(1), 2-28.

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Estoque, R. C., Murayama, Y., & Myint, S. W. (2017). Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia. Science of the Total Environment, 577, 349-359.

Feyisa, G. L., Dons, K., & Meilby, H. (2014). Efficiency of parks in mitigating urban heat island effect: An example from Addis Ababa. Landscape and Urban Planning, 123, 87-95.

Giridharan, R., Ganesan, S., & Lau, S. S. Y. (2004). Daytime urban heat island effect in high-rise and high-density residential developments in Hong Kong. Energy and buildings, 36(6), 525-534.

Jusuf, S. K., Wong, N. H., Hagen, E., Anggoro, R., & Hong, Y. (2007). The influence of land use on the urban heat island in Singapore. Habitat international, 31(2), 232-242.

Kurn, D. M., Bretz, S. E., Huang, B., & Akbari, H. (1994). The potential for reducing urban air temperatures and energy consumption through vegetative cooling (No. LBL-35320). Lawrence Berkeley Lab., CA (United States).

Leal Filho, W., Icaza, L. E., Neht, A., Klavins, M., & Morgan, E. A. (2018). Coping with the impacts of urban heat islands. A literature based study on understanding urban heat vulnerability and the need for resilience in cities in a global climate change context. Journal of cleaner production, 171, 1140-1149.

Li, J., Song, C., Cao, L., Zhu, F., Meng, X., & Wu, J. (2011). Impacts of landscape structure on surface urban heat islands: A case study of Shanghai, China. Remote Sensing of Environment, 115(12), 3249-3263.

Sharifi, A., & Yamagata, Y. (2016). Principles and criteria for assessing urban energy resilience: A literature review. Renewable and Sustainable Energy Reviews, 60, 1654-1677.

Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. Energy and buildings, 25(2), 99-103.

Wang, Y., & Akbari, H. (2016). The effects of street tree planting on urban heat island mitigation in montreal. Sustainable Cities and Society, 27, 122-128. doi:10.1016/j.scs.2016.04.013

Sea Level Rise

Sea level rise as a consequence of global warming has received much attention within the resiliency literature (Aerts et al, 2014; Wardekker et al, 2010; Muller, 2007; Mimura, 1999). Ocean thermal expansion and ice-sheet melt caused by increasingly global temperatures are key mechanisms through which sea level rise is currently occurring (Milne et al, 2009). According to recent projections, it is likely that the average global sea level rise by the end of the century will be between 26cm - 82cm (Church et al, 2013), although there will be significant regional variation in these figures. Based on such predictions, the province of British Columbia has advised municipalities to plan for 1 metre of sea level rise by 2100, and 2 metres by 2200 (City of Vancouver, 2017). In accordance with these sea level predictions, the Vancouver Climate Change Adaption Strategy estimates that sea level rise will cause between $2.1 - $7.6 billion in damages to human property and infrastructure in British Columbia (mostly within the wider Vancouver region) by 2050 (City of Vancouver, 2018). Due to the gravity of these costs the City of Vancouver has adopted a 4.6m flood construction level for neighbourhoods most vulnerable to sea level rise, including Burrard Inlet, English Bay, False Creek, and the Fraser River Flood Plain, which specifies that "the underside of a floor system or the top of a concrete slab of a building used for habitation, business or storage of goods shall not be lower than 4.6m" (City of Vancouver, 2014, pg.6).

Given that more than 10% of the global population live in low-elevation coastal zones vulnerable to the effects of sea level rise (McGranahan et al, 2007), adapting to sea level rise in a resilient way will be a key challenge over the coming decades for cities globally. This is especially true given that a concurrent implication of climate change will be an increase in extreme weather events such as storm surges, and hurricanes (Tebaldi et al, 2012; IPCC, 2001; Knutson et al, 1998). For example, a recent study of New York City (NYC) conducted by Lin et al (2012) estimates that the "combined effects of storm climatology change and a 1-m sea level rise may cause the current NYC 100-year surge flooding to occur every 3-20 years and the 500-year flooding to occur every 25-240 years by the end of century" (pg.2).

As a consequence of global warming, the province of British Columbia has advised municipalities to plan for 1 metre of sea level rise by 2100, and 2 metres by 2200. Due to the gravity of these predictions, the City of Vancouver has adopted a 4.6m flood construction level for neighbourhoods most vulnerable to sea level rise. Photo sourced from the City of Vancouver.

As a reference point of the economic implications an increase in such extreme weather events could cause cities already vulnerable to sea level rise and coastal inundation, the total costs of Hurricane Sandy (2012) are approximately $71 billion, whilst the costs of Hurricane Maria were in excess of $90 billion (NOAA, 2019).

Models developed to measure the resilience of cities to coastal inundation hazards in light of sea level rise predictions are fairly common within the literature (see for example the Coastal City Flood Vulnerability Index developed by Balica et al (2012)), and indicators measuring a community's flood resilience are commonly used in holistic resilience assessment frameworks. Cutter et al (2010) for example, uses 'flood coverage' (defined as the percentage of housing units covered by NFIP policies) as a key indicator of disaster resilience at an institutional level. The justification for this indicator is that NFIP (National Flood Insurance Program) policies provide insurance rate reductions for communities with floodplain management plans, which in turn will likely enhance flood resilience within a community (Burby et al, 2000; Wetmore & Jamieson, 1999). Similarly, the Resilience Index developed by Abdrabo & Hassaan (2015) utilizes a set of indicators which aim to quantity the resilience of the Nile Delta area to global sea level rise. Some of these indicators include the 'population susceptible to inundation' and 'vulnerable built up areas'.

Due to the increasing relevance of sea level rise at both a global and local scale and the potentially severe physical and economic implications of this phenomenon, the RNDT uses an indicator to assess the resiliency of the built environment to sea level rise in the design phase. This indicator adopts the 4.6m flood construction level advised by the City of Vancouver (2014) to measure the percentage of neighbourhood GFA that is built for 4.6m of sea level rise.

The Vancouver Climate Change Adaption Strategy estimates that sea level rise as a consequence of global warming will cause between $2.1 – $7.6 billion in damages to human property and infrastructure in British Columbia (mostly within the wider Vancouver region) by 2050.

Reference

Abdrabo, M. A., & Hassaan, M. A. (2015). An integrated framework for urban resilience to climate change–Case study: Sea level rise impacts on the Nile Delta coastal urban areas. Urban Climate, 14, 554-565.

Aerts, J. C., Botzen, W. W., Emanuel, K., Lin, N., De Moel, H., & Michel-Kerjan, E. O. (2014). Evaluating flood resilience strategies for coastal megacities. Science, 344(6183), 473-475.

Balica, S. F., Wright, N. G., & van der Meulen, F. (2012). A flood vulnerability index for coastal cities and its use in assessing climate change impacts. Natural hazards, 64(1), 73-105.

Burby, R. J., Deyle, R. E., Godschalk, D. R., & Olshansky, R. B. (2000). Creating hazard resilient communities through land-use planning. Natural hazards review, 1(2), 99-106.

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, (2013). Sea Level Change. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

City of Vancouver (2017). Vancouver's changing shoreline: preparing for sea level rise. Retrieved from https://vancouver.ca/green-vancouver/sea-level-rise.aspx

City of Vancouver. (2014). Flood Plain Standards and Requirements. Retrieved from https://guidelines.vancouver.ca/F014.pdf

City of Vancouver. (2018, December). Climate Change Adaption Strategy. Retrieved from https://vancouver.ca/files/cov/Vancouver-Climate-Change-Adaptation-Strategy-2012-11-07.pdf

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1).

Knutson, T. R., Tuleya, R. E., & Kurihara, Y. (1998). Simulated increase of hurricane intensities in a CO2-warmed climate. Science, 279(5353), 1018-1021.

McGranahan, G., Balk, D., & Anderson, B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environment and urbanization, 19(1), 17-37.

Milne, G. A., Gehrels, W. R., Hughes, C. W., & Tamisiea, M. E. (2009). Identifying the causes of sea-level change. Nature Geoscience, 2(7), 471.

Mimura, N. (1999). Vulnerability of island countries in the South Pacific to sea level rise and climate change. Climate research, 12(2-3), 137-143.

Muller, M. (2007). Adapting to climate change: water management for urban resilience. Environment and Urbanization, 19(1), 99-113.

NOAA Office for Coastal Management. (2019, January). Fast Facts: Hurricane Costs. Retrieved from https://coast.noaa.gov/states/fast-facts/hurricane-costs.html

Tebaldi, C., Strauss, B. H., & Zervas, C. E. (2012). Modelling sea level rise impacts on storm surges along US coasts. Environmental Research Letters, 7(1), 014032.

Wardekker, J. A., de Jong, A., Knoop, J. M., & van der Sluijs, J. P. (2010). Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. Technological Forecasting and Social Change, 77(6), 987-998.

Wetmore, F., & Jamieson, G. (1999). Flood mitigation planning: The CRS approach. University of Boulder, Natural Hazards Research and Applications Information Center.

Droughts + Flood Mitigation

The effects of climate change over the next 100 years will likely see a significant increase in extreme weather events, including droughts and rainfall induced flooding (IPCC, 2001). In light of such stressors, maintaining a reliable water supply to meet demand through effective water management (whilst also having capacity to deal with extreme rainfall events) will be a crucial priority for enhancing urban resilience at a city level (Muller, 2007; Tanner et al, 2009). Although such matters will be especially germane to parts of the world already vulnerable to water shortages and extreme weather events, cities like Vancouver will also be affected. For instance, rainfall in Vancouver is projected to increase by 5% by 2050 and 8% by 2080, with much of this increased rainfall occurring during winter and fall (Metro Vancouver & Pinna Sustainability, 2016). This increased intensity and frequency of heavy rainfall events will put increasing pressure on city infrastructure and has the potential to cause significant damage to residents' property and livelihoods (City of Vancouver, 2018a). To deal with the increased intensity of rainfall events, the recent Vancouver Rain City Strategy has set a city-wide water quality treatment target of 48mm over a 24-hour period (City of Vancouver, 2018b). Broken down, this target requires that an area within the city is able to infiltrate and capture the first 24mm of rainfall in a day (typical of anything from a drizzle to a small storm), as well as being able to infiltrate and treat (ideally through subsurface soils) the second 24mm of rainfall that could occur within this same time period (48mm of rainfall over 24 hrs would only occur in a large storm that would be expected to occur once in a typical year) (City of Vancouver, 2018b).

During the summer however, Vancouver will experience a -19% and -29% decrease in rainfall by 2050 and 2080 respectively. Paired with increasingly hotter days, this will increase demand for water in the City during the summer substantially (Metro Vancouver & Pinna Sustainability, 2016). This demand will likely be amplified by the reductions in spring snowpack (the April 1st snowpack is projected to decrease by 58% by 2050 (City of Vancouver Sustainability Group, 2018)). Droughts and floods also have the potential to create food security issues through crop failure (Devereux, 2007). In the developing world especially, this can lead to major societal shocks such as famine (Rockstrom,

Rainfall in Vancouver is projected to increase by 5% by 2050 and 8% by 2080, wit
to such climatic shifts will need to be an increasingly important priority for cities a

2003). Droughts also have the potential to drastically change the aesthetic of the built environment, and significantly impact on ecological life and habitat. (Bond et al, 2008).

Because of the serious and multifaceted problems emerging from extreme weather events such as drought and flooding, the resilience of a community to these stressors is an important hallmark of overall urban resilience. The importance of resilience to extreme weather events is well covered in the literature – especially in relation to climate change (Jha et al, 2013; Djordjevic et al, 2011; Keil et al, 2007; Muller, 2007). Indices such as that developed by Keil et al (2007) have been created to specifically measure the drought resilience of households and communities for instance, whilst several holistic frameworks for assessing urban resilience more generally have incorporated indicators relating to drought and flood sensitivity and resilience (EPA, 2016; Siemens, 2013; Rueda, 2012; Bay Localize, 2009). The Ecological Urbanism model developed by Rueda (2012) uses multiple indicators germane to droughts and water management, including 'water demand by sector', 'reclaimed marginal water, and 'self-sufficiency water'; whilst the Community Resilience Toolkit created by Bay Localize (2009) also incorporates several indicators which speak to the resilience of urban water supply and usage. Effective water management, including the "collection, treatment, and distribution of drinking water" is heavily emphasized as a key component of urban resilience in the Toolkit for Resilience developed by Siemens (2013), whilst the Flood Vulnerability Index developed by Balica and Wright (2010) takes into account over 70 indicators germane to resilience including runoff storage (calculated as storage capacity / yearly volume runoff), the number of days with heavy rainfall (greater than 100mm / day), 'land use' as a proxy for natural pervious surface with infiltration potential (measured as the percentage of a river basin which is forested), and dam storage capacity (measured as the total volume of water which can be stored by dams and polders).

h much of this increased rainfall occurring during winter and fall. Adapting
nd communities. Image sourced from [Clarksville Online]

Due to the growing relevance of extreme weather events such as rainfall-induced flooding and drought and the attention these stressors have received within the resilience literature, the RNDT has incorporated an indicator on drought and flood mitigation (measured as the rainwater storage and infiltration capacity based on a 100 year storm event). Rainwater storage is relevant to both the capacity of a neighbourhood to deal with an extreme rainfall event and to water management during periods of drought or shortage, whilst infiltration capacity is predominantly linked to flood mitigation.

Reference

Balica, S., & Wright, N. G. (2010). Reducing the complexity of the flood vulnerability index. Environmental Hazards, 9(4), 321-339.

Bay Localize. (2009). Community Resilience Toolkit. Retrieved from http://www.baylocalize.org/files/Community_Resilience_Toolkit_v1.0.pdf

Bond, N. R., Lake, P. S., & Arthington, A. H. (2008). The impacts of drought on freshwater ecosystems: an Australian perspective. Hydrobiologia, 600(1), 3-16.

City of Vancouver Sustainability Group. (2018). Climate Change Adaption Strategy: 2018 Update and Action Plan. Retrieved from https://vancouver.ca/files/cov/Vancouver-Climate-Change-Adaptation-Strategy-2018.pdf

City of Vancouver. (2018a). Climate Change Adaption Strategy. Retrieved from https://vancouver.ca/files/cov/Vancouver-Climate-Change-Adaptation-Strategy-2012-11-07.pdf

City of Vancouver. (2018b). Vancouver Integrated Rainwater Management Plan. Retrieved from https://vancouver.ca/home-property-development/city-wide-integrated-stormwater-management-plan.aspx

Devereux, S. (2007). The impact of droughts and floods on food security and policy options to alleviate negative effects. Agricultural Economics, 37, 47-58.

Djordjević, S., Butler, D., Gourbesville, P., Mark, O., & Pasche, E. (2011). New policies to deal with climate change and other drivers impacting on resilience to flooding in urban areas: the CORFU approach. Environmental Science & Policy, 14(7), 864-873.

EPA (Environmental Protection Agency). (2016). Evaluation Urban Resilience to Climate Change: A multi-Sector Approach.

IPCC. (2001). Climate change 2001; impacts adaption and vulnerability. Report of Working Group II of the Intergovernmental Panel on Climate Change, Hydrology and Water Resources Section.

Jha, A. K., Miner, T. W., & Stanton-Geddes, Z. (Eds.). (2013). Building urban resilience: principles, tools, and practice. The World Bank.

Keil, A., Zeller, M., Wida, A., Sanim, B., & Birner, R. (2008). What determines farmers' resilience towards ENSO-related drought? An empirical assessment in Central Sulawesi, Indonesia. Climatic Change, 86(3-4), 291.

Metro Vancouver & Pinna Sustainability. (2016). Climate Projections for Metro Vancouver. Retrieved from http://www.metrovancouver.org/services/air-quality/AirQualityPublications/ClimateProjectionsForMetroVancouver.pdf

Muller, M. (2007). Adapting to climate change: water management for urban resilience. Environment and Urbanization, 19(1), 99-113.

Rockström, J. (2003). Resilience building and water demand management for drought mitigation. Physics and Chemistry of the Earth, Parts A/B/C, 28(20-27), 869-877.

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

Siemens. (2013). Toolkit for Resilient Cities. Retrieved from https://assets.new.siemens.com/siemens/assets/public.1543066657.641ee2256c5a0d5919d1aa3094a701f6ec9c3f90.toolkit-for-resilient-cities.pdf

Tanner, T., Mitchell, T., Polack, E., & Guenther, B. (2009). Urban governance for adaptation: assessing climate change resilience in ten Asian cities. IDS Working Papers, 2009(315), 01-47.

ECOLOGY

Effective Pervious Area

Effective pervious area (EPA) refers to the amount of pervious surface that infiltrates water into the ground without impacting a natural hydrological system, as a percentage of a total given area (Condon, 2010). Increasing the amount of pervious area within a neighbourhood or city can enhance urban resilience against external stressors such as flooding, UHI, aquatic and atmospheric pollution, and ecological degradation.

To the first of these: pervious surfaces allow infiltration of water which can reduce surface water runoff. This in turn significantly mitigates the risk of floods during heavy rainfall events or during storm surges (Condon, 2010). Because of this 'pervious surfaces' are commonly used as a primary indicator of flood risk (Brody et al, 2012). In their analysis of flood hazards along the Gulf of Mexico for example, Brody et al (2012) adopts 'pervious surfaces' as one of four key ecological indicators of flood risk (the others being floodplain area, soil porosity, and naturally occurring wetlands).

In a similar fashion, pervious surfaces can also act as a filter for polluted stormwater, which in turn reduces the amount of toxic material entering aquatic waterways and habitats, thereby reducing the vulnerability of aquatic communities (Ferguson, 2017; Condon, 2010). In The Importance of Imperviousness (1994), Schueler suggests that a threshold for urban stream quality exists at about 85-90% pervious area in a given watershed (10-15% total impervious surface). If the effective pervious area drops below this threshold, then urban stream habitat quality begins to degrade significantly and is classified as poor (Schueler, 1994). Similar pervious thresholds of around 90% (below which significant ecological degradation occurs) have been identified elsewhere within the literature such as by the likes of Wang et al (2000), Wang and Kenehl (2003), and Paul and Meyer (2001), as well as in a British Columbian context (Stephens et al, 2002). Other studies, such as May et al (1998), recommend an even higher threshold for pervious surface coverage and ecological degradation of around 5%. Some of these thresholds for pervious surface coverage in relation to ecological degradation are presented in table 6 below. Note: all figures for Effective Impervious Area (EIP) have been converted to Effective Pervious Area (EIP) values.

Lastly, vegetated pervious areas reduce the amount of solar-absorbent urban surface within an area that contribute to the Urban Heat Island (UHI) effect by reemitting solar energy as sensible heat (Yuan & Bauer, 2007). Studies such as that conducted by Yuan and Bauer (2007) identify a strong linear relationship between the amount of impervious surface in an urban area and the land surface temperature, highlighting the importance of reducing impervious surface as a

Source	EPA (%) threshold for ecological degradation
May et al (1998)	95%
Wang & Kenehl (2003)	93%
Stephens et al (2002)	90%
Paul & Meyer (2001)	90%
Wang et al (2000)	90%
Schueler (1994)	85-90%

Table 6: Generally, the EPA threshold at which ecological degradation will occur in a watershed is around 90% coverage. That is, if less than 90% of a watershed area is pervious surface, then the health of ecological aquatic communities will begin to decline significantly.

Pervious surfaces can also act as a filter for polluted stormwater, which in turn reduces the amount of toxic material entering aquatic waterways and habitats, thereby reducing the vulnerability of aquatic communities.

mitigation strategy to reduce the severity of UHI. Such findings have been supporting by the likes of Stone and Norman (2006), and the percent of impervious surface within a given area is commonly used as a metric to assess vulnerability to extreme heat events and UHI (Uejio et al, 2011).

Extrapolating from these results, it follows that if impervious surface is a reliable indicator of increased vulnerability to UHI, then a decrease in the percentage of impervious surface in a given area (and a relative increase in pervious surface) can be an equally reliable indicator of resilience to UHI. 'Perviousness' is used as an indicator of environmental resilience in the Baseline Resilience Index developed by the Hazards & Vulnerability Research Institute at the University of South Carolina (Cutter, 2015), and 'impervious surface intensity' (measured as the percent of effective pervious area) is used as an indicator in the holistic sustainability framework developed by the Design Centre for Sustainability at the University of British Columbia (DCS, 2009) which aims to reduce impervious surfaces to at most 40% or less of an area, with an ideal target of less than 10% (which corresponds to an effective pervious area of 60%< and 90%< respectively). 'Percent of impervious surface' is also utilized as an indicator in resilience assessments such as the Disaster Resilience of Place (DROP) model developed by Cutter et al (2008) where a reduction in impervious surface (and a corresponding increase in pervious surface) positively contributes to resilience, and is recommended as a potential indicator of overall habitat and ecosystem functioning by the EcoDistricts Toolkit developed by the Portland Sustainability Institute (2011).

For these reasons, the RNDT utilizes 'effective pervious area' (which measures the percentage of a total site area that is designed to infiltrate, capture, and/or store rainwater) as an indicator of urban resilience.

Reference

Brody, S. D., Peacock, W. G., & Gunn, J. (2012). Ecological indicators of flood risk along the Gulf of Mexico. Ecological Indicators, 18, 493-500.

Condon, P. M. (2010). Seven rules for sustainable communities: Design strategies for a post-carbon world. Washington, D.C: Island Press.

Cutter, S. (2015, April). Resilience Metrics and Tools: A Quick Overview. Presentation given at the Building Blocks for a National Resilience Scorecard Workshop, Washington DC.

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. Global environmental change, 18(4), 598-606.

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Ferguson, B. K. (2017). Stormwater infiltration. CRC Press.

May, C. W., Horner, R. R., Karr, J. R., Mar, B. W., & Welch, E. B. (1998). The cumulative effects of urbanization on small streams in the Puget Sound Lowland Ecoregion. In Proceedings of the Puget Sound Research.

Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. Annual review of Ecology and Systematics, 32(1), 333-365.

Portland Sustainability Institute. (2011). EcoDistricts Toolkit: Assessment.

Schueler, T. (1994). The importance of imperviousness. Watershed protection techniques, 1(3), 100-101.

Stephens, K., Graham, P., & Reid, D. (2002). Stormwater Planning: A Guidebook for British Columbia. Retrieved from file:///C:/Users/pok51/Downloads/stormwater_planning_guidebook_for_bc.pdf

Stone, B., & Norman, J. M. (2006). Land use planning and surface heat island formation: A parcel-based radiation flux approach. Atmospheric Environment, 40(19), 3561-3573.

Uejio, C. K., Wilhelmi, O. V., Golden, J. S., Mills, D. M., Gulino, S. P., & Samenow, J. P. (2011). Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability. Health & Place, 17(2), 498-507.

Wang, L., & Kanehl, P. (2003). Influences of watershed urbanization and instream habitat on macroinvertebrates in cold water streams1. Journal of the American Water Resources Association, 39(5), 1181

Wang, L., Lyons, J., Kanehi, P., Bannerman, R., & Emmons, E. (2000). watershed urbanization and changes in fish communities in southeastern wisconsin streams. Journal of the American Water Resources Association, 36(5), 1173-1189. doi:10.1111/j.1752-1688.2000.tb05719.x

Yuan, F., & Bauer, M. E. (2007). Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. Remote Sensing of environment, 106(3), 375-386.

Habitat Connectivity

Habitat connectivity refers to the extent to which different ecological areas are interconnected to create a single continuous habitat for wildlife, and can be defined as "the degree to which a landscape facilitates or impedes the movement of organisms among resource patches" (Tischendorf & Fahrig, 2000, pg.7). Habitat connectivity has been shown to improve the resilience of ecological communities in numerous ecological contexts (Olds et al, 2012). The reverse of this relationship also applies: fragmentation and decreased connectivity between ecological areas has negative implications for ecological resilience, biodiversity, and overall wellbeing (Thrush et al, 2008).

Biodiversity in cities is generally perceived to be an important environmental goal of urban planning (Ahern, 2013), and facilitating urban biodiversity is one way in which cities can become more sustainable and resilient (Oke, 2017). Urban ecosystems and biodiversity can provide a range of unique services which directly enhance urban resilience (Oke, 2017; McPhearson et al, 2015). Wetlands and mangroves for example, provide habitat to a diversity of ecological life, but can also enhance disaster resilience by mitigating the risk of storm surges and coastal flooding (McPhearson et al, 2015). Similarly, urban forests and parks provide ecological habitat to a wide range of flora and fauna species (Fong, 2010), but can also reduce the impacts of UHI and enhance urban air quality (Nowak & Heisler, 2010; Kurn et al, 1994), as well as positively benefiting human physical and mental health which in turn boosts social and psychological resilience (Braubach et al, 2017). The known association between greenspace (which can often contain a rich range of flora and fauna biodiversity (Fong, 2010)) proximity and real estate prices may even contribute to a more stable real estate market, thereby enhancing local economic resilience (McPhearson et al, 2015).

A key prerequisite for biodiversity is habitat connectivity, and the movement of organisms between different habitats is deemed to be crucial for ecological performance and persistence (Olds et al, 2012). As articulated by Correa Ayram al (2016), "the integrity and functionality of ecosystems and the maintenance of biodiversity and ecosystem services are made possible by the flow of organisms, materials, energy, and information across landscapes" (pg.8). Habitat connectivity, area, and quality have been identified by Hodgson et al (2009) as fundamental components of ecological conservation, and each of these components has the potential to positively interact with and benefit the other. For instance, enhancing habitat quality and area can enhance habitat connectivity (Hodgson et al, 2011; Hodgson et al, 2009), and increasing habitat connectivity can positively contribute to overall habitat quality (Perlman & Milder, 2005). For this reason, habitat connectivity has been used widely as an indicator of ecological health and biodiversity, both in conservation management (Lindenmayer et al, 2000), and in holistic models such as that created by Rueda (2012) which measures the "connectivity of urban green corridors" (calculated as the amount of urban green corridor section area as a percentage of total street section area, where ideally more than 10% of total street area is a green corridor). 'Ecological connectivity' is explicitly referenced in the Mercy

> ***Habitat connectivity can be defined as "the degree to which a landscape facilitates or impedes the movement of organisms among resource patches".***

Corps Urban Resilience Measurement manual as a useful indicator for quantifying resilience in urban systems (Mercy Corps, n.d.).

For these reasons, the RNDT has adopted a 'habitat connectivity' metric as a resilience indicator. This metric takes into account the interconnectedness of habitat patches (such as parks and urban greenspaces) and corridors (such as green streets) by performing a weighted calculation of continuous habitat area, with greater connectivity between different habitat segments produced a higher overall resilience score. Our research has highlighted the importance of several design features which impact on habitat connectivity in the built environment. These include traffic design speed (Tejera et al, 2018), tree canopy coverage (Rueda, 2012; Ignatieva et al, 2011), effective pervious area, (Singh et al, 2010; Perlman & Milder, 2005) and conservation area (Hodgson et al, 2009).

Traffic Design Speed

Increased automobile speed on highways is associated with a greater rate of wildlife-automobile collisions. This negatively impacts habitat connectivity, as high-speed roads create a deadly division for wildlife trying to move between different ecological patches (Tejera et al. 2018). Conversely, slower traffic speeds increases habitat connectivity by allowing wildlife to more safely move from one ecological area to another (Beckmann & Hilty, 2010).

Tree Canopy (%)

Increasing tree canopy coverage along streets enhances habitat connectivity, by creating continuous urban ecological corridors which different wildlife species may use to move from one ecological patch to another (Ignatieva et al, 2011). As Rueda (2012) describes:

Increased traffic speeds on highways creates a potentially lethal barrier for wildlife trying to move between different ecolocigal patches. Image sourced from Jerry Coyne.

"trees are a major vegetal element that can impact on a city's climate and when organized along street sidewalks, they become a structural element of the urban ecosystem's biodiversity" (pg.80).

Effective Pervious Area

Increasing effective pervious area by establishing vegetation in urban areas can create ecological patches and corridors, which improves habitat connectivity (Singh et al, 2010; Perlman & Milder, 2005). Increasing pervious area will also increase natural infiltration of polluted stormwater runoff, which can itself reduce the amount of contaminants entering different ecological habitats (including waterways) and the frequency and intensity of flood events, which can benefit overall ecological health (Arnold Jr & Gibbons, 1996).

Conservation Area

Conservation areas which link different ecological patches through green corridors can improve habitat connectivity by creating a continuous ecological space (Perlman & Milder, 2005). Such corridors are a fundamental part of ecological health, as they create a potentially continuous habitat for wildlife, which reduces ecological vulnerability and enhances redundancy and resiliency in ecological systems (Perlman & Milder, 2005). Prioritizing habitat quality and area in conservation efforts is a key way to improve habitat connectivity (Hodgson et al, 2009).

> "
>
> *Trees are a major vegetal element that can impact on a city's climate and when organized along street sidewalks, they become a structural element of the urban ecosystem's biodiversity.*
>
> "

Reference

Ahern, J. (2013). Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design. Landscape ecology, 28(6), 1203-1212.

Arnold Jr, C. L., & Gibbons, C. J. (1996). Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American planning Association, 62(2), 243-258.

Beckmann, J. P., & Hilty, J. A. (2010). Connecting wildlife populations in fractured landscapes. Safe passages: Highways, wildlife, and habitat connectivity, 3-16.

Braubach, M., Egorov, A., Mudu, P., Wolf, T., Thompson, C. W., & Martuzzi, M. (2017). Effects of urban green space on environmental health, equity and resilience. In Nature-Based Solutions to Climate Change Adaptation in Urban Areas (pp. 187-205). Springer, Cham.

Correa Ayram, C. A., Mendoza, M. E., Etter, A., & Salicrup, D. R. P. (2016). Habitat connectivity in biodiversity conservation: A review of recent studies and applications. Progress in Physical Geography, 40(1), 7-37.

Hodgson, J. A., Moilanen, A., Wintle, B. A., & Thomas, C. D. (2011). Habitat area, quality and connectivity: striking the balance for efficient conservation. Journal of Applied Ecology, 48(1), 148-152.

Hodgson, J. A., Thomas, C. D., Wintle, B. A., & Moilanen, A. (2009). Climate change, connectivity and conservation decision making: back to basics. Journal of Applied Ecology, 46(5), 964-969.

Ignatieva, M., Stewart, G. H., & Meurk, C. (2011). Planning and design of ecological networks in urban areas. Landscape and ecological engineering, 7(1), 17-25.

Kong, F., Yin, H., Nakagoshi, N., & Zong, Y. (2010). Urban green space network development for biodiversity conservation: Identification based on graph theory and gravity modeling. Landscape and urban planning, 95(1-2), 16-27.

Kurn, D. M., Bretz, S. E., Huang, B., & Akbari, H. (1994). The potential for reducing urban air temperatures and energy consumption through vegetative cooling (No. LBL-35320). Lawrence Berkeley Lab., CA (United States).

Lindenmayer, D. B., Margules, C. R., & Botkin, D. B. (2000). Indicators of biodiversity for ecologically sustainable forest management. Conservation biology, 14(4), 941-950.

McPhearson, T., Andersson, E., Elmqvist, T., & Frantzeskaki, N. (2015). Resilience of and through urban ecosystem services. Ecosystem Services, 12, 152-156.

Mercy Corps. (n.d.). Urban Resilience Measurement: An Approach Guide and Training Curriculum. Retrieved from https://www.mercycorps.org/sites/default/files/Urban%20Resilience%20Measurement_Training%20Guide_FINAL.pdf

Nowak, D., & Heisler, G. (2010). Air quality effects of urban trees and parks. Research Series Monograph. Ashburn, VA: National Recreation and Parks Association Research Series Monograph. 44 p., 1-44.

Oke, C. (2017, October). Why Cities Should Focus on Biodiversity. Retrieved from https://www.100resilientcities.org/why-cities-should-focus-on-biodiversity/

Olds, A. D., Connolly, R. M., Pitt, K. A., & Maxwell, P. S. (2012). Habitat connectivity improves reserve performance. Conservation Letters, 5(1), 56-63.

Perlman, D. L., & Milder, J. (2005). Practical ecology for planners, developers, and citizens. Island Press.

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

Singh, V. S., Pandey, D. N., & Chaudhry, P. (2010). Urban forests and open green spaces: lessons for Jaipur, Rajasthan India (pp. 1-18). Jaipur: Rajasthan State Pollution Control Board.

Tejera, G., Rodríguez, B., Armas, C., & Rodríguez, A. (2018). Wildlife-vehicle collisions in Lanzarote Biosphere Reserve, Canary Islands. PloS one, 13(3), e0192731.

Tischendorf, L., & Fahrig, L. (2000). On the usage and measurement of landscape connectivity. Oikos, 90(1), 7-19.

Habitat Provision

Habitat provision is crucial for the wellbeing and resilience of non-human ecosystems and lifeforms (Hodgson et al, 2009). Habitat provision is a fundamental prerequisite for biodiversity in cities, and is perceived to be an important environmental goal of urban planning (Ahern, 2013). Ecological habitat provision and the biodiversity this facilitates has numerous benefits for urban resilience, primarily by providing a range of unique ecosystem services (Oke, 2017; McPhearson et al, 2015). Wetlands and mangrove habitats for instance, home to a range of aquatic and bird communities, can enhance disaster resilience by mitigating the risk of storm surges and coastal flooding (McPhearson et al, 2015), whilst urban forests and parks can reduce the impacts of UHI and improve urban air quality (Nowak & Heisler, 2010; Kurn et al, 1994) and positively benefit human physical and mental health, which in turn boosts social and psychological resilience (Braubach et al, 2017). The known association between greenspace proximity and real estate prices may even contribute to a more stable real estate market, thereby enhancing economic resilience (McPhearson et al, 2015).

Given these diverse range of benefits, it is apparent that habitat provision, biodiversity, and ecological health can contribute meaningfully to urban resilience. Indicators measuring ecological habitat quality have been used in resilience models such as UN-Habitat's flagship City Resilience Profiling Tool (UN-Habitat, n.d.), and 'protecting terrestrial and aquatic habitat' is a guiding principle of the holistic sustainability framework developed by the Design Centre for Sustainability at the University of British Columbia (DCS, 2009), which adopts an indicator measuring 'natural habitat preserved, restored, enhanced, or created' (with a minimum threshold of 20% of total land area). 'Biodiversity' and 'wetland acreage and loss' (both functions of quality habitat provision) are used as indicators in the likes of Cutter et al (2008), and an 'index of urban parks functionality' (which aims to evaluate the potential of urban parks to provide habitat for a maximum variety of birds) is used as an indicator in the Ecological Urbanism model developed by Rueda (2012).

Providing and maintaining ecological habitat is crucial for the wellbeing of plant and wildlife communities, and can help foster the unique ecosystem services these communities may provide. Photo by the author.

Reference

Ahern, J. (2013). Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design. Landscape ecology, 28(6), 1203-1212.

Braubach, M., Egorov, A., Mudu, P., Wolf, T., Thompson, C. W., & Martuzzi, M. (2017). Effects of urban green space on environmental health, equity and resilience. In Nature-Based Solutions to Climate Change Adaptation in Urban Areas (pp. 187-205). Springer, Cham.

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. Global environmental change, 18(4), 598-606.

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Hodgson, J. A., Thomas, C. D., Wintle, B. A., & Moilanen, A. (2009). Climate change, connectivity and conservation decision making: back to basics. Journal of Applied Ecology, 46(5), 964-969.

Kurn, D. M., Bretz, S. E., Huang, B., & Akbari, H. (1994). The potential for reducing urban air temperatures and energy consumption through vegetative cooling (No. LBL-35320). Lawrence Berkeley Lab., CA (United States).

McPhearson, T., Andersson, E., Elmqvist, T., & Frantzeskaki, N. (2015). Resilience of and through urban ecosystem services. Ecosystem Services, 12, 152-156.

Nowak, D., & Heisler, G. (2010). Air quality effects of urban trees and parks. Research Series Monograph. Ashburn, VA: National Recreation and Parks Association Research Series Monograph. 44 p., 1-44.

Oke, C. (2017, October). Why Cities Should Focus on Biodiversity. Retrieved from https://www.100resilientcities.org/why-cities-should-focus-on-biodiversity/

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

UN-Habitat. (n.d.). City Resilience Profiling Tool: Guide, Retrieved from http://urbanresiliencehub.org/wp-content/uploads/2018/02/CRPT-Guide.pdf

HEALTHY ENVIRONMENTS

Green Space Proximity

Proximity to urban green space has a host of positive implications for urban resilience. For instance, proximity to green space has been demonstrated to be strongly related to human health (Ekkel & Vries, 2017). Living closer to urban parks have been associated with better mental health outcomes (Sturm & Cohen, 2014), and lower stress levels (Thompson et al, 2012). For women, proximity to greenspace has been associated with more stable blood pressure levels during pregnancy (Grazuleviciene et al, 2014) and lower rates of depressive symptoms (Reklaitiene et al, 2014). Proximity to green parks has also been associated with higher levels of physical activity, especially amongst young adults (Kaczynski et al, 2009), which in turn has innumerable human health benefits including reducing the risk of cardiovascular disease, certain types of cancer, obesity, hypertension, and depression (Warburton et al, 2006). Proximate greenspace also provides a forum for informal social interaction, which can enhance sense of community (Kuo et al, 1998) and positively impact residents' psychological wellbeing (Kawachi & Berkman, 2001). Exposure to greenery is considered to be a key component of healthy childhood development (Vanaken & Danckaerts, 2018; Taylor et al, 2006), and proximity to greenspace is especially important for children, who are not able to travel to travel as easily or as far as their adult counterparts (ARUP, 2017). Additionally, he association between greenspace proximity and increased real estate prices may even

Exposure to greenery is considered to be a key component of healthy childhood development. Image by EvangiiAnd via Shutterstock.

contribute to a more stable real estate market, thereby enhancing economic resilience (McPhearson et al, 2015).

The potential for greenspace proximity to contribute to urban resilience is well established in the literature (Braubach, 2017; Colding & Barthel, 2013), and access to greenspace (for which proximity is often used as a key metric) is used as an indicator for urban resilience in holistic models such as the climate change resilience model developed by Sivell et al (2008). Proximity to greenspace is also utilized as an indicator by the Ecological Urbanism model developed by Rueda (2012), and a requirement for 90% of dwelling units to have a green space within an 800m walking distance is outlined in as one of the prerequisites for LEED (v4.1) certified neighbourhoods (U.S. Green Building Council, 2019). Other studies have adopted smaller walking distance buffers as a threshold of proximity to greenspace, including Sturm and Cohen (2014) who use a 400m walking distance threshold in order for greenspace to be considered as within a proximate "short walking distance", whilst Toftager et al (2011) use an even shorter proximity threshold of 300m on the grounds that there is "a steep decline in the use frequency of recreational facilities with increasing distance, especially over the first 300m" (pg.742). The 400m walking distance used by Sturm and Cohen (2014) coincides with the 0.25mile (approximately 400m) pedestrian walkshed radius that is generally considered within the literature to indicate 'proximity' for a walker (Evangelopoulos, 2014; Miyake et al 2010; Babey et al, 2007), and is emphasized in the public open space health and wellbeing guidelines developed by Villanueva et al (2015), which recommend that at least 95% of dwellings should have access to a small (0.3-0.5ha) and medium (0.5-1.5ha) neighbourhood park within a 400m distance. The Vancouver Greenest City 2020 Action Plan (City of Vancouver, 2015) also uses a 400m distance threshold for determining city-wide access to greenspace.

Accordingly, the RNDT has included 'greenspace proximity' as an indicator of urban resilience, which measures the percentage of GFA within 400m of a greenspace. Some of these common threshold values are summarized in table .

Source	**Greenspace proximity target**
LEED (2019)	<800m
Sturm and Cohen (2014)	<400m
Evangelopoulus (2014)	<400m
Villanueva et al (2015)	<400m
City of Vancouver (2015)	<400m
Miyake et al (2010)	<400m
Babey et al (2007)	<400m
Toftager et al (2011)	<300m
Rueda (2012)	<200m
RNDT	<400m

Table 7 above depicts a variety of greenspace proximity targets used within the literature.

Reference

ARUP. (2017). Cities Alive: Designing for urban childhoods. Retrieved from https://www.arup.com/perspectives/publications/research/section/cities-alive-designing-for-urban-childhoods

Babey, S. H., Hastert, T. A., & Brown, E. R. (2007). Teens living in disadvantaged neighborhoods lack access to parks and get less physical activity.

Braubach, M., Egorov, A., Mudu, P., Wolf, T., Thompson, C. W., & Martuzzi, M. (2017). Effects of urban green space on environmental health, equity and resilience. In Nature-Based Solutions to Climate Change Adaptation in Urban Areas (pp. 187-205). Springer, Cham.

City of Vancouver. (2015). Greenest City 2020 Action Plan. Retrieved from https://vancouver.ca/files/cov/greenest-city-2020-action-plan-2015-2020.pdf

Colding, J., & Barthel, S. (2013). The potential of 'Urban Green Commons' in the resilience building of cities. Ecological economics, 86, 156-166.

Ekkel, E. D., & de Vries, S. (2017). Nearby green space and human health: Evaluating accessibility metrics. Landscape and urban planning, 157, 214-220.

Evangelopoulos, E. (2014). Neighborhoods, Proximity to Daily Needs, & Walkability in Form-Based Codes.

Grazuleviciene, R., Dedele, A., Danileviciute, A., Vencloviene, J., Grazulevicius, T., Andrusaityte, S., ... & Nieuwenhuijsen, M. (2014). The influence of proximity to city parks on blood pressure in early pregnancy. International journal of environmental research and public health, 11(3), 2958-2972.

Kaczynski, A. T., Potwarka, L. R., Smale, B. J., & Havitz, M. E. (2009). Association of parkland proximity with neighborhood and park-based physical activity: variations by gender and age. Leisure Sciences, 31(2), 174-191.

Kawachi, I., & Berkman, L. F. (2001). Social ties and mental health. Journal of Urban health, 78(3), 458-467.

Kuo, F. E., Sullivan, W. C., Coley, R. L., & Brunson, L. (1998). Fertile ground for community: Inner-city neighborhood common spaces. American Journal of Community Psychology, 26(6), 823-851. doi:10.1023/A:1022294028903

McPhearson, T., Andersson, E., Elmqvist, T., & Frantzeskaki, N. (2015). Resilience of and through urban ecosystem services. Ecosystem Services, 12, 152-156.

Miyake, K. K., Maroko, A. R., Grady, K. L., Maantay, J. A., & Arno, P. S. (2010). Not just a walk in the park: Methodological improvements for determining environmental justice implications of park access in New York City for the promotion of physical activity. Cities and the Environment, 3(1), 1.

Reklaitiene, R., Grazuleviciene, R., Dedele, A., Virviciute, D., Vensloviene, J., Tamosiunas, A., ... & Bernotiene, G. (2014). The relationship of green space, depressive symptoms and perceived general health in urban population. Scandinavian journal of public health, 42(7), 669-676.

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

Sivell, P. M., Reeves, S. J., Baldachin, L., & Brightman, T. G. (2008). Climate change resilience indicators. Client project report CPR, 117.

Sturm, R., & Cohen, D. (2014). Proximity to urban parks and mental health. The journal of mental health policy and economics, 17(1), 19.

Taylor, A. F., Kuo, F. E., Spencer, C., & Blades, M. (2006). Is contact with nature important for healthy child development? State of the evidence. Children and their environments: Learning, using and designing spaces, 124.

Toftager, M., Ekholm, O., Schipperijn, J., Stigsdotter, U., Bentsen, P., Grønbæk, M., ... & Kamper-Jørgensen, F. (2011). Distance to green space and physical activity: a Danish national representative survey. Journal of Physical Activity and Health, 8(6), 741-749.

Thompson, C. W., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. Landscape and urban planning, 105(3), 221-229.

U.S. Green Building Council. (2019). LEED v4.1 Cities and Communities: Plan and Design. Retrieved from https://new.usgbc.org/leed-v41

Vanaken, G. J., & Danckaerts, M. (2018). Impact of green space exposure on children's and adolescents' mental health: A systematic review. International journal of environmental research and public health, 15(12), 2668.

Villanueva, K., Badland, H., Hooper, P., Koohsari, M. J., Mavoa, S., Davern, M., ... & Giles-Corti, B. (2015). Developing indicators of public open space to promote health and wellbeing in communities. Applied geography, 57, 112-119.

Voicu, I., & Been, V. (2008). The effect of community gardens on neighboring property values. Real Estate Economics, 36(2), 241-283.

Warburton, D. E., Nicol, C. W., & Bredin, S. S. (2006). Health benefits of physical activity: the evidence. Cmaj, 174(6), 801-809.

Green Street Frontage

From enhancing ecological habitat connectivity (City of New Westminster, 2016) and boosting human wellbeing (Ulmer et al, 2016; Kuo, 2015), to reducing rates of nearby crime (Donovan & Prestemon, 2012), regulating pedestrian thermal comfort (Kong et al, 2017; Lin et al, 2008), and increasing the economic value of nearby properties (Pandit et al, 2013; Wolf, 2007), green streets contribute to urban resilience goals at numerous levels (Staddon et al, 2018). The ecosystem services offered by green streets also have important implications for resilience against hazards such as flooding and UHI (City of Toronto, 2017), and numerous cities (including Seattle, Portland, Chicago, and Los Angeles) have adopted incentives programs to encourage the creation and maintenance of green streets. For these reasons, the RDNT has included green street frontage (measured as the percent of building gross floor area which fronts onto a green street) as an indicator of urban resilience. Components of the built environment that are influenced by, or interact with green streets, include traffic volume, traffic design speed, curb-to-curb width, sidewalk width, softscape, and effective pervious areas. A brief exploration of these components is provided below.

Traffic Volume

Automobile induced air and noise pollution is known to increases with traffic volume (Rakowska et al, 2014; Tang & Wang, 2007). Green streets can act as a screen to mitigate the impacts of traffic-related noise (Huddart, 1990) and air pollution (Tong et al, 2016). For air pollution, this is primarily achieved by physically trapping pollutants through carbon sequestration and storage in trees. Noise pollution is reduced by physically screening and dampening vehicular related noise, and reducing how far this noise can travel.

Traffic Design Speed

Increased traffic speed are generally correlated with higher rates of emissions (Owen, 2005), although the relationship between vehicular speed and emissions rate is U-shaped rather than linear (Krzanowski et al, 2005; Bel & Rosell, 2013). Speeds between 60-80km / hour generally have the lowest emissions, with speeds outside this range corresponding increasingly high emissions rates (Krzanowski et al, 2005).

Green streets can act as a screen to mitigate the impacts of traffic related emissions (Staddon et al, 2018; Tong et al, 2016) and some of the effects of traffic related noise pollution (Huddart, 1990). In regards to automobile-induced noise pollution (which typically receives less attention than emissions and air pollution), the ability of green streets to dampen and reduce traffic noise has positive implications for human wellbeing, which is detrimentally effected by traffic-induced noise pollution (Goines & Hagler, 2007), and for ecological health, which is also detrimentally impacted by traffic noise pollution (Halfwerk et al, 2011; Siemers & Schaub, 2010). Street trees reduce noise pollution through both deflection and absorption (as opposed to hard design features which tend to only deflect noise), and the noise reduction performance of street trees generally increases with tree height up until around 10-12m (GreenBlue Urban, 2015). The effectiveness of street trees is closely related to canopy vegetation, and for most effective noise reduction, street trees should be

Street trees reduce noise pollution through both deflection and absorption, as opposed to hard design features which tend to only deflect noise.

located as close to the source of noise (the road) as possible (GreenBlue Urban, 2015).

Curb-to-curb width

Decreasing street width can potentially reduce the total amount of impervious area in a neighbourhood, which in turn reduces the amount of stormwater runoff. This mitigates flood risk, and enhances the resilience of the built environment to flood hazards (Cook, 2007). Reduced street widths may also provide opportunities for additional street tree planting, by creating a wider verge.

Narrower streets have also been associated with increased safety and a lower number of vehicular and pedestrian collisions (Cook, 2007). A study in 1997 for example found that in Longmont (Colorado), a typical residential street with a width of 36 feet has annual accident rate 487% greater than that for a comparable 24-foot wide street (Swift, 1997). These findings present a strong case for pairing narrow streets with green street design, in order to reduce human vulnerability to traffic accidents in the built environment, and ultimately improve the resiliency of communities to traffic hazards.

Sidewalk width

Conversely, increasing sidewalk width provides more space for green design features, which can in turn increase the amount of green street frontage (Beatley, 2011). Narrow sidewalk widths also limit the amount of green urban design interventions that can be implemented without impeding pedestrian flow.

Softscape (%)

Green streets increase the amount of vegetation and other softscape design features in an area. As well as provided an aesthetic value, this can enhance

Green streets can positively impact urban resilience in a host of ways, including by enhancing by traffic, reducing the urban heat island effect through evapotranspiration and by providin resilience against UHI by providing shade, and by regulating the thermal environment through increased evapotranspiration and lowered sensible heat flux being reemitted from absorbent urban surfaces (Staddon, 2018; Taha, 1997; Kurn et al, 1994). Softscape design features may also absorb and deflect traffic noise pollution (GreenBlue Urban, 2015) and filter air pollutants (Kuo, 2015), which can positively benefit pedestrian user experience. In addition to these functional services, the vegetation inherent in green streets has the potential to provide a plethora of benefits to human health (Kuo, 2015). For example, the presence of streetscape greenery and urban tree canopy has also been associated with reduced stress (De Vries et al, 2013) and improved mental health (Sugiyama et al, 2008) amongst residents, and a greater amount of neighbourhood tree coverage in urban areas is positively related to improved pedestrian wellbeing and experience (Ulmer et al, 2016).

ecological connectivity, creating a screen that can mitigate the air and noise pollution caused
g shade, and boosting human mood and wellbeing. Image by Ted McGrath via 8-80 Cities.

Effective Pervious Area

Green streets, facades, and roofs increase the amount of pervious urban surface in an area, which has significant potential to reduce storm water runoff and mitigate flood risk (EPA, 2009; Roehr et al, 2008). This in turn enhances urban resilience to these potential hazards. These benefits are amplified if green streets result in a narrowing of the curb-to-curb road width (and therefore an additional reduction in the total impervious surface conducive to surface flooding (Cook, 2007)).

By increasing the amount of pervious area within a streetscape, green streets provide an opportunity to filter storm water of pollutants (EPA, 2009). This reduces the amount of pollutant storm water entering streams and other aquatic habitat and damaging aquatic communities (Girling & Kellett, 2005). Consequently, by increasing the amount of pervious area in a streetscape, greenstreets simultaneously provide a host of human and ecological co-benefits.

Reference

Beatley, T. (2011). Biophilic cities: integrating nature into urban design and planning. Island Press.

Bel, G., & Rosell, J. (2013). Effects of the 80 km/h and variable speed limits on air pollution in the metropolitan area of Barcelona. Transportation Research Part D: Transport and Environment, 23, 90-97.

City of New Westminster. (2016, July). Downtown Building and Public Realm Design Guidelines and Master Plan. Retrieved from https://www.newwestcity.ca/database/files/library/Final_Version___NW_Downtown_Building_and_Public_Realm_Design_Guidelines_and_Master_Plan.pdf

City of Toronto. (2017, August). Toronto Green Streets Technical Guidelines, version 1.0. Retrieved from https://www.toronto.ca/legdocs/mmis/2017/pw/bgrd/backgroundfile-107514.pdf

Cook, E. A. (2007). Green site design: strategies for storm water management. Journal of Green Building, 2(4), 46-56.

De Vries, S., Van Dillen, S. M., Groenewegen, P. P., & Spreeuwenberg, P. (2013). Streetscape greenery and health: stress, social cohesion and physical activity as mediators. Social Science & Medicine, 94, 26-33.

Donovan, G. H., & Prestemon, J. P. (2012). The effect of trees on crime in Portland, Oregon. Environment and Behavior, 44(1), 3-30.

EPA. (2009). Green Streets: A Conceptual Guide to Effective Green Streets Design Solutions. Retrieved from https://www.epa.gov/G3/learn-about-green-streets

Girling, C., & Kellett, R. (2005). Skinny streets and green neighborhoods: design for environment and community. Island press.

Goines, L., & Hagler, L. (2007). Noise pollution: a modern plague. SOUTHERN MEDICAL JOURNAL-BIRMINGHAM ALABAMA-, 100(3), 287.

GreenBlue Urban. (2015, April). Trees as Sound Barriers. Retrieved from https://www.greenblue.com/na/trees-as-sound-barriers/

Halfwerk, W., Holleman, L. J., Lessells, C. K. M., & Slabbekoorn, H. (2011). Negative impact of traffic noise on avian reproductive success. Journal of applied Ecology, 48(1), 210-219.

Huddart, L. (1990). The use of vegetation for traffic noise screening. Vehicles and Environment Division, Vehicle Group, Transport and Road Research Laboratory.

Krzyżanowski, M., Kuna-Dibbert, B., & Schneider, J. (Eds.). (2005). Health effects of transport-related air pollution. WHO Regional Office Europe.

Kuo, M. (2015). How might contact with nature promote human health? Promising mechanisms and a possible central pathway. Frontiers in psychology, 6, 1093.

Kurn, D. M., Bretz, S. E., Huang, B., & Akbari, H. (1994). The potential for reducing urban air temperatures and energy consumption through vegetative cooling (No. LBL-35320). Lawrence Berkeley Lab., CA (United States).

Owen, B. (2005). Air quality impacts of speed-restriction zones for road traffic. Science of The Total Environment, 340(1-3), 13-22.

Pandit, R., Polyakov, M., Tapsuwan, S., & Moran, T. (2013). The effect of street trees on property value in Perth, Western Australia. Landscape and Urban Planning, 110, 134-142.

Rakowska, A., Wong, K. C., Townsend, T., Chan, K. L., Westerdahl, D., Ng, S., ... & Ning, Z. (2014). Impact of traffic volume and composition on the air quality and pedestrian exposure in urban street canyon. Atmospheric Environment, 98, 260-270.

Roehr, D., Laurenz, J., & Kong, Y. (2008). Green Envelopes. In Proceedings of the 2008 International LID Conference (pp. 16-19).

Siemers, B. M., & Schaub, A. (2010). Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. Proceedings of the Royal Society B: Biological Sciences, 278(1712), 1646-1652.

Staddon, C., Ward, S., De Vito, L., Zuniga-Teran, A., Gerlak, A. K., Schoeman, Y., ... & Booth, G. (2018). Contributions of green infrastructure to enhancing urban resilience. Environment Systems and Decisions, 38(3), 330-338.

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2008). Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships?. Journal of Epidemiology & Community Health, 62(5), e9-e9.

Swift, P., Painter, D., & Goldstein, M. (1997). Residential street typology and injury accident frequency. Swift and Associates.

Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. Energy and buildings, 25(2), 99-103.

Street Level Air Quality

Atmospheric pollution presents a significant global challenge, and is a key driver behind anthropogenic amplified climate change (Seinfeld & Pandis, 2016; Ramanathan & Feng, 2009). In addition to the climatic effects of air pollution, this phenomenon is also a huge detriment to ecosystem and human health (WHO, 2018). More than 4.2 million annual premature human deaths globally are attributed to air pollution, with 91% of the world's population living in areas that exceed the WHO air quality guidelines (WHO, 2018). A number of recent reports have suggested that outdoor air pollution will likely become the main environmental cause of premature human death over the coming decades (OECD, 2012). The negative effects of air pollution are not only limited to human life however, and have been shown to have a wide range of detrimental implications for ecosystem health and biological diversity right across the food web (Lovett et al, 2009). Studies of mice exposed to traffic related air pollution in Brazil for instance show an increased rate of tumors (Reymao et al, 1997), and exposure to urban air pollution has conclusively been demonstrated to be damaging to plant life, and vital plant functions such as photosynthesis (Kulshrestha & Saxena, 2016; Lovett et al, 2009).

The concept of urban resilience offers a holistic framework for addressing air pollution at the city scale (Cariolet et al, 2018). A city that is resilient to air pollution is one that is able to effectively reduce air-polluting emissions, decrease concentrations of these emissions, and decrease exposure to these emissions (Cariolet et al, 2018). A key indicator of resilience to air pollution at the neighbourhood design level then, is the street level air quality. Consequently, the RNDT has adopted an indicator on 'street-level air quality' in the design phase, which measures the percentage of GFA fronting a street with a poor air quality score. Air pollution has been used as an indicator in other holistic models within the literature, such as the WILUTE model of urban sustainability developed by Zhao et al (2013) and the Ecological Urbanism model developed by Rueda (2012), which measures the percentage of a population exposed to emission levels of NO2 and PM10 less than 40 µg (micrograms) /m^3.

Traffic volume, speed, trucking routes, fleet composition, and transit stations were identified in our research as important design features which may influence street level air quality (Rakowska et al, 2014; Bates-Frymel & Jennejohn, 2013; Transport for London, 2011; Krzanowski et al, 2005; Lewis-Workman & Brod, 1997). A brief discussion of each of these components is provided below.

Traffic Volume

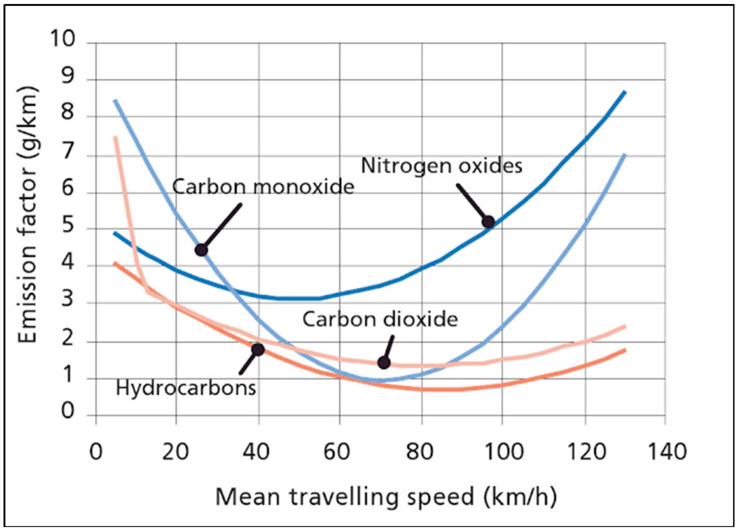
Traffic volume is negatively associated with street level air quality (Rakowska et al, 2014). Increasing traffic volume corresponds to a greater amount of emissions and air pollutants produced by vehicles, which in turn worsens the overall street level air quality. Major roads with traffic volumes greater than 15,000 regular vehicles per day are considered to have a significant influence on street level air quality, which in turn detrimentally impacts human health (Bates-Frymel & Jennejohn, 2013; Brauer et al, 2012). Table 8, adapted from Brauer et al (2012) (a recent Canadian case study on traffic related air pollution and health), gives an indication of the typical traffic volumes experienced on different road types.

Road classification	**Annual average daily traffic Volume (AADT)**
Local	6,500
Collector	9,000
Main	15,000
Secondary highway	18,000
Primary highway	21,000
Expressway	>115,000

Table 8: Traffic volumes above 15,000 (such as those seen on main roads, highways, or expressways) are considered to have a significant detrimental effect on street level air quality.

Traffic Design Speed

Increased traffic speeds are generally correlated with higher rates of atmospheric-polluting emissions (Owen, 2005), although the relationship between vehicular speed and emission rates is typically U-shaped rather than linear (Krzanowski et al, 2005; Bel & Rosell, 2013). That is to say, speeds between 50-80km per hour generally have the lowest rate of emissions, with speeds outside this range corresponding to increasingly high rates of emissions and a subsequent decline in street level air quality (Krzanowski et al, 2005). This U-shaped relationship between traffic speed and emissions has been described elsewhere (e.g. Nechyba & Walsh, 2004) and seems to be generally accepted within the literature, although the speed that produces the least emissions (i.e. the trough of the 'U') varies depending on the emission type.



The relationship between emissions of key traffic related air pollutants and vehicle speed is typically considered to be U-shaped rather than linear. Image sourced from Krzanowski et al (2005).

Trucking Routes

Freight trucks are typically heavy duty diesel vehicles, and are significant emitters of particulate matter (PM) and nitrogen oxides (NOx). Both types of emissions negatively impact street air quality and human health (Bickford et al, 2013; Lee, 2011). A recent study of London (UK) for example found that, 57% of NOx and 25% of PM_{10} emissions from road transport come from heavy vehicles such as trucks (Transport for London, 2011), highlighting the significant impact trucking routes can have in detrimentally impacting street level air quality.

Fleet composition

Heavy vehicles such as trucks produce significantly more air polluting emissions than light vehicles such as cars, with most trucks producing more than 10 times the PM produced by cars (Bates-Frymel & Jennejohn, 2013). A fleet composition with a high proportion of heavy vehicles then will produce greater amounts of air pollutants that will lower the overall street level air quality.

Assuming equivalent vehicular sizes (such as two equally sized cars for example), the relationship between engine type (diesel versus petrol) and atmospheric pollution is not so clear cut. Petrol engines for instance, have been found to have lower emission rates of NO_2 and PM_{10} relative to diesel engines, but have higher rates of CO and Benzene (Tang et al, 2019). Increasing the number of electric vehicles in a fleet however, has been demonstrated to reduce total traffic emissions (Alam et al, 2018) and improve street level air quality.

Transit Stations

Increasing transit infrastructure and usage has the potential to improve urban street level air quality by reducing automobile usage and the associated atmospheric pollution caused by this mode of transportation (Lewis-Workman & Brod, 1997).

Heavy vehicles such as trucks produce significantly more air polluting emissions than light vehicles such as cars, with most trucks producing more than 10 times the PM produced by automobiles. This makes trucking routes a particular hotspot for traffic related air pollution. Photo taken on Clark Drive (a Vancouver trucking route) by the author.

A recent study of London (UK) found that, 57% of NOx and 25% of PM_{10} emissions from road transport come from heavy vehicles such as trucks (Transport for London, 2011), highlighting the significant impact trucking routes can have in detrimentally impacting street level air quality.

Reference

Alam, M. S., Hyde, B., Duffy, P., & McNabola, A. (2018). Analysing the Co-Benefits of transport fleet and fuel policies in reducing PM2. 5 and CO2 emissions. Journal of cleaner production, 172, 623-634.

Bates-Frymel, L. & Jennejohn, D. (2013). Reducing Exposure to Traffic Emissions (staff report). Retrieved from http://www.metrovancouver.org/services/air-quality/AirQualityPublications/ReducingExposureToTrafficEmissionsProject.pdf

Bel, G., & Rosell, J. (2013). Effects of the 80 km/h and variable speed limits on air pollution in the metropolitan area of Barcelona. Transportation Research Part D: Transport and Environment, 23, 90-97.

Bickford, E., Holloway, T., Karambelas, A., Johnston, M., Adams, T., Janssen, M., & Moberg, C. (2013). Emissions and air quality impacts of truck-to-rail freight modal shifts in the Midwestern United States. Environmental science & technology, 48(1), 446-454.

Brauer, M., Reynolds, C., & Hystad, P. (2012). Traffic-related air pollution and health: a Canadian perspective on scientific evidence and potential exposure-mitigation strategies (Doctoral dissertation, University of British Columbia).

Cariolet, J. M., Colombert, M., Vuillet, M., & Diab, Y. (2018). Assessing the resilience of urban areas to traffic-related air pollution: Application in Greater Paris. Science of the Total Environment, 615, 588-596.

Krzyżanowski, M., Kuna-Dibbert, B., & Schneider, J. (Eds.). (2005). Health effects of transport-related air pollution. WHO Regional Office Europe.

Kulshrestha, U., & Saxena, P. (Eds.). (2016). Plant Responses to Air Pollution. Springer.

Lee, G. (2011). Integrated modeling of air quality and health impacts of a freight transportation corridor. University of California, Irvine.

Lewis-Workman, S., & Brod, D. (1997). Measuring the neighborhood benefits of rail transit accessibility. Transportation Research Record, 1576(1), 147-153.

Lovett, G. M., Tear, T. H., Evers, D. C., Findlay, S. E., Cosby, B. J., Dunscomb, J. K., ... & Weathers, K. C. (2009). Effects of air pollution on ecosystems and biological diversity in the eastern United States. Annals of the New York Academy of Sciences, 1162(1), 99-135.

Nechyba, T. J., & Walsh, R. P. (2004). Urban sprawl. Journal of economic perspectives, 18(4), 177-200.

Seinfeld, J. H., & Pandis, S. N. (2016). Atmospheric chemistry and physics: from air pollution to climate change. John Wiley & Sons.

Rakowska, A., Wong, K. C., Townsend, T., Chan, K. L., Westerdahl, D., Ng, S., ... & Ning, Z. (2014). Impact of traffic volume and composition on the air quality and pedestrian exposure in urban street canyon. Atmospheric Environment, 98, 260-270.

Reymão, M. S. F., Cury, P. M., Lichtenfels, A. J. F. C., Lemos, M., Battlehner, C. N., Conceição, G. M. S., ... & Böhm, G. M. (1997). Urban air pollution enhances the formation of urethane-induced lung tumors in mice. Environmental research, 74(2), 150-158.

Ramanathan, V., & Feng, Y. (2009). Air pollution, greenhouse gases and climate change: Global and regional perspectives. Atmospheric environment, 43(1), 37-50.

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

Transport for London. (2011). Stricter emissions standards for central or inner London: A provisional assessment of potential feasibility and effectiveness.

Tang, J., McNabola, A., Misstear, B., Pilla, F., & Alam, M. (2019). Assessing the impact of vehicle speed limits and fleet composition on air quality near a school. International journal of environmental research and public health, 16(1), 149.

WHO. (2018). Air Pollution. Retrieved from https://www.who.int/airpollution/en/

Zhao, P., Chapman, R., Randal, E., & Howden-Chapman, P. (2013). Understanding resilient urban futures: a systemic modelling approach. Sustainability, 5(7), 3202-3223.

Noise Pollution

As centres of human interaction, movement, and industry, sound is a daily component of urban living (Aitkinson, 2007; Burgess, 2015; Goines & Hagler, 2007; Stansfeld & Matheson, 2003). When sound reaches a certain threshold of intensity and/or duration however, it can quickly become noise that is detrimental to human health and wellbeing (Burgess, 2015; Goines & Hagler, 2007). Within the literature, "noise is defined as unwanted sound" (Goines & Hagler, 2007, pg.287). The causes of urban noise pollution can be varied, although road traffic is typically the most widespread of these (WHO, 2011). Other common sources include industrial and manufacturing activities, construction, and aeroplanes (Singh & Davar, 2004).

One of the most pervasive negative impacts of excessive noise to human health is noise-induced hearing loss (NIDCD, 2019). Other common negative health effects include stress, high blood pressure, sleep disturbance, a reduction in productivity, and a general diminishing quality of life (Singh & Davar, 2004). Sound levels less than 70db do not cause hearing damage irrespective of exposure duration, whereas exposure to loud sound in excess of 85db for more than 8hrs can be damaging (Goines & Hagler, 2007). Very loud sounds, such as those between 90-110db, are dangerous over a much shorter timeframe (30mins or more), and sounds in excess of 130db can be dangerous and painful irrespective of duration (Burgess, 2015)). For a tangible example of these sound levels, a 20db sound is comparable to leaves rustling, a 60db sound comparable to a dishwasher, an 85db sound to the noise of a heavy truck on a busy road, and a 140 db sound to a gunshot (Burgess, 2015; Goines & Hagler, 2007). It is recommended that to protect the majority of people from being annoyed, sound pressure levels should not exceed 50db near living environments during the daytime and 45db at nighttime (Berglund & Lindvall, 1995). This number coincides with the guidelines for community noise specified by the WHO, which emphasis the need to "limit the noise events exceeding 45 dB" (Schwela, 2001, pg.196).

Some of the aforementioned detrimental effects of noise can cause a range of further negative health implications themselves. High quality uninterrupted sleep for instance, is perceived as a cornerstone of healthy physiological and psychological functioning (Goines & Hagler, 2007), and environmental noise is considered to be one of the most widespread causes of disrupted sleep globally (Stansfeld & Matheson, 2003). In turn, frequent sleep disruption has been linked to a host of negative health outcomes, including hypertension, colorectal cancer, dyslipidemia, cardiovascular diseases, increased stress responsivity, reduced quality of life, emotional distress, mood disorders, and cognitive performance and memory deficits (Medic et al, 2017). A recent study undertaken by the World Health Organization (2011) estimates that in terms of annual DALYs (disability adjusted life years) lost in Europe alone due to the health effects of noise pollution, 61,000 years are lost due to heart disease, 45,000 years for cognitive impairment of children, 903,000 years for sleep disturbance, 22,000 years for tinnitus, and 587,000 for annoyance.

Within the literature, children are perceived as being especially vulnerable to the negative health effects of noise (Van Kamp & Davies, 2013; Goines & Hagler, 2007). A study by Shield & Dockrell (2008) for example found that external noise had a significant negative impact on classroom performance, whilst a study in France (Mir, 2008) among 10-year-old school children found an association between exposure to noise and fatigue, headaches, and stress (based on cortisol levels). During 2001, it was estimated that approximately 12.5% of American children aged 6-19 had impaired hearing in at least one ear (Niskar et al, 2001). It is also likely that the adverse effects

The WHO estimates that at least 1 million healthy life years are lost each year in western Europe alone as a consequence of traffic related noise.

of sleep disruption caused by noise pollution are "more pronounced amongst youth, given the level of plasticity and rapid rate of development in young brains" (El-Sheikh et al, 2013, pg.282)

Due to the numerous serious health implications of noise pollution, the RNDT uses 'noise pollution' (which measures the amount of GFA which fronts a street with a low noise quality score) as a resilience indicator. Similar metrics have been adopted elsewhere by holistic resilience assessment frameworks. Rueda's (2012) Ecological Urbanism model for instance utilizes an indicator on 'acoustic comfort' which measures the percent of a population which is affected by sound levels less than 65db, whilst the Community Wellbeing Framework developed by Markovich et al (2018) utilizes an indicator which measures the extent to which a "project employs noise reduction materials and measures to reduce ambient noise levels (50db for large public spaces, 40db for general spaces, and 30db for quiet spaces)" (pg.56). The CityLab Action Guide recommends aiming for 55db sound levels at the outdoor façade, with a maximum sound level outdoors at the façade of 70db (Sweden Green Building Council, 2018). These thresholds coincide with those described in the literature in relation to human health effects (Burgess, 2015; Goines & Hagler, 2007). Although there is a general consensus that incorporating design features which minimize noise pollution as much as possible is optimal for human health and wellbeing, table 9 provides a brief visual summary of some of the aforementioned accepted thresholds for 'low-noise'.

Source	**Low-noise threshold (dB)**
Marckovich et al (2018)	40 dB
Schwela (2001)	45 dB
CityLab Action Guide (2018)	55 dB
Rueda (2012)	65 dB

Table 9 above shows some of the low-noise thresholds adopted in different frameworks within the literature.

Given that traffic is the greatest source of noise pollution in cities (WHO, 2011), understanding how variables such as traffic volume and speed influence noise pollution is important for assessing which street will have likely have a low noise quality score in the design phase. According to the City of Vancouver Noise Control Manual (Wakefield Acoustics Ltd., n.d.), "average traffic noise levels along the edges of busy arterial roads and highways can often reach 75-80 dB while maximum levels from passing heavy trucks and buses and motorcycles can reach 90 to 100 dB – levels that can cause temporary hearing degradation over short exposures and permanent hearing loss over more prolonged exposure" (pg.30), whilst urban residential dwellings away from arterial/main streets will typically be exposed to 24-hour average noise levels of between 50-55 dB. Within the literature there is unanimous agreement that increased traffic volumes and vehicle speeds are both positively associated with increased noise pollution (Subramani et al, 2012). In some models, such as that created by Abo-Qudais and Alhiary (2007), traffic volume is shown to be the greatest determinant of noise pollution levels, with around 88.5% of road noise level variations able to be explained by changes in traffic volume. However, the number of heavy vehicles within a fleet can also significantly impact noise volume independent of traffic volume (Abo-Qudais and Alhiary (2007). That is to say, if traffic volume remains constant and the proportion of heavy vehicles within a fleet increases, traffic noise will also significantly increase. Additionally, other factors such as the gradient of the road, the quality and type of road surface, and the presence of stop signs and intersections may also impact the noise pollution produced on a given road independent of traffic volume (and to an extent, speed) (Subramani et al, 2012; Abo-Qudais and Alhiary, 2007).

However, based on the average traffic volumes associated with different road classifications used by Brauer et al (2012) (a recent Canadian case study on traffic related air pollution and health) and the average levels of noise experienced by Vancouver residences living adjacent to difference road types described in the City of Vancouver Noise Control Manual, table 10 provides an estimation of the average noise levels associated with different traffic volumes in a Vancouver context.

It should be emphasized that the noise levels reported in the far right column of table 10 associated with each road classification have been averaged over a 24-hour period, meaning that these values would in many instances be expected to be significantly higher during certain times of the day such as the morning and evening rush hour – especially on highways. Average noise levels were also measured at residential dwellings proximate to different road types, rather than directly at the noise source (which again, would have given a significantly louder value).

Road classification	Approximate annual average daily traffic Volume (AADT) [1]	Estimated 24-Hour Average Noise Level (dB) experienced by nearby residential dwellings [2]
Quiet suburban residential	<6,500	45-50
Local / residential away from main streets	6,500	50-55
Collector	9,000	55-60
Main road or minor highway	15,000-18,000	60-65
Primary highway	21,000	65-75
Expressway	>115,000	>75

Table 10 provides an estimation of the average 24-hour noise level experienced by Vancouver residents in relation to traffic volume based on the Canadian-specific road classification scheme used by Brauer et al (2012) [1] , and the measurements of noise experienced in different residential environments described within the 'Vancouver Noise Control Manual' [2].

Source	Typical Noise Range (dB)
Emergency vehicle sirens	82-105
Motorcycles	67-87
Heavy tvrucks	66-84
Regular buses	66-83
Skytrain	66-80
Sports cars, or cars with unusually loud exhaust systems	68-87

Table 11 (adapted from Wakefield Acoustics Ltd. (2015)) depicts the typical noise ranges associated with different traffic-related noise sources in Vancouver, measured at the noise source.

Reference

Abo-Qudais, S., & Alhiary, A. (2007). Statistical models for traffic noise at signalized intersections. Building and Environment, 42(8), 2939-2948. doi:10.1016/j.buildenv.2005.05.040

Atkinson, R. (2007). Ecology of sound: the sonic order of urban space. Urban studies, 44(10), 1905-1917.

Berglund, B., & Lindvall, T. (Eds.). (1995). Community noise. Stockholm: Center for Sensory Research, Stockholm University and Karolinska Institute.

Brauer, M., Reynolds, C., & Hystad, P. (2012). Traffic-related air pollution and health: a Canadian perspective on scientific evidence and potential exposure-mitigation strategies (Doctoral dissertation, University of British Columbia).

Burgess, M. (2015). Quiet please! Fighting noise pollution. Retrieved from https://www.science.org.au/curious/people-medicine/noise-pollution

El-Sheikh, M., Erath, S. A., & Bagley, E. J. (2013). Parasympathetic nervous system activity and children's sleep. Journal of sleep research, 22(3), 282-288.

Goines, L., & Hagler, L. (2007). Noise pollution: a modern plague. SOUTHERN MEDICAL JOURNAL-BIRMINGHAM ALABAMA-, 100(3), 287.

Markovich, J., Slovinec, D., & Dinh, T. (2018). Community Wellbeing: A Framework for the Design Professionals. Ottawa: The Conference Board of Canada.

Medic, G., Wille, M., & Hemels, M. E. (2017). Short-and long-term health consequences of sleep disruption. Nature and science of sleep, 9, 151.

Mir, L. (2008). Noise in class: A stress factor for children? Environnement, Risques & Santé, 7(1),5-6.

NIDCD. (2019, May). Noise-Induced Hearing Loss. Retrieved from https://www.nidcd.nih.gov/health/noise-induced-hearing-loss

Niskar, A. S., Kieszak, S. M., Holmes, A. E., Esteban, E., Rubin, C., & Brody, D. J. (2001). Estimated prevalence of noise-induced hearing threshold shifts among children 6 to 19 years of age: the Third National Health and Nutrition Examination Survey, 1988–1994, United States. Pediatrics, 108(1), 40-43.

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

Schwela, D. H. (2001). The new world health organization guidelines for community noise. Noise Control Engineering Journal, 49(4), 193-198. doi:10.3397/1.2839659

Shield, B. M., & Dockrell, J. E. (2008). The effects of environmental and classroom noise on the academic attainments of primary school children. The Journal of the Acoustical Society of America, 123(1), 133-144.

Singh, N., & Davar, S. C. (2004). Noise pollution-sources, effects and control. Journal of Human Ecology, 16(3), 181-187.

Stansfeld, S. A., & Matheson, M. P. (2003). Noise pollution: non-auditory effects on health. British medical bulletin, 68(1), 243-257.

Subramani, T., Kavitha, M., & Sivaraj, K. P. (2012). Modelling of traffic noise pollution. International journal of Engineering research and applications, 2(3), 3175-3182.

Sweden Green Building Council. (2018). CityLab Action Guide – Version 2.0. Retrieved from http://www.decodeprojektet.se/media/1167/eng-citylabactionguide-180516-webb_com.pdf

Van Kamp, I., & Davies, H. (2013). Noise and health in vulnerable groups: a review. Noise and health, 15(64), 153.

Wakefield Acoustics Ltd. (2005, March 30). Traffic noise levels and traffic noise composition on arterial roads study: summary of unmanned noise monitoring. Retrieved from https://vancouver.ca/files/cov/2017-525-release_Part1.pdf

Wakefield Acoustics Ltd. (n.d.). City of Vancouver Noise Control Manual. Retrieved from https://vancouver.ca/files/cov/noise-control-manual.pdf

World Health Organization (WHO). (2011). Burden of disease from environmental noise: Quantification of healthy life years lost in Europe. Retrieved from https://www.who.int/quantifying_ehimpacts/publications/e94888/en/

CONNECTION

Public Open Space

As cities continue to grow and densify, open space will become an increasingly important amenity for facilitating livable and resilient neighborhoods. For example, open space can place a crucial role in facilitating social interaction and cohesion amongst community members (Peters et al, 2010), which in turn can enhance social ties and contribute to the overall resilience of a neighborhood. Similarly, open greenspace can provide a therapeutic environment where residents can exercise, and which positively benefits their mental and physical wellbeing (Finlay et al, 2015; De Vries et al, 2013; Sugiyama et al, 2008; Maas et al, 2006). This in turn benefits the physical and psychological resiliency of community members, as well as enhancing the economic resilience of a city through reduced spending on public health. Open greenspace can booster ecological connectivity and habitat area, positively impacting biodiversity (Ignatieva et al, 2011). Green open space has the potential to mitigate the effects of UHI and the risk of flooding and stormwater pollution, improving resilience against such hazards (Nowak & Heisler, 2010; Byrne & Jinjun, 2009). Often, resilience outcomes of public open space can be multifaceted and complementary. The seawall in Vancouver for example, “expertly blends hard resilience with everyday recreational use” by providing an attractive amenity space for people to walk, run, cycle, and socialise, whilst simultaneously also acting as a flood protection mechanism for Stanley Park (Peinhardt, 2019).

The ways in which open space can contribute to

As cities continue to grow in the future, open space will become an increasingly important amenity that can encourage urban resilience in numerous ways. Open greenspa resilience are well explored within the literature (Ni'mah & Lenonb, 2017; Fuentes & Tastes, 2015; Urban Land Institute, n.d.). The City Resilience Index created by ARUP and the Rockfeller Foundation for instance, emphasizes the importance of open space in contributing to the organization and social resilience of a city, whilst Sharifi and Yamagata (2014) identify the 'provision of open space' as an important criteria for assessing urban resilience. The "average share of the built-up area of cities that is open space for public use for all" is used as an indicator for goal 11 of the Sustainable Development Goals developed by the United Nations, which is to "make cities and human settlements inclusive, safe, resilient and sustainable" (United Nations, 2015). The CityLab Action Guide uses 'public spaces' (which measures the safety, accessibility, diversity, and connectivity of public spaces, as well as setting a threshold of 15% of the total built environment which should be dedicated to open space) as an assessment indicator for sustainable urban development in the design and planning phase (Sweden Green Building Council, 2018), whilst the EcoDistricts Toolkit developed by the Portland Sustainability Institute (2011) uses the percentage of residents who live within half a mile of parks and public open spaces as a measure of neighbourhood health and wellbeing. The Sustainable Development framework created by the WCCD (World Council on City Data) also uses an indicator which measures the amount of public outdoor recreation space per capita (WCCD, 2016), and the WHO has set a minimum target of 9m^2 of open greenspace per person, with an ideal value of 50m^2 per person (WHO, 2010).

For these reasons, the RNDT has adopted 'public open space' (which measures the amount of public open

ce for example can provide a calming and therapeutic environment where residents can exercise, relax, and socialize. Image sourced from One City.

space per inhabitant) as a resilience indicator, with a greater amount of public open space corresponding to a better resilience score. Parks have been identified as a key type of public open space that can positively contribute to urban resilience.

Parks

Parks provide one form of public space with many benefits for urban resilience. For instance, proximity to green parks has been demonstrated to be strongly related to human health (Ekkel & Vries, 2017). Living closer to urban parks have been associated with better mental health outcomes (Sturm & Cohen, 2014), and lower stress levels (Thompson et al, 2012). Proximity to green parks has also been associated with higher levels of physical activity, especially amongst young adults (Kaczynski et al, 2009), which in turn has innumerable human health benefits including reducing the risk of cardiovascular disease, certain types of cancer, obesity, hypertension, and depression (Warburton et al, 2006). In addition to these human health benefits which booster the individual psychological and physiological resilience of community members, urban parks provide a setting for social interaction (Kuo et al, 1998) which can strengthen community ties and enhance social capital and resilience within a neighbourhood. Parks also have the potential to improve local air quality and regulating the atmospheric thermal environment (Nowak & Heisler, 2010). This in turn enhances urban resilience against external stressors such as atmospheric pollution and UHI.

Synergies + Trade-offs:

Residential density

The value of residential property proximate to open public space increases in response to increased density (Anderson & West, 2006). That is, in more dense urban environments, proximity to open space becomes an increasingly important amenity (Geoghegan, 2002). As such, the preservation of open space is becoming an increasingly important policy concern in many densifying cities globally (Geoghegan, 2002).The increase in value for residential properties proximate to open space relative to density provides an economic incentive for developers to include open space in their developments, and for them to increase resident density in their projects if sufficient demand exists in order to capture an "open space premium" for each residential unit / household (Lewis et al, 2009).

Jobs density

Some forms of public open space, such as urban parks, may increase job density in an area by providing park-related employment opportunities (gardening, maintenance, outdoor instructors etc.) (Walker, 2004). The usefulness of these jobs for teen and youth employment opportunities in particular is discussed within the literature (Lawson & McNally, 1995). Furthermore, If an urban public space is frequently used by pedestrians, this has the potential to enhance job density in an area further by creating the demand for informal commercial activities such as street vending (Kim, 2012). Although such informal commercial activity has for the most part been restricted from urban public spaces across North America over the previous century, street food globally is a significant industry (Jayasuriya, 1994) and is an important source of employment in many cities (Bhowmik, 2005).The city of Portland (USA) provides a North American case study example of how an informal food cart industry can thrive in urban public spaces and increase job density within an area (Newman & Burnett, 2013).

Land ownership (public or private)

Privatization of open urban space leads to increased control over use, access, and behaviour (Nemeth & Schmidt, 2011). This is often achieved through increased surveillance, policing , and design features which influence how a space can be used (Nemeth & Schmidt, 2011) and who can use the space (Low, 2006).The privatization of urban space is seen by

Often, public open space can produce resilience co-benefits. As described by Peinhardt (2019) for example, open spaces like the seawall in Vancouver can, "expertly blends hard resilience with everyday recreational use" by providing an attractive amenity space for people to walk, run, cycle, and socialise in, whilst simultaneously acting as a flood protection mechanism for Stanley Park. Photo sourced from Discover Vancouver.

Due to the plethora of evidence linking urban open greenspace to improved health and wellbeing amongst community members, the World Health Organization has set a minimum target of 9m^2 of open greenspace per person in cities, with an ideal value of 50m^2 per person. Image sourced from Pixabay via Journalist's Resource.

many within the literature as contributing to the fragmentation of the city, and as a socially divisive and exclusionary trend in many north American cities that restricts social, economic, and cultural diversity (Kirby, 2008; Low, 2006; Austin, 1997; Loukaitou-Sideris, 1993), which in turn can limit social and economic resilience.

The privatization of urban open space has also been linked to concerns over limiting democracy by taking away places where the public can gather (Nasution & Zahrah, 2012). Given that top-down authoritative forms of government are often not as conducive to resilience outcomes over the long term as more community grounded co-creation approaches (Poskitt, 2017) such impediments on democracy can be viewed as a potential constraint on community resilience. In contrast, successful open space is freely accessible to all people (Jacobs, 1965), encourages social interaction (Whyte, 1980), and takes into account physical and psychological comfort (Nasution & Zahrah, 2012). Social and recreational usage of an open space is highly contingent on the quality of the space (Gehl, 2011). Such features of successful open space may be more common in public land ownership models than in privatized space.

Reference

ARUP and The Rockfeller Foundation. (2014). City Resilience Index; understanding and measuring city resilience.

Austin, R. (1997). Not just for the fun of it: Governmental restraints on black leisure, social inequality, and the privatization of public space. S. Cal. L. Rev., 71, 667.

Bhowmik, S. K. (2005). Street vendors in Asia: a review. Economic and political weekly, 2256-2264.

Byrne, J., & Jinjun, Y. (2009). Can urban greenspace combat climate change? Towards a subtropical cities research agenda. Australian Planner, 46(4), 36-43.

De Vries, S., Van Dillen, S. M., Groenewegen, P. P., & Spreeuwenberg, P. (2013). Streetscape greenery and health: stress, social cohesion and physical activity as mediators. Social Science & Medicine, 94, 26-33.

Ekkel, E. D., & de Vries, S. (2017). Nearby green space and human health: Evaluating accessibility metrics. Landscape and urban planning, 157, 214-220.

Finlay, J., Franke, T., McKay, H., & Sims-Gould, J. (2015). Therapeutic landscapes and wellbeing in later life: Impacts of blue and green spaces for older adults. Health & Place, 34, 97-106.

Gehl, J. (2011). Life between buildings: using public space. Island press.

Geoghegan, J. (2002). The value of open spaces in residential land use. Land use Policy, 19(1), 91-98. doi:10.1016/S0264-8377(01)00040-0

Ignatieva, M., Stewart, G. H., & Meurk, C. (2011). Planning and design of ecological networks in urban areas. Landscape and ecological engineering, 7(1), 17-25.

Jayasuriya, D. C. (1994). Street food vending in Asia: some policy and legal aspects. Food Control, 5(4), 222-226.

Kaczynski, A. T., Potwarka, L. R., Smale, B. J., & Havitz, M. E. (2009). Association of parkland proximity with neighborhood and park-based physical activity: variations by gender and age. Leisure Sciences, 31(2), 174-191.

Kim, A. M. (2012). The mixed-use sidewalk: Vending and property rights in public space. Journal of the American Planning Association, 78(3), 225-238. doi:10.1080/01944363.2012.715504

Kirby, A. (2008). The production of private space and its implications for urban social relations. Political Geography, 27(1), 74-95.

Kuo, F. E., Sullivan, W. C., Coley, R. L., & Brunson, L. (1998). Fertile ground for community: Inner-city neighborhood common spaces. American Journal of Community Psychology, 26(6), 823-851. doi:10.1023/A:1022294028903

Lawson, L., & McNally, M. (1995). Putting teens at the center: Maximizing public utility of urban space through youth involvement in planning and employment. Children's Environments, 12(2), 209-221

Lewis, D. J., Provencher, B., & Butsic, V. (2009). The dynamic effects of open-space conservation policies on residential development density. Journal of Environmental Economics and Management, 57(3), 239-252. doi:10.1016/j.jeem.2008.11.001

Loukaitou-Sideris, A. (1993). Privatisation of public open space: The Los Angeles experience. Town Planning Review, 64(2), 139.

Low, S. (2006). Towards a theory of urban fragmentation: a cross-cultural analysis of fear, privatization, and the state. Cybergeo: European Journal of Geography.

Reference

Maas, J., Verheij, R. A., Groenewegen, P. P., De Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity, and health: how strong is the relation?. Journal of Epidemiology & Community Health, 60(7), 587-592.

Nasution, A. D., & Zahrah, W. (2012). Public open space privatization and quality of life, case study merdeka square medan. Procedia - Social and Behavioral Sciences, 36, 466-475. doi:10.1016/j.sbspro.2012.03.051

Németh, J., & Schmidt, S. (2011). The privatization of public space: modeling and measuring publicness. Environment and Planning B: Planning and Design, 38(1), 5-23.

Newman, L. L., & Burnett, K. (2013). Street food and vibrant urban spaces: lessons from Portland, Oregon. Local Environment, 18(2), 233-248.

Ni'mah, N. M., & Lenonb, S. (2017, June). Urban greenspace for resilient city in the future: Case study of Yogyakarta City. In IOP Conference Series: Earth and Environmental Science(Vol. 70, No. 1, p. 012058). IOP Publishing.

Nowak, D., & Heisler, G. (2010). Air quality effects of urban trees and parks. Research Series Monograph. Ashburn, VA: National Recreation and Parks Association Research Series Monograph. 44 p., 1-44.

Peters, K., Elands, B., & Buijs, A. (2010). Social interactions in urban parks: stimulating social cohesion?. Urban forestry & Urban greening, 9(2), 93-100.

Portland Sustainability Institute. (2011). EcoDistricts Toolkit: Assessment.

Poskitt, M. (2017). Shaping urban resilience: An analysis of post-earthquake recovery in Christchurch.

Sharifi, A., & Yamagata, Y. (2014). Resilient urban planning: Major principles and criteria. Energy Procedia, 61, 1491-1495.

Sturm, R., & Cohen, D. (2014). Proximity to urban parks and mental health. The journal of mental health policy and economics, 17(1), 19.

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2008). Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships?. Journal of Epidemiology & Community Health, 62(5), e9-e9.

Sweden Green Building Council. (2018). CityLab Action Guide – Version 2.0. Retrieved from http://www.decodeprojektet.se/media/1167/eng-citylabactionguide-180516-webb_com.pdf

Thompson, C. W., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. Landscape and urban planning, 105(3), 221-229.

United Nations. (2015). 2030 Agenda for Sustainable Development. Retrieved from https://sustainabledevelopment.un.org/sdgs

Urban Land Institute. (n.d.). Resilience Parks and Open Spaces. Delveoping Urban Resilience. Retrieved from https://developingresilience.uli.org/themes/resilient-parks-and-open-spaces/

W. H. O. (2010). Urban Planning, Environment and Health: From Evidence to Policy Action, meeting report. Copenhagen: World Health Organization.

Walker, C. The Public Value of Urban Parks. Beyond Recreation: A Broader View of Urban Parks. Retrieved from https://www.wallacefoundation.org/knowledge-center/Documents/The-Public-Value-of-Urban-Parks.pdf

Warburton, D. E., Nicol, C. W., & Bredin, S. S. (2006). Health benefits of physical activity: the evidence. Cmaj, 174(6), 801-809

WCCD. (2016). ISO 37120 Indicators for Certification by the WCCD

Public Facilities

The need for a wide range of high quality and accessible public facilities for urban resilience is well established in the resiliency literature, and is emphasized in a range of holistic resilience models (Rueda, 2012; Cutter et al, 2010; DCS, 2009). 'Provision of public facilities' and 'proximity to public facilities' for instance are both used as indicators in the holistic Ecological Urbanism model developed by Rueda (2012), and the provision of social infrastructure facilities (such as libraries, museums, sports centres, health care centres, and educational facilities) are a prerequisite for cities and neighbourhoods seeking LEED certification (U.S. Green Building Council, 2019). Public facilities have also received attention in holistic disaster resilience models such as that developed by Cutter et al (2010), where 'number of public schools per square mile' and 'number of hospital beds per 10,000 population' are both used as indicators of overall disaster resilience. Similarly, the sustainability framework developed by the Design Centre for Sustainability at the University of British Columbia uses an indicator on 'civic amenity', which measures the percentage of dwellings within 400m of a civic amenity (including public facilities such as schools, community centres, libraries, places of worship, and childcare centres) (DCS, 2009).

Because of the fundamental importance of public facilities to urban resilience, the RNDT has included 'public facilities' as a resilience indicator, which measures the number of public facilities per inhabitant within a 1200m buffer. Table 12 below provides a summary of some of the proximity thresholds for access to public facilities found in different holistic resilient neighbourhood design frameworks within the literature.

SOURCE	INDICATOR	DEFINTION	PROXIMITY TARGET
Rueda (2012)	Proximity to public facilities	Public facilities include cultural and civic centres, sports facilities, educational facilities, health centres, and welfare / service centres.	300-600m
DCS (2009)	Civic amenity proximity	"Civic amenities include public facilities such as: schools, community centres, libraries, public safety offices, places of worship, recreational facilities, and licensed childcare facilities". (pg.26)	400m
Markovich et al (2018)	Easy access to cultural destinations	"Project is within easy walking distance of arts, cultural, leisure, and recreational facilities". (pg.82)	400m [1]
LEED (2009)	Nearby neighbourhood assets (defined as "diverse uses")	"Diverse uses" here includes 'civic and community facilities' such as places of worship, public libraries, community or recreational facilities, social service centres, and government offices that service.	400m
EcoDistricts (2017)	Housing is close to facilities that offer a complete set of daily needs	Here 'daily needs' includes public facilities such as civic, educational, and recreational centres.	800m
RNDT	Public facilities	The number of public facilities per inhabitant within a 1200m buffer.	1200m

Table 12 above shows the proximity thresholds for public facilities used by different holistic resilient design frameworks within the literature. It should be noted that the 1200m threshold used by the RNDT (which is slightly higher than those values found elsewhere in the literature) has been recommended by the social policy department of the City of Vancouver.

[1] "Easy walking distance" within the literature is typically considered to be about 400m (Evangelopoulos, 2014).

Public facilities such as libraries and community centres are an integral component of a healthy and resilient neighbourhood. Photo of Trout Lake Community Centre (Vancouver) sourced from the City of Vancouver.

Reference

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1).

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

EcoDistricts (2017). EcoDistricts Protocol Version 1.2, the standard for community development.

Markovich, J., Slovinec, D., & Dinh, T. (2018). Community Wellbeing: A Framework for the Design Professionals. Ottawa: The Conference Board of Canada.

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

U.S. Green Building Council. (2019). LEED v4.1 Cities and Communities: Plan and Design. Retrieved from https://new.usgbc.org/leed-v41#cities-and-communities

Communal Amenity Space

Communal amenity spaces can contribute directly to urban resilience by creating a space for people to socialize, exercise, play, and relax – all of which positively impacts the wellbeing of people and the overall resilience of communities (Tavakoli, 2017). Higher quality communal amenity spaces that are functional and appealing to use attract more people and encourage greater social interaction (Farida, 2013; Willliams, 2005). For example communal amenity spaces that are permeable and visible are more likely to be perceived as 'safe', meaning people are more likely to spend a greater amount of time there. This increases the opportunity for social interaction (Monfared & Hashemnejad, 2015), which in turn can enhance social capital and contribute to community resilience. Design features which enhance the quality of outdoor communal amenity space include the presence of vegetation (Sullivan et al, 2004), appropriate seating and resting options (Carmona, 2019), solar access (Capeluto et al, 2006), and appropriate shade and shelter from wind and rain during different seasons and weather conditions (Mehta & Bosson, 2010; Whyte, 1980).

For residential developments, the 'Hey Neighbour!' study carried out by the City of Vancouver (2018) found that shared amenity spaces such community gardens, workshops, party rooms, shared kitchens, courtyards, playgrounds, balconies, and rooftop patios can be effective in encouraging social interaction and increasing neighbourly connection, which contribute to social resiliency. Building massing which creates a central partially-protected shared amenity space where social interaction can occur between neighbours (such as an outdoor courtyard predominantly enclosed by building massing) has also been demonstrated to contribute to more sociable neighbourhoods (Abu-Ghazzeh, 1999). In standard multi-family housing developments, The Happy City Happy Homes toolkit recommends creating sub-clusters within residential developments where no more than 12 households share a semi-private amenity space in order to facilitate interaction and contribute to social capital amongst residents (Happy City, 2017). The justification for this is that a smaller number of households sharing an amenity space can reduce feelings of over-crowdedness and anonymity, and increase opportunities for regular

Shared amenity spaces can contribute to resilience by creating an appealing space for human interaction and socializing to occur, which can in turn strengthen social ties and build community resilience. Photo sourced from Samantha Edwards via Now.

contact between neighbours which builds trust and social capital (Happy City, 2017). Designing flexible amenity spaces that allow the space to be used in a variety of different ways is also recommended by this toolkit (Happy City, 2018).

Due to the importance of community amenity spaces in providing an anchor place for social capital to flourish and contribute to the social resilience of a community, the RNDT uses 'community amenity space' (which measures the percentage of multi-family GFA with communal amenity space) as a resilience indicator. Similar indicators have been used in holistic resilience assessments elsewhere such as in Sharifi and Yamagata (2016), where 'public spaces and communal facilities' is discussed as an important criterion for assessing urban resilience. The Community Wellbeing Framework developed by Markovich et al (2018) also uses several indicators at both the neighbourhood and building scale to assess whether communal amenity spaces have been provided for social interaction, including a metric which assesses if a "project provides a minimum of 0.4m2 per full-time occupant of interior space for social gathering" and whether the "project provides access to outdoor social gathering space" (pg.47).

> ***The Happy City Happy Homes toolkit recommends creating sub-clusters within residential developments where no more than 12 households share a semi-private amenity space in order to facilitate interaction and contribute to social capital amongst residents.***

Reference

Abu-Ghazzeh, T. M. (1999). Housing layout, social interaction, and the place of contact in Abu-Nuseir, Jordan. Journal of environmental psychology, 19(1), 41-73.

Capeluto, I. G., Yezioro, A., Bleiberg, T., & Shaviv, E. (2006, September). Solar rights in the design of urban spaces. In Comunicación presentada en la 23rd Conference on Passive and Low Energy Architecture, Ginebra.

Carmona, M. (2019). Principles for public space design, planning to do better. Urban Design International, 24(1), 47-59.

City of Vancouver. (2018). Hey Neighbour! Exploring sociability in multi-unit buildings across Vancouver. Retrieved from https://vancouver.ca/files/cov/hey-neighbour-case-study-booklet.pdf

Farida, N. (2013). Effects of outdoor shared spaces on social interaction in a housing estate in Algeria. Frontiers of Architectural Research, 2(4), 457-467.

Happy City. (2017). Happy Homes toolkit. Retrieved from https://thehappycity.com/project/happy-homes/

Happy City. (2018). Designed to Engage, Policy recommendations for promoting sociability in multi-family housing design. Retrieved from https://thehappycity.com/wp-content/uploads/2018/11/Designed-to-Engage-report.pdf

Mehta, V., & Bosson, J. K. (2010). Third places and the social life of streets. Environment and Behavior, 42(6), 779-805.

Monfared, N. S. S., Hashemnejad, H., & Yazdanfar, S. A. (2015). Design principles in sustainable local community with security and socialization approach (Case study: Chizar). Procedia-Social and Behavioral Sciences, 201, 62-70.

Sharifi, A., & Yamagata, Y. (2016). Principles and criteria for assessing urban energy resilience: A literature review. Renewable and Sustainable Energy Reviews, 60, 1654-1677.

Sullivan, W. C., Kuo, F. E., & Depooter, S. F. (2004). The fruit of urban nature: Vital neighborhood spaces. Environment and behavior, 36(5), 678-700.

Tavakoli, A. (2017). Supporting friendlier, more neighbourly multi-unit buildings in Vancouver. Retrieved from https://sustain.ubc.ca/sites/sustain.ubc.ca/files/GCS/2017_GCS/Final_Reports/Supporting%20friendlier%20more%20neighbourly%20multi-unit%20buildings%20in%20Vancouver_Tavakoli_%202017%20GCS.pdf

Whyte, W. H. (1980). The social life of small urban spaces.

Williams, J. (2005). Designing neighbourhoods for social interaction: The case of cohousing. Journal of Urban Design, 10(2), 195-227. doi:10.1080/13574800500086998

Conclusion

Although the purpose of this document has largely been to explore and describe the relationships between built form and performance in a neighbourhood design context, a parallel purpose has been to establish the level of support within the literature for the indicators used in the RNDT. In this respect, several insights can be drawn from this research.

Firstly, this research has found that generally within the literature there is a sizable body of support behind each indicator and clear threads linking the indicator to resilience outcomes. This provides an academic grounding and validation for the choice of indicators used in the RNDT, and ensures that the RNDT is an objective and research-informed tool. Where an absence of support was evident, some indicators were dropped and new ones adopted. In this regard, the research process behind the creation of this document has at times been iterative, with research findings shaping the choice of some indicators and/or metrics and how these are used, which then set the scence for further research.

For many indicators, such as greenspace proximity, residential density, and noise pollution, quantitative performance thresholds were able to be easily identified within the literature and incorporated into the RNDT accordingly. In some instances however, identifying specific performance thresholds proved more elusive. Partly, this may be because many of the holistic resilience assessment frameworks referenced within the literature tend to be post-occupancy tools that focus on high-level relationships and patterns rather than on specific design details and benchmarks. Given that one of the inherent challenges of identifying hard thresholds and cut-off points is avoiding apparent arbitrariness, it is also plausible that many researchers may be more likely to describe an association or relationship between two phenomenon, rather than describing a specific threshold at which that relationship occurs, strengthens, weakens, plateaus, or stops. Identifying that there is a positive relationship between greenery and mental health for instance, is one matter. Identifying whether there is an optimal amount and type of greenery which can maximize human wellbeing and whether there is a cut-off point at which the benefits of greenery for human health subside or plateau are inherently more difficult and detail-orientated questions which have tended to receive less attention within the literature.

Moving forward, identifying meaningful and reliable performance thresholds will continue to be a key challenge for the RNDT. It is anticipated that future pilot studies, ongoing comparison and alignment with the results of post-occupancy assessments, and actual usage of the RNDT to test different local neighborhoods will be helpful in this respect, and will enable continual refinement in how different indicators and metrics are applied.

Finally, this research has shown that the relationships between built form and resilience are abundant, diverse, and complex. It is hoped that this document will shed some light on these relationships, and be a useful guide for those seeking to better understanding and leverage urban design in order to improve the performance of communities, neighbourhoods, and cities.

Overall Reference List

Abdrabo, M. A., & Hassaan, M. A. (2015). An integrated framework for urban resilience to climate change–Case study: Sea level rise impacts on the Nile Delta coastal urban areas. Urban Climate, 14, 554-565.

Abo-Qudais, S., & Alhiary, A. (2007). Statistical models for traffic noise at signalized intersections. Building and Environment, 42(8), 2939-2948. doi:10.1016/j.buildenv.2005.05.040

Abson, D. J., Fraser, E. D., & Benton, T. G. (2013). Landscape diversity and the resilience of agricultural returns: a portfolio analysis of land-use patterns and economic returns from lowland agriculture. Agriculture & food security, 2(1), 2.

Abu-Ghazzeh, T. M. (1999). Housing layout, social interaction, and the place of contact in Abu-Nuseir, Jordan. Journal of environmental psychology, 19(1), 41-73.

Abu-Ghazzeh, T. M. (1999). Housing layout, social interaction, and the place of contact in Abu-Nuseir, Jordan. Journal of environmental psychology, 19(1), 41-73.

Aerts, J. C., Botzen, W. W., Emanuel, K., Lin, N., De Moel, H., & Michel-Kerjan, E. O. (2014). Evaluating flood resilience strategies for coastal megacities. Science, 344(6183), 473-475.

Agudelo-Vera, C. M., Leduc, W. R., Mels, A. R., & Rijnaarts, H. H. (2012). Harvesting urban resources towards more resilient cities. Resources, conservation and recycling, 64, 3-12.

Ahern, J. (2013). Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design. Landscape ecology, 28(6), 1203-1212.

Ahern, J. (2013). Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design. Landscape ecology, 28(6), 1203-1212.

Akbari, H. (2005). Energy saving potentials and air quality benefits of urban heat island mitigation (No. LBNL-58285). Ernest Orlando Lawrence Berkeley NationalLaboratory, Berkeley, CA (US).

Aksoezen, M., Daniel, M., Hassler, U., & Kohler, N. (2015). Building age as an indicator for energy consumption. Energy and Buildings, 87, 74-86.

Alam, M. S., Hyde, B., Duffy, P., & McNabola, A. (2018). Analysing the Co-Benefits of transport fleet and fuel policies in reducing PM2. 5 and CO2 emissions. Journal of cleaner production, 172, 623-634.

Albacete, X., Olaru, D., Paül, V., & Biermann, S. (2017). Measuring the accessibility of public transport: A critical comparison between methods in Helsinki. Applied Spatial Analysis and Policy, 10(2), 161-188.

Aldrich, D. P. (2012). Building resilience: Social capital in post-disaster recovery. University of Chicago Press.

Aldrich, D. P., & Meyer, M. A. (2015). Social capital and community resilience. American behavioral scientist, 59(2), 254-269.

Ali, M. M. (2001). Evolution of concrete skyscrapers: from Ingalls to Jin mao. Electronic Journal of Structural Engineering, 1(1), 2-14.

Alina. (2017). Residential Timber Cost Model. Building Magazine. Retrieved from http://www.alineacostconsulting.com/wp-content/uploads/2017/06/20170609_alinea-for-building_Residential-Timber-CM.pdf

Alkhresheh, M. M. (2007). Enclosure as a function of height-to-width ratio and scale: its influence on user's sense of comfort and safety in urban street space (Doctoral dissertation, University of Florida).

Alley, W. M., & Veenhuis, J. E. (1983). Effective impervious area in urban runoff modeling. Journal of Hydraulic Engineering, 109(2), 313-319.

Altman, I., & Zube, E. H. (Eds.). (2012). Public places and spaces (Vol. 10). Springer Science & Business Media.

Alvey, A. A. (2006). Promoting and preserving biodiversity in the urban forest. Urban Forestry & Urban Greening, 5(4), 195-201.

Aminipouri, M., Knudby, A. J., Krayenhoff, E. S., Zickfeld, K., & Middel, A. (2019). Modelling the impact of increased street tree cover on mean radiant temperature across Vancouver's local climate zones. Urban Forestry & Urban Greening, 39, 9-17.

Andersen, L. B., Schnohr, P., Schroll, M., & Hein, H. O. (2000). All-cause mortality associated with physical activity during leisure time, work, sports, and cycling to work. Archives of internal medicine, 160(11), 1621-1628.

Anderson, R. W., McLean, A. J., Farmer, M. J. B., Lee, B. H., & Brooks, C. G. (1997). Vehicle travel speeds and the incidence of fatal pedestrian crashes. Accident Analysis & Prevention, 29(5), 667-674.

Arbon, P., Gebbie, K., Cusack, L., Perera, S., & Verdonk, S. (2012). Developing a model and tool to measure community disaster resilience: Final report. Australia: Torrens Resilience Institute.

Armstrong, M., and Sears, B. (2001, April). The New Economy and Jobs/Housing Balance in Southern California. Retrieved from http://www.scag.ca.gov/Documents/NewEconomyJobsHousingBalance.pdf

Arnold Jr, C. L., & Gibbons, C. J. (1996). Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American planning Association, 62(2), 243-258.

ARUP and The Rockfeller Foundation. (2014). City Resilience Index; understanding and measuring city resilience.

ARUP. (2017). Cities Alive: Designing for urban childhoods. Retrieved from https://www.arup.com/perspectives/publications/research/section/cities-alive-designing-for-urban-childhoods

Asahi, K. (2014). The impact of better school accessibility on student outcomes.

Aspinall, P., Mavros, P., Coyne, R., & Roe, J. (2015). The urban brain: analysing outdoor physical activity with mobile EEG. Br J Sports Med, 49(4), 272-276.

Atkinson, R. (2007). Ecology of sound: the sonic order of urban space. Urban studies, 44(10), 1905-1917.

Atkinson, R. (2016). Limited exposure: Social concealment, mobility and engagement with public space by the super-rich in London. Environment and Planning A: Economy and Space, 48(7), 1302-1317.

Atlas Group (2018). 2018 Canadian Cost Guide. Retrieved from http://creston.ca/DocumentCenter/View/1957/Altus-2018-Construction-Cost-Guide-web-1

Audirac, I. (1999). Stated preference for pedestrian proximity: an assessment of new urbanist sense of community. Journal of Planning Education and Research, 19(1), 53-66.

Aurbach, L. (2005). TND Design Rating Standards Version 2.2. Retrieved from https://www.epa.gov/sites/production/files/2014-02/documents/tnd_design_rating_standards_2.2.pdf

Austin, R. (1997). Not just for the fun of it: Governmental restraints on black leisure, social inequality, and the privatization of public space. S. Cal. L. Rev., 71, 667.

Aye, L., Bamford, N., Charters, B., & Robinson, J. (1999). Optimising embodied energy in commercial office development. RICS Foundation, 217-223.

Azar, H.S., Meskouris, K., & Azar, M.S. (2004). Probabilistic seismic risk and damageability assessment, presented at 13th World Conference on Earthquake Engineering, Vancouver, B.C. Retrieved from http://www.iitk.ac.in/nicee/wcee/article/13_2758.pdf

Babey, S. H., Hastert, T. A., & Brown, E. R. (2007). Teens living in disadvantaged neighborhoods lack access to parks and get less physical activity.

Balica, S. F., Wright, N. G., & van der Meulen, F. (2012). A flood vulnerability index for coastal cities and its use in assessing climate change impacts. Natural hazards, 64(1), 73-105.

Balica, S., & Wright, N. G. (2010). Reducing the complexity of the flood vulnerability index. Environmental Hazards, 9(4), 321-339.

Banica, A., Rosu, L., Muntele, I., & Grozavu, A. (2017). Towards Urban Resilience: A Multi-Criteria Analysis of Seismic Vulnerability in Iasi City (Romania). Sustainability, 9(2), 270.

Barrios, S., & Barrios, D. (2004). Reconsidering economic development: The prospects for economic gardening. Public Administration Quarterly, 70-101.

Bastin, J. F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., ... & Crowther, T. W. (2019). The global tree restoration potential. Science, 365(6448), 76-79.

Bates-Frymel, L. & Jennejohn, D. (2013). Reducing Exposure to Traffic Emissions (staff report). Retrieved from http://www.metrovancouver.org/services/air-quality/AirQualityPublications/ReducingExposureToTrafficEmissionsProject.pdf

Bathurst, P. E., & Butler, D. A. (1973). Building cost control techniques and economics. Heinemann Educational Books.

Baum, S., & Payea, K. (2005). The Benefits of Higher Education for Individuals and Society. Retrieved from https://trends.collegeboard.org/sites/default/files/education-pays-2004-full-report.pdf

Bay Localize. (2009). Community Resilience Toolkit. Retrieved from http://www.baylocalize.org/files/Community_Resilience_Toolkit_v1.0.pdf

BC Housing. (2017, October). A Scan of Leading Practices in Affordable Housing. Retrieved from https://www.bchousing.org/research-centre/library/housing-affordability/scan-leading-practices-affordable-housing&sortType=sortByDate

BC Housing. (2019). Design Guidelines and Construction Standards. Retrieved from https://www.bchousing.org/.../BCH-Design-Guidelines-Construction-Standards.pdf

BC Transit. (2010). Infrastructure Design Guidelines. Retrieved from https://www.bctransit.com/documents/1507213417526

BCNPHA & Urban Matters CCC. (2018, July). Vancouver Homeless Count 2018. Retrieved from https://vancouver.ca/files/cov/vancouver-homeless-count-2018-final-report.pdf

Beatley, T. (2011). Biophilic cities: integrating nature into urban design and planning. Island Press.

Beatley, T., & Newman, P. (2013). Biophilic cities are sustainable, resilient cities. Sustainability, 5(8), 3328-3345.

Beaudoin, J., Farzin, Y. H., & Lawell, C. Y. C. L. (2015). Public transit investment and sustainable transportation: A review of studies of transit's impact on traffic congestion and air quality. Research in Transportation Economics, 52, 15-22.

Beckmann, J. P., & Hilty, J. A. (2010). Connecting wildlife populations in fractured landscapes. Safe passages: Highways, wildlife, and habitat connectivity, 3-16.

Beirão, J., & Duarte, J. (2005). Urban grammars: towards flexible urban design.

Bel, G., & Rosell, J. (2013). Effects of the 80 km/h and variable speed limits on air pollution in the metropolitan area of Barcelona. Transportation Research Part D: Transport and Environment, 23, 90-97.

Berglund, B., & Lindvall, T. (Eds.). (1995). Community noise. Stockholm: Center for Sensory Research, Stockholm University and Karolinska Institute.

Bhowmik, S. K. (2005). Street vendors in Asia: a review. Economic and political weekly, 2256-2264.

Bickford, E., Holloway, T., Karambelas, A., Johnston, M., Adams, T., Janssen, M., & Moberg, C. (2013). Emissions and air quality impacts of truck-to-rail freight modal shifts in the Midwestern United States. Environmental science & technology, 48(1), 446-454.

Bieda, A. (2017). Urban renewal and the value of real properties. In Studia Regionalne I Lokalne.

Bionova. (2018). The 10 design commandments for cutting your building's embodied carbon: how to reduce embodied carbon in the built environment. Retrieved from https://www.oneclicklca.com/embodied-carbon-reduction-in-construction/

Biswas, S., Chandra, S., & Ghosh, I. (2017). Effects of on-street parking in urban context: A critical review. Transportation in developing economies, 3(1), 10.

Bond, N. R., Lake, P. S., & Arthington, A. H. (2008). The impacts of drought on freshwater ecosystems: an Australian perspective. Hydrobiologia, 600(1), 3-16.

Boser, U. (2013). Size Matters: A Look at School-District Consolidation. Center for American Progress.

Bostancıoğlu, E. (2007). Factors Affect Residential Buildings Cost in Pre Design Phase.

Bostancioğlu, E. (2010). Effect of building shape on a residential building's construction, energy and life cycle costs. Architectural Science Review, 53(4), 441-467

Bourdic, L., Salat, S., & Nowacki, C. (2012). Assessing cities: a new system of cross-scale spatial indicators. Building Research & Information, 40(5), 592-605.

Box, P. C. (2004). Curb-parking problems: Overview. Journal of Transportation Engineering, 130(1), 1-5.

Braubach, M., Egorov, A., Mudu, P., Wolf, T., Thompson, C. W., & Martuzzi, M. (2017). Effects of urban green space on environmental health, equity and resilience. In Nature-Based Solutions to Climate Change Adaptation in Urban Areas (pp. 187-205). Springer, Cham.

Brauer, M., Reynolds, C., & Hystad, P. (2012). Traffic-related air pollution and health: a Canadian perspective on scientific evidence and potential exposure-mitigation strategies (Doctoral dissertation, University of British Columbia).

Bristow, D. N., & Kennedy, C. A. (2013). Urban metabolism and the energy stored in cities: Implications for resilience. Journal of Industrial Ecology, 17(5), 656-667.

Brody, S. D., Peacock, W. G., & Gunn, J. (2012). Ecological indicators of flood risk along the Gulf of Mexico. Ecological Indicators, 18, 493-500.

Brown, L., & Greenbaum, R. T. (2017). The role of industrial diversity in economic resilience: An empirical examination across 35 years. Urban Studies, 54(6), 1347-1366.

Brueggeman, W.B., & Fisher, J.D. (2008). Real estate and finance investment (14th ed.). Boston: McGraw-Hill Irwin.

Bruse, M. (2007, November). Simulating human thermal comfort and resulting usage patterns of urban open spaces with a multi-agent system. In Proceedings of the 24th International Conference on Passive and Low Energy Architecture PLEA (Vol. 24, pp. 699-706).

Buchanan, A. H., & Levine, S. B. (1999). Wood-based building materials and atmospheric carbon emissions. Environmental Science & Policy, 2(6), 427-437.

Burby, R. J., Deyle, R. E., Godschalk, D. R., & Olshansky, R. B. (2000). Creating hazard resilient communities through land-use planning. Natural hazards review, 1(2), 99-106.

Burgess, M. (2015). Quiet please! Fighting noise pollution. Retrieved from https://www.science.org.au/curious/people-medicine/noise-pollution

Burns, C. M., & Inglis, A. D. (2007). Measuring food access in Melbourne: access to healthy and fast foods by car, bus and foot in an urban municipality in Melbourne. Health & place, 13(4), 877-885.

Burton, C. G. (2015). A validation of metrics for community resilience to natural hazards and disasters using the recovery from Hurricane Katrina as a case study. Annals of the Association of American Geographers, 105(1), 67-86.

Byrd, H., Ho, A., Sharp, B., & Kumar-Nair, N. (2013). Measuring the solar potential of a city and its implications for energy policy. Energy policy, 61, 944-952.

Byrne, J., & Jinjun, Y. (2009). Can urban greenspace combat climate change? Towards a subtropical cities research agenda. Australian Planner, 46(4), 36-43.

Cabeza, L. F., Barreneche, C., Miró, L., Morera, J. M., Bartolí, E., & Fernández, A. I. (2013). Low carbon and low embodied energy materials in buildings: A review. Renewable and Sustainable Energy Reviews, 23, 536-542.

California Department of Government Services. (2002). Seismic Safety Inventory of California Public Schools.

Canadell, J. G., & Raupach, M. R. (2008). Managing forests for climate change mitigation. science, 320(5882), 1456-1457.

Canadian Federal Government. (2017). Canada's National Housing Strategy: A Place to Call Home. Retrieved from https://www.placetocallhome.ca/-/media/sf/project/placetocallhome/pdfs/canada-national-housing-strategy.pdf

Canadian Wood Council. (2018). Brock Commons Tallwood House, University of British Columbia Vancouver Campus. The advent of tall wood structures in Canada, A Case Study. Retrieved from http://cwc.ca/wp-content/uploads/2018/07/CS-BrockCommon.Study_.23.lr_.pdf

Capeluto, I. G., Yezioro, A. B. R. A. H. A. M., & Shaviv, E. D. N. A. (2003). Climatic aspects in urban design—a case study. Building and environment, 38(6), 827-835.

Capeluto, I. G., Yezioro, A., Bleiberg, T., & Shaviv, E. (2006, September). Solar rights in the design of urban spaces. In Comunicación presentada en la 23rd Conference on Passive and Low Energy Architecture, Ginebra.

Cariolet, J. M., Colombert, M., Vuillet, M., & Diab, Y. (2018). Assessing the resilience of urban areas to traffic-related air pollution: Application in Greater Paris. Science of the Total Environment, 615, 588-596.

Carl, C. (2014). Calculating solar photovoltaic potential on residential rooftops in Kailua Kona, Hawaii. University of Southern California.

Carmona, M. (2019). Principles for public space design, planning to do better. Urban Design International, 24(1), 47-59.

Carmona, M., Heath, T. & Tiesdell, S. (2003). Public Places, Urban Spaces: The Dimensions of Urban Design. Burlington, Ma: Architectural Press

Centre for Disaster and Risk Reduction Technology (CEDIM). (2015). Nepal Earthquakes – Report #3. Retrieved from https://www.cedim.kit.edu/english/2850.php

Cerin, E., Conway, T. L., Cain, K. L., Kerr, J., De Bourdeaudhuij, I., Owen, N., ... & Christiansen, L. B. (2013). Sharing good NEWS across the world: developing comparable scores across 12 countries for the Neighborhood Environment Walkability Scale (NEWS). BMC public health, 13(1), 309.

Cervero, R. (1996). Jobs-housing balance revisited: trends and impacts in the San Francisco Bay Area. Journal of the American Planning Association, 62(4), 492-511.

Cervero, R., & Duncan, M. (2006). 'Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing?. Journal of the American planning association, 72(4), 475-490.

Cervero, R., Caldwell, B., & Cuellar, J. (2013). Bike-and-ride: build it and they will come. Journal of Public Transportation, 16(4), 5.

Champagne, C. L., & Aktas, C. B. (2016). Assessing the resilience of LEED certified green buildings. Procedia Engineering, 145, 380-387.

Chan, E. H., Tang, B. S., & Wong, W. S. (2002). Density control and the quality of living space: a case study of private housing development in Hong Kong. Habitat international, 26(2), 159-175.

Chan, M. Y., Burnett, J., & Chow, W. K. (1998). Energy use for ventilation systems in underground car parks. Building and Environment, 33(5), 303-314.

Chandra, A., Acosta, J., Howard, S., Uscher-Pines, L., Williams, M., Yeung, D., ... & Meredith, L. S. (2011). Building community resilience to disasters: A way forward to enhance national health security. Rand health quarterly, 1(1).

Chen, K., & Norford, L. (2017). Evaluating urban forms for comparison studies in the massing design stage. Sustainability, 9(6), 987.

Cheng, V. (2009). Understanding density and high density. In Designing High-Density Cities (pp. 37-51). Routledge.

Cheung, C. (2018, February 21). Meet the realtor transforming Vancouver one block at a time. Vancouver Courier. Retrieved from https://www.vancourier.com/real-estate/meet-the-realtor-transforming-vancouver-one-block-at-a-time-1.23180020

Chien, S. I., & Qin, Z. (2004). Optimization of bus stop locations for improving transit accessibility. Transportation planning and Technology, 27(3), 211-227.

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, (2013). Sea Level Change. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

City of New Westminster. (2016, July). Downtown Building and Public Realm Design Guidelines and Master Plan. Retrieved from https://www.newwestcity.ca/database/files/library/Final_Version___NW_Downtown_Building_and_Public_Realm_Design_Guidelines_and_Master_Plan.pdf

City of New Westminster. (2017). Our City New Westminster, Official Community Plan Development Permit Areas. Retrieved from https://www.newwestcity.ca/council_minutes/0710_17/DPA%20Guidelines%20Aug%2028%202017.pdf

City of Toronto. (2014, June). Privately-owned publicly accessible spaces (POPS), creative place making to enhance urban life. Retrieved from https://www.toronto.ca/wp-content/uploads/2017/08/8527-draft-design-guidelines-for-privately-owned-publicly-accessible-space-Di....pdf

City of Toronto. (2017). City of Toronto Official Plan Indicators. Retrieved from https://www.toronto.ca/legdocs/mmis/2017/pg/bgrd/backgroundfile-107360.pdf

City of Toronto. (2017). Complete Streets Guidelines. Retrieved from https://www.toronto.ca/services-payments/streets-parking-transportation/enhancing-our-streets-and-public-realm/complete-streets/complete-streets-guidelines/

City of Toronto. (2017, August). Toronto Green Streets Technical Guidelines, version 1.0. Retrieved from https://www.toronto.ca/legdocs/mmis/2017/pw/bgrd/backgroundfile-107514.pdf

City of Vancouver (2017). Vancouver's changing shoreline: preparing for sea level rise. Retrieved from https://vancouver.ca/green-vancouver/sea-level-rise.aspx

City of Vancouver Sustainability Group. (2018). Climate Change Adaption Strategy: 2018 Update and Action Plan. Retrieved from https://vancouver.ca/files/cov/Vancouver-Climate-Change-Adaptation-Strategy-2018.pdf

City of Vancouver. (1992). Plaza Design Guidelines. Retrieved from https://vancouver.ca/docs/planning/plaza-design-guidelines-1992-november-17.pdf

City of Vancouver. (2014). Flood Plain Standards and Requirements. Retrieved from https://guidelines.vancouver.ca/F014.pdf

City of Vancouver. (2015). Greenest City 2020 Action Plan. Retrieved from https://vancouver.ca/files/cov/greenest-city-2020-action-plan-2015-2020.pdf

City of Vancouver. (2017, April 30). Housing Characteristics Fact Sheet. Retrieved from https://vancouver.ca/files/cov/housing-characteristics-fact-sheet.pdf

City of Vancouver. (2018). Cambie Corridor Public Realm Plan. Retrieved from https://vancouver.ca/images/web/cambie-corridor/cambie-corridor-public-realm-plan.pdf

City of Vancouver. (2018). Climate Change Adaption Strategy. Retrieved from https://vancouver.ca/files/cov/Vancouver-Climate-Change-Adaptation-Strategy-2012-11-07.pdf

City of Vancouver. (2018a). Housing Vancouver Strategy Annual Progress Report and Data Book 2018. Retrieved from https://vancouver.ca/files/cov/2018-housing-vancouver-annual-progress-report-and-data-book.pdf

City of Vancouver. (2018). RM-8A and RM-8AN Guidelines. Land Use and Development Policies and Guidelines. Retrieved from https://guidelines.vancouver.ca/R031.pdf

City of Vancouver. (2018). Hey Neighbour! Exploring sociability in multi-unit buildings across Vancouver. Retrieved from https://vancouver.ca/files/cov/hey-neighbour-case-study-booklet.pdf

City of Vancouver. (2018). Vancouver Integrated Rainwater Management Plan. Retrieved from https://vancouver.ca/home-property-development/city-wide-integrated-stormwater-management-plan.aspx

City of Vancouver. (2018, September). Density Bous Zoning & Public Benefits. Retrieved from https://vancouver.ca/files/cov/density-bonus-zoning-bulletin.pdf

City of Vancouver. (2018). Housing Vancouver Strategy. Retrieved from https://council.vancouver.ca/20171128/documents/rr1appendixa.pdf

City of Vancouver. (2019). Resilient Vancouver Strategy. Retrieved from https://vancouver.ca/files/cov/resilient-vancouver-strategy.pdf

City of Vancouver. (2019, April 16). Climate Emergency Response (RTS No. 12978; VanRIMS No. 08-2000-20). Retrieved from https://council.vancouver.ca/20190424/documents/cfsc1.pdf

City of Vancouver. (2019). Resilient Vancouver Strategy. Retrieved from https://vancouver.ca/files/cov/resilient-vancouver-strategy.pdf

City of Vancouver. (2019). Residential property tax rates. Retrieved from https://vancouver.ca/home-property-development/residential.aspx

City of Waterloo. (2019). Guidelines for Privately Owned Publically Accessible Spaces (POPS). Retrieved from https://www.waterloo.ca/en/government/resources/Documents/Cityadministration/Uptown-Public-Realm-Strategy/Guideline-for-Privately-Owned-Publicly-Accessible-Spaces-POPS.pdf

CityLab. (n.d.). Is Inefficient Construction Worsening the Affordable Housing Crisis? Retrieved from https://www.citylab.com/sponsored/Katerra/is-inefficient-construction-worsening-the-affordable-housing-crisis/134/

Clowers, G. (2017). Director's Report and Recommendation Neighbourhood Parking September 2017. Retrieved from http://www.seattle.gov/dpd/cs/groups/pan/@pan/documents/web_informational/p3494121.pdf

CMHC. (2018). About Affordable Housing in Canada. Retrieved from https://www.cmhc-schl.gc.ca/en/developing-and-renovating/develop-new-affordable-housing/programs-and-information/about-affordable-housing-in-canada

Colding, J., & Barthel, S. (2013). The potential of 'Urban Green Commons' in the resilience building of cities. Ecological economics, 86, 156-166.

Cole, R. J., & Kernan, P. C. (1996). Life-cycle energy use in office buildings. Building and environment, 31(4), 307-317.

Colliers International. (2019). Millennials, then and now. Retrieved from http://www.collierscanada.com/en/commercial-property-research/2019/spark-report-millennials-then-and-now#.XVRKdehKg2w

Compton, J., & Pollak, R. A. (2014). Family proximity, childcare, and women's labor force attachment. Journal of Urban Economics, 79, 72-90.

Condon, P. M. (2010). Seven rules for sustainable communities: Design strategies for a post-carbon world. Washington, D.C: Island Press.

Condon, P. M. (2012). Seven rules for sustainable communities: design strategies for the post carbon world. Island Press.

Cook, E. A. (2007). Green site design: strategies for storm water management. Journal of Green Building, 2(4), 46-56.

Cooper, M. (2018). Urban Park Street Edges: Enhancing Functionality for the Performance of the 21st Century City. Retrieved from https://atrium.lib.uoguelph.ca/xmlui/handle/10214/13547

Coriolis Consulting Corp. & Wollenberg Munro Consulting Inc. (2019). Reducing the Barrier of High Land Cost: Strategies for Facilitating More Affordable Rental Housing Construction in Vancouver, Phase 2 of The Transit-Oriented Affordable Housing Study. Retrieved from http://www.metrovancouver.org/services/regional-planning/PlanningPublications/ReducingBarrierHighLandCost.pdf

Correa Ayram, C. A., Mendoza, M. E., Etter, A., & Salicrup, D. R. P. (2016). Habitat connectivity in biodiversity conservation: A review of recent studies and applications. Progress in Physical Geography, 40(1), 7-37.

Coutts, A. M., Tapper, N. J., Beringer, J., Loughnan, M., & Demuzere, M. (2013). Watering our cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context. Progress in Physical Geography, 37(1), 2-28.

Cullen, A. J. (2005). Urban intensification and affordable housing in Auckland (Doctoral dissertation, Centre for Housing Research Aotearoa New Zealand).

Curran, J. H., Ward, H. D., Shum, M., & Davies, H. W. (2013). Reducing cardiovascular health impacts from traffic-related noise and air pollution: intervention strategies. Environmental Health Review, 56(02), 31-38.

Cutter, S. (2015, April). Resilience Metrics and Tools: A Quick Overview. Presentation given at the Building Blocks for a National Resilience Scorecard Workshop, Washington DC.

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. Global environmental change, 18(4), 598-606.

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1).

D'Amico, A., & Currà, E. (2014). Paper 20: Urban Resilience and Urban Structure: Vulnerability assessment of historical Italian towns. Proceedings ANDROID Residential Doctoral School.

Dadvand, P., Nieuwenhuijsen, M. J., Esnaola, M., Forns, J., Basagaña, X., Alvarez-Pedrerol, M., ... & Jerrett, M. (2015). Green spaces and cognitive development in primary schoolchildren. Proceedings of the National Academy of Sciences, 112(26), 7937-7942.

Dalton, M. (2017). Density and Housing Affordability. Retrieved from http://theoryandpractice.planning.dal.ca/_pdf/multiple_plans/mdalton_2017.pdf

De Boer, J., Muggah, R., Patel, R. (2016). Conceptualizing City Fragility and Resilience. United Nations University Centre for Policy Research Working Paper 5. Retrieved from https://ocw.tudelft.nl/wp-content/uploads/2Conceptualising-city-fragility-and-resilience.pdf

De Vries, S., Van Dillen, S. M., Groenewegen, P. P., & Spreeuwenberg, P. (2013). Streetscape greenery and health: stress, social cohesion and physical activity as mediators. Social Science & Medicine, 94, 26-33.

Design Centre for Sustainability (DCS), University of British Columbia. (2009). Specification of Indicators and Selection Methodology for a Potential Community Demonstration Project.

Devereux, S. (2007). The impact of droughts and floods on food security and policy options to alleviate negative effects. Agricultural Economics, 37, 47-58.

Dill, J. (2004, January). Measuring network connectivity for bicycling and walking. In 83rd Annual Meeting of the Transportation Research Board, Washington, DC (pp. 11-15).

Disaster Waste Recovery (DWR), ProAct Network, & Shelter Centre. (n.d.).Planning Centralised Building Waste Management Programmes in Response to Large Disasters. Retrieved form https://postconflict.unep.ch/humanitarianaction/documents/02_03-04_01-03.pdf

Djordjević, S., Butler, D., Gourbesville, P., Mark, O., & Pasche, E. (2011). New policies to deal with climate change and other drivers impacting on resilience to flooding in urban areas: the CORFU approach. Environmental Science & Policy, 14(7), 864-873.

Doğangün, A., Tuluk, Ö. İ., Livaoğlu, R., & Acar, R. (2006). Traditional wooden buildings and their damages during earthquakes in Turkey. Engineering Failure Analysis, 13(6), 981-996.

Dominguez, S. (n.d.). Living Up, Or Living Apart? Addressing the Social Consequences of High-Rise Living. Retrieved from https://vancouver.ca/files/cov/living-up-or-living-apart.pdf

Donovan, G. H., & Prestemon, J. P. (2012). The effect of trees on crime in Portland, Oregon. Environment and Behavior, 44(1), 3-30.

Donovan, G. H., Butry, D. T., Michael, Y. L., Prestemon, J. P., Liebhold, A. M., Gatziolis, D., & Mao, M. Y. (2013). The relationship between trees and human health: evidence from the spread of the emerald ash borer. American journal of preventive medicine, 44(2), 139-145.

Drewes, J. E., van Aswegen, M., & Richter, M. (2018). Towards More Resilient Cities: Land Use and Urban Efficiency. The Academic Research Community publication, 2(1), 12.

Drobniak, A. (2012). The urban resilience–economic perspective. Journal of Economics and Management, 10, 5-20.

Dussaillant, F. (2016). Usage of child care and education centers: The proximity factor. SAGE Open, 6(2), 2158244016652668.

Eberle, M., Woodward, J., Thomson, M., & Kraus, D. (2011). Municipal measures for housing affordability and diversity in Metro Vancouver. Retrieved from http://www.housing.gov.bc.ca/pub/CMHC_MunicipalMeasures.pdf

EcoDistricts (2017). EcoDistricts Protocol Version 1.2, the standard for community development.

Economic Intelligence Unit. (2010). US and Canada Green City Index: Assessing the environmental performance of 27 major US and Canadian Cities.

Economist Intelligence Unit. (2012). The Green City Index, A summary of the Green City Index research series.

Ekkel, E. D., & de Vries, S. (2017). Nearby green space and human health: Evaluating accessibility metrics. Landscape and urban planning, 157, 214-220.

El-Sheikh, M., Erath, S. A., & Bagley, E. J. (2013). Parasympathetic nervous system activity and children's sleep. Journal of sleep research, 22(3), 282-288.

Eom, H. J., & Cho, G. H. (2015). Exploring thresholds of built environment characteristics for walkable communities: Empirical evidence from the Seoul Metropolitan area. Transportation Research Part D: Transport and Environment, 40, 76-86.

EPA (Environmental Protection Agency). (2016). Evaluation Urban Resilience to Climate Change: A multi-Sector Approach.

EPA. (2009). Green Streets: A Conceptual Guide to Effective Green Streets Design Solutions. Retrieved from https://www.epa.gov/G3/learn-about-green-streets

EPA. (2014, June). Reducing Urban Heat Islands: Compendium of Strategies. Retrieved from https://www.epa.gov/sites/production/files/2014-06/documents/basicscompendium.pdf

Estoque, R. C., Murayama, Y., & Myint, S. W. (2017). Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia. Science of the Total Environment, 577, 349-359.

Evan. (2016, April). What building material has the smallest overall environmental impact? Retrieved from https://blogs.umass.edu/natsci397a-eross/what-building-material-wood-steel-concrete-has-the-smallest-overall-environment-impact/

Evangelopoulos, E. (2014). Neighborhoods, Proximity to Daily Needs, & Walkability in Form-Based Codes.

Evans, G. W., Wells, N. M., & Moch, A. (2003). Housing and mental health: a review of the evidence and a methodological and conceptual critique. Journal of social issues, 59(3), 475-500.

Evans, G. 2003. The built environment and mental health. Journal of Urban Health, 80(4): 536–555.

Ewing, R., & Cervero, R. (2010). Travel and the built environment: A meta-analysis. Journal of the American planning association, 76(3), 265-294.

Ewing, R., DeAnna, M., Heflin, C. C., & Porter, D. R. (1996). Best development practices.

Ewing, R., M. DeAnna, et al. (1996). "Best development practices: Doing the right thing and making money at the same time " Urban Land Institute; Florida. Dept. of Community Affair.

Fallah, M., Masoud, M., & Navaie, A. (2014). Role of resilient and flexible urban space in disaster management. Bulletin of Environment, Pharmacology and Life Sciences, 3(3), 1-6.

Farida, N. (2013). Effects of outdoor shared spaces on social interaction in a housing estate in Algeria. Frontiers of Architectural Research, 2(4), 457-467.

Fayyaz S, S. K., Liu, X. C., & Zhang, G. (2017). An efficient General Transit Feed Specification (GTFS) enabled algorithm for dynamic transit accessibility analysis. PloS one, 12(10), e0185333.

Felfe, C., & Lalive, R. (2018). Does early child care affect children's development?. Journal of Public Economics, 159, 33-53.

Ferguson, B. K. (2017). Stormwater infiltration. CRC Press.

Feyisa, G. L., Dons, K., & Meilby, H. (2014). Efficiency of parks in mitigating urban heat island effect: An example from Addis Ababa. Landscape and Urban Planning, 123, 87-95.

FHWA. (n.d.). Walkways, Sidewalks, and Public Space. FHWA course on bicycle and pedestrian transportation. Retrieved from https://safety.fhwa.dot.gov/ped_ bike/univcourse/pdf/swless13.pdf

Fiksel, J. (2003). Designing resilient, sustainable systems. Environmental science & technology, 37(23), 5330-5339.

Fingleton, B. (2008). Housing supply, housing demand, and affordability. Urban Studies, 45(8), 1545-1563.

Finlay, J., Franke, T., McKay, H., & Sims-Gould, J. (2015). Therapeutic landscapes and wellbeing in later life: Impacts of blue and green spaces for older adults. Health & Place, 34, 97-106.

Food and Agricultural Organization of the United Nations (FAO). (2008). Climate Change and Food Security: A Framework Document. Retrieved from http://www.fao.org/3/k2595e/k2595e00.pdf

Forinash, C. V., Millard-Ball, A., Dougherty, C., & Tumlin, J. (2003, July). Smart growth alternatives to minimum parking requirements. In 2nd Urban Street Symposium: Uptown, Downtown or Small Town: Designing Urban Streets That Work, Anaheim, California: Transportation Research Board: Washington, DC.

Foth, N., Manaugh, K., & El-Geneidy, A. M. (2013). Towards equitable transit: examining transit accessibility and social need in Toronto, Canada, 1996–2006. Journal of transport geography, 29, 1-10.

Frank, K. (2012). Tall Towers 2012: London's high-rise residential developments. Retrieved from https://content.knightfrank.com/research/478/documents/en/2012-1101.pdf

Frank, L. D., & Pivo, G. (1994). Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking. Transportation research record, 1466, 44-52.

Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., & Bachman, W. (2006). Many pathways from land use to health: associations between neighborhood walkability and active transportation, body mass index, and air quality. Journal of the American planning Association, 72(1), 75-87.

Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). The development of a walkability index: application to the Neighborhood Quality of Life Study. British journal of sports medicine, 44(13), 924-933.

Frank, L., Pivo, G. (1994) Relationships between Land Use and Travel Behavior in the Puget Sound Region. 397 Seattle: Washington State Transportation Center.

Franzie, C. (2014, April 4). Land Assembly: A Brief Overview. Retrieved from https://www.camoinassociates.com/landassembly

French, D., Atkinson, M., & Rugen, L. (2007). Creating small schools: A handbook for Raising Equity and Achievement. Thousand Oaks, CA: Corwin and Center for Collaborative Education.

Frumkin, N. (2015). Guide to economic indicators. Routledge.

Galderisi, A., & Ferrara, F. F. (2012). Enhancing urban resilience in face of climate change: a methodological approach. Tema. Journal of Land Use, Mobility and Environment, 5(2), 69-88.

Gao, W., Ariyama, T., Ojima, T., & Meier, A. (2001). Energy impacts of recycling disassembly material in residential buildings. Energy and Buildings, 33(6), 553-562.

Garmestani, A. S., Allen, C. R., Mittelstaedt, J. D., Stow, C. A., & Ward, W. A. (2006). Firm size diversity, functional richness, and resilience. Environment and Development Economics, 11(4), 533-551.

Gehl, J. (1986). "Soft edges" in residential streets. Scandinavian housing and planning research, 3(2), 89-102.

Gehl, J. (1987). Life between Buildings: Using Public Space,[trans by Jo Koch, Van Nostrand] Reinhold: New York.

Gehl, J. (2011). Life between buildings: using public space. Island press.

Gehl, J. (2013). Cities for people. Island press.

Geoghegan, J. (2002). The value of open spaces in residential land use. Land use Policy, 19(1), 91-98. doi:10.1016/S0264-8377(01)00040-0

Gifford, R. (2007). The consequences of living in high-rise buildings. Architectural science review, 50(1), 2-17.

Gillis, D., Semanjski, I., & Lauwers, D. (2016). How to monitor sustainable mobility in cities? Literature review in the frame of creating a set of sustainable mobility indicators. Sustainability, 8(1), 29.

Giridharan, R., Ganesan, S., & Lau, S. S. Y. (2004). Daytime urban heat island effect in high-rise and high-density residential developments in Hong Kong. Energy and buildings, 36(6), 525-534.

Girling, C., & Kellett, R. (2005). Skinny streets and green neighborhoods: design for environment and community. Island press.

Giuliano, G. (1991). Is jobs-housing balance a transportation issue? Retrieved from https://cloudfront.escholarship.org/dist/prd/content/qt4874r4hg/qt4874r4hg.pdf

Godoy-Shimizu, D., Steadman, P., Hamilton, I., Donn, M., Evans, S., Moreno, G., & Shayesteh, H. (2018). Energy use and height in office buildings. Building Research & Information, 46(8), 845-863.

Godschalk, D. R. (2003). Urban hazard mitigation: Creating resilient cities. Natural Hazards Review, 4(3), 136-143. doi:10.1061/(ASCE)1527-6988(2003)4:3(136)

Goffin, P. (2015). Public Works: How to Make Parks More Accessible. Retrieved from https://torontoist.com/2015/11/public-works-how-to-make-parks-more-accessible/

Goines, L., & Hagler, L. (2007). Noise pollution: a modern plague. SOUTHERN MEDICAL JOURNAL-BIRMINGHAM ALABAMA-, 100(3), 287.

Golub, A., & Martens, K. (2014). Using principles of justice to assess the modal equity of regional transportation plans. Journal of Transport Geography, 41, 10-20.

Graham, S. (2016). Vertical: The City from Satellite to Bunkers. Verso: London.

Grant, J. (2007). Encouraging mixed use in practice. Incentives, regulations and plans: The role of states and nation-states in smart growth planning, 1(10), 57-76.

Gray, N. (2019, June). How Luxury Units Turn Into Affordable Housing. Retrieved from https://www.citylab.com/perspective/2019/06/housing-supply-debate-affordable-home-prices-rent-yimby/591061/

Grazuleviciene, R., Dedele, A., Danileviciute, A., Vencloviene, J., Grazulevicius, T., Andrusaityte, S., ... & Nieuwenhuijsen, M. (2014). The influence of proximity to city parks on blood pressure in early pregnancy. International journal of environmental research and public health, 11(3), 2958-2972.

GreenBlue Urban. (2015, April). Trees as Sound Barriers. Retrieved from https://www.greenblue.com/na/trees-as-sound-barriers/

Grigoryeva, I., & Ley, D. (2019). The price ripple effect in the Vancouver housing market. Urban Geography, 1-23.

Guerra, E., Cervero, R., & Tischler, D. (2012). Half-mile circle: Does it best represent transit station catchments?. Transportation Research Record, 2276(1), 101-109.

Guggemos, A. A., & Horvath, A. (2005). Comparison of environmental effects of steel-and concrete-framed buildings. Journal of infrastructure systems, 11(2), 93-101.

Gülkan, P., & Langenbach, R. (2004, August). The earthquake resistance of traditional timber and masonry dwellings in Turkey. In 13th World Conference on Earthquake Engineering (pp. 1-6).

Haider, M. (2018, August 2). For Neighbours, the dividends of selling homes together as part of a larger plot can be huge. Financial Post. Retrieved from https://business.financialpost.com/real-estate/haider-moranis-bulletin-in-land-assembly-two-plus-two-can-equal-more-than-four

Hajrasouliha, A., & Yin, L. (2015). The impact of street network connectivity on pedestrian volume. Urban Studies, 52(13), 2483-2497.

Halfwerk, W., Holleman, L. J., Lessells, C. K. M., & Slabbekoorn, H. (2011). Negative impact of traffic noise on avian reproductive success. Journal of applied Ecology, 48(1), 210-219.

Hammond, G. P., & Jones, C. I. (2008). Embodied energy and carbon in construction materials. Proceedings of the Institution of Civil Engineers-Energy, 161(2), 87-98.

Happy City. (2017). Happy Homes toolkit. Retrieved from https://thehappycity.com/project/happy-homes/

Happy City. (2017, July). Happy Streets Living Lab. Retrieved from https://thehappycity.com/wp-content/uploads/2017/07/Happy-Streets-Living-Lab-Report-Final_0710_web.pdf

Happy City. (2018). Designed to Engage, Policy recommendations for promoting sociability in multi-family housing design. Retrieved from https://thehappycity.com/wp-content/uploads/2018/11/Designed-to-Engage-report.pdf

Hardy, J. T. (2003). Climate change: causes, effects, and solutions. John Wiley & Sons.

Hayes, J. L., III. (2018). Realizing the ideal school district size: How district size affects achievement and expenditure.

Health Canada. (n.d.). Nutrition and Healthy Eating. Retrieved from https://www.canada.ca/en/health-canada/services/food-nutrition/healthy-eating.html

Hess, D. B. (2009). Access to public transit and its influence on ridership for older adults in two US cities. Journal of Transport and Land Use, 2(1), 3-27.

Hess, P. M., Vernez Moudon, A., Catherine Snyder, M., & Stanilov, K. (1999). Site design and pedestrian travel. Transportation research record, 1674(1), 9-19.

Hibberd, R. E., & Nelson, A. C. (2018). Longitudinal Cluster Analysis of Jobs–Housing Balance in Transit Neighborhoods(No. 18-03557).

Hipp, J.R., Kane, K., and Kim, J.H. (2017). Jobs-Housing balance in Egohoods in Southern California, MFI Quarterly Report: 2017_1. Irvine, CA: Metropolitan Futures Initiative (MFI), University of California Irvine. Retrieved rom https://mfi.soceco.uci.edu/files/2017/01/UCi16_MFI_Report4_Jobs-Housing-Balance.pdf

Hirt, S. (2007). The mixed-use trend: Planning attitudes and practices in Northeast Ohio. Journal of architectural and planning research, 224-244.

Hodgson, J. A., Moilanen, A., Wintle, B. A., & Thomas, C. D. (2011). Habitat area, quality and connectivity: striking the balance for efficient conservation. Journal of Applied Ecology, 48(1), 148-152.

Hodgson, J. A., Thomas, C. D., Wintle, B. A., & Moilanen, A. (2009). Climate change, connectivity and conservation decision making: back to basics. Journal of Applied Ecology, 46(5), 964-969.

Holtzclaw, J. (1994). Using residential patterns and transit to decrease auto dependence and costs (Vol. 11). San Francisco, CA: Natural Resources Defense Council.

Howley, C. B., & Bickel, R. (2000). When It Comes to Schooling... Small Works: School Size, Poverty, and Student Achievement.

Hsu, S. L. (2010). Life cycle assessment of materials and construction in commercial structures: variability and limitations (Doctoral dissertation, Massachusetts Institute of Technology).

Huddart, L. (1990). The use of vegetation for traffic noise screening. Vehicles and Environment Division, Vehicle Group, Transport and Road Research Laboratory.

Hulchanski, J. D. (2003). What factors shape Canadian housing policy? The intergovernmental role in Canada's housing system. Municipal-federal-provincial relations in Canada, 221-250.

Hull, A., & O'Holleran, C. (2014). Bicycle infrastructure: can good design encourage cycling?. Urban, Planning and Transport Research, 2(1), 369-406.

Hutton, T. A. (2009). The new economy of the inner city: Restructuring, regeneration and dislocation in the 21st century metropolis. Routledge.

Hylden, J. (2005). What's So Big about Small Schools? The Case for Small Schools: Nationwide and in North Dakota. PEPG 05-05. Program on Education Policy and Governance.

IFRC. (2014). IFRC Framework for community resilience. International Federation or Red Cross and Red Crescent Societies, Geneva, Switzerland.

Ignatieva, M., Stewart, G. H., & Meurk, C. (2011). Planning and design of ecological networks in urban areas. Landscape and ecological engineering, 7(1), 17-25.

Institute for Local Self Reliance (ILSR). (2012, March 19). Small Schools vs. Big Schools. Retrieved from https://ilsr.org/rule/small-schools-vs-big-schools/

IPCC. (2001). Climate change 2001; impacts adaption and vulnerability. Report of Working Group II of the Intergovernmental Panel on Climate Change, Hydrology and Water Resources Section.

IPCC. (2001). Climate change 2001; impacts adaption and vulnerability. Report of Working Group II of the Intergovernmental Panel on Climate Change, Hydrology and Water Resources Section.

ITE (Institute of Transportation Engineers). (2006). Context Sensitive Solutions in Designing Major Urban Thoroughfares for Walkable Communities, an ITE Proposed Recommended Practice. Retrieved from https://www.epa.gov/sites/production/files/2015-11/documents/rp036.pdf

Jacobs, A., & Appleyard, D. (1987). Toward an urban design manifesto. Journal of the American Planning Association, 53(1), 112-120.

Jacobs, J. (1965). The death and life of great American cities. Harmondsworth, UK: Penguin.

Jayasuriya, D. C. (1994). Street food vending in Asia: some policy and legal aspects. Food Control, 5(4), 222-226.

Jeffrey, C. (2011, September). Construction and Demolition Waste Recycling: A Literature Review. Retrieved from https://cdn.dal.ca/content/dam/dalhousie/pdf/dept/sustainability/Final%20C%26D%20literature%20review.pdf

Jha, A. K., Miner, T. W., & Stanton-Geddes, Z. (Eds.). (2013). Building urban resilience: principles, tools, and practice. The World Bank.

Jia, W., & Wachs, M. (1999). Parking requirements and housing affordability: Case study of San Francisco. Transportation Research Record, 1685(1), 156-160.

Johnson, T. W. (2006). Comparison of environmental impacts of steel and concrete as building materials using the Life Cycle Assessment method (Doctoral dissertation, Massachusetts Institute of Technology).

Jones, C. E., & Ley, D. (2016). Transit-oriented development and gentrification along Metro Vancouver's low-income SkyTrain corridor. The Canadian Geographer/Le Géographe Canadien, 60(1), 9-22.

Jung, O. (2009). Who is really paying for your parking space? Estimating the marginal implicit value of off-street parking spaces for condominiums in central Edmonton, Canada. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.192.202&rep=rep1&type=pdf

Jusuf, S. K., Wong, N. H., Hagen, E., Anggoro, R., & Hong, Y. (2007). The influence of land use on the urban heat island in Singapore. Habitat international, 31(2), 232-242.

Kaczynski, A. T., Potwarka, L. R., Smale, B. J., & Havitz, M. E. (2009).

Association of parkland proximity with neighborhood and park-based physical activity: variations by gender and age. Leisure Sciences, 31(2), 174-191.

Kang, L., & Fricker, J. D. (2016). Sharing urban sidewalks with bicyclists? An exploratory analysis of pedestrian perceptions and attitudes. Transport Policy, 49, 216-225.

Karsh, E. (2014, February). Wood-frame construction advantageous in areas prone to seismic activity. Civil + Structural Engineer media. Retrieved from https://csengineermag.com/article/wood-frame-construction-advantageous-in-areas-prone-to-seismic-activity/

Katzmarzyk, P. T., Gledhill, N., & Shephard, R. J. (2000). The economic burden of physical inactivity in Canada. Cmaj, 163(11), 1435-1440.

Kawachi, I., & Berkman, L. F. (2001). Social ties and mental health. Journal of Urban health, 78(3), 458-467.

Kearns, A., Whitley, E., Mason, P., & Bond, L. (2012). 'Living the high life'? Residential, social and psychosocial outcomes for high-rise occupants in a deprived context. Housing Studies, 27(1), 97-126.

Keil, A., Zeller, M., Wida, A., Sanim, B., & Birner, R. (2008). What determines farmers' resilience towards ENSO-related drought? An empirical assessment in Central Sulawesi, Indonesia. Climatic Change, 86(3-4), 291.

Kern, L. (2007). Reshaping the boundaries of public and private life: Gender, condominium development, and the neoliberalization of urban living. Urban Geography, 28(7), 657-681.

Kim, A. M. (2012). The mixed-use sidewalk: Vending and property rights in public space. Journal of the American Planning Association, 78(3), 225-238. doi:10.1080/01944363.2012.715504

Kim, S., Choi, J., & Kim, Y. (2011). Determining the sidewalk pavement width by using pedestrian discomfort levels and movement characteristics. KSCE Journal of Civil Engineering, 15(5), 883.

Kirby, A. (2008). The production of private space and its implications for urban social relations. Political Geography, 27(1), 74-95.

Klemm, W., Heusinkveld, B. G., Lenzholzer, S., & van Hove, B. (2015). Street greenery and its physical and psychological impact on thermal comfort. Landscape and Urban Planning, 138, 87-98.

Kneebone, E. & Holmes, N. (2015). The growing distance between people and jobs in metropolitan America. Metropolitan Policy Program at Brookings. Retrieved from https://www.brookings.edu/wp-content/uploads/2016/07/Srvy_JobsProximity.pdf

Knutson, T. R., Tuleya, R. E., & Kurihara, Y. (1998). Simulated increase of hurricane intensities in a CO2-warmed climate. Science, 279(5353), 1018-1021.

Kodransky, M., & Hermann, G. (2010). Europe's parking u-turn: from accomodation to regulation. Institute for Transportation and Development Policy.

Kondo, M., Fluehr, J., McKeon, T., & Branas, C. (2018). Urban green space and its impact on human health. International journal of environmental research and public health, 15(3), 445.

Kong, F., Yin, H., Nakagoshi, N., & Zong, Y. (2010). Urban green space network development for biodiversity conservation: Identification based on graph theory and gravity modeling. Landscape and urban planning, 95(1-2), 16-27.

Kong, L., Lau, K. K. L., Yuan, C., Chen, Y., Xu, Y., Ren, C., & Ng, E. (2017). Regulation of outdoor thermal comfort by trees in Hong Kong. Sustainable Cities and Society, 31, 12-25.

Kovács, Z., Wiessner, R., & Zischner, R. (2013). Urban renewal in the inner city of Budapest: Gentrification from a post-socialist perspective. Urban Studies, 50(1), 22-38.

Krizek, K. J. (2003). Operationalizing neighborhood accessibility for land use-travel behavior research and regional modeling. Journal of Planning Education and Research, 22(3), 270-287.

Krzyżanowski, M., Kuna-Dibbert, B., & Schneider, J. (Eds.). (2005). Health effects of transport-related air pollution. WHO Regional Office Europe.

Kulshrestha, U., & Saxena, P. (Eds.). (2016). Plant Responses to Air Pollution. Springer.

Kumari, N. (2011). Urban Edge as a Responsive Urban Space: Examination of the impact on the city with special reference to the city of Colombo. Retrieved from http://dl.lib.mrt.ac.lk/bitstream/handle/123/1443/chapter%202.pdf?sequence=6&isAllowed=y

Kuo, F. E., & Sullivan, W. C. (2001). Environment and crime in the inner city: Does vegetation reduce crime?. Environment and behavior, 33(3), 343-367.

Kuo, F. E., Sullivan, W. C., Coley, R. L., & Brunson, L. (1998). Fertile ground for community: Inner-city neighborhood common spaces. American Journal of Community Psychology, 26(6), 823-851. doi:10.1023/A:1022294028903

Kuo, M. (2015). How might contact with nature promote human health? Promising mechanisms and a possible central pathway. Frontiers in psychology, 6, 1093.

Kurn, D. M., Bretz, S. E., Huang, B., & Akbari, H. (1994). The potential for reducing urban air temperatures and energy consumption through vegetative cooling (No. LBL-35320). Lawrence Berkeley Lab., CA (United States).

Kuryj-Wysocka, O., & Wiśniewski, R. (2013). The problem of competition on real estate market on the example of the local housing market in Olsztyn. Real Estate Management and Valuation, 21(1), 69-76.

Kuznecova, T., Romagnoli, F., & Rochas, C. (2014). Energy metabolism for resilient urban environment: a methodological approach. Procedia Economics and Finance, 18, 780-788.

Lam, J. C., Chan, R. Y., Tsang, C. L., & Li, D. H. (2004). Electricity use characteristics of purpose-built office buildings in subtropical climates. Energy Conversion and Management, 45(6), 829-844.

LaMondia, J. J., Blackmar, C. E., & Bhat, C. R. (2010, August). Comparing transit accessibility measures: A case study of access to healthcare facilities. In Proceedings of the 89rd Annual Meeting of Transportation Research Board, Washington, DC, USA.

Lawson, L., & McNally, M. (1995). Putting teens at the center: Maximizing public utility of urban space through youth involvement in planning and employment. Children's Environments, 12(2), 209-221

Leaf, W. A., & Preusser, D. F. (1999). Literature review on vehicle travel speeds and pedestrian injuries. US Department of Transportation, National Highway Traffic Safety Administration.

Leal Filho, W., Icaza, L. E., Neht, A., Klavins, M., & Morgan, E. A. (2018). Coping with the impacts of urban heat islands. A literature based study on understanding urban heat vulnerability and the need for resilience in cities in a global climate change context. Journal of cleaner production, 171, 1140-1149.

Ledogar, R. J., & Fleming, J. (2008). Social capital and resilience: A review of concepts and selected literature relevant to Aboriginal youth resilience research. Pimatisiwin, 6(2), 25.

Lee, G. (2011). Integrated modeling of air quality and health impacts of a freight transportation corridor. University of California, Irvine.

Lee, V. E., & Smith, J. B. (1997). High school size: Which works best and for whom?. Educational Evaluation and Policy Analysis, 19(3), 205-227.

Leslie, E., Butterworth, I., & Edwards, M. (2006, October). Measuring the walkability of local communities using Geographic Information Systems data. In Walk21-VII,"The Next Steps", The 7th International Conference on Walking and Liveable Communities. Melbourne. http://www. walk21. com/papers/m (Vol. 6).

Leung, D. Y., Tsui, J. K., Chen, F., Yip, W. K., Vrijmoed, L. L., & Liu, C. H.

(2011). Effects of urban vegetation on urban air quality. Landscape research, 36(2), 173-188.

Levelt, P. B. M. (1992). Improvement of Pedestrian Safety and Comfort at Traffic Lights: Results from French, British and Dutch Field Tests (Vol. 92, No. 56). SWOV Institute for Road Safety.

Levin, M., Belfield, C., Muennig, P., & Cecilia, R. (2007, January). The Costs and Benefits of an Excellent Education for All of Americas Children. Retrieved from https://pdfs.semanticscholar.org/af57/1f8380a94ed03875dc7adc5b907e8b47707c.pdf

Lewis, D. J., Provencher, B., & Butsic, V. (2009). The dynamic effects of open-space conservation policies on residential development density. Journal of Environmental Economics and Management, 57(3), 239-252. doi:10.1016/j.jeem.2008.11.001

Lewis-Workman, S., & Brod, D. (1997). Measuring the neighborhood benefits of rail transit accessibility. Transportation Research Record, 1576(1), 147-153.

Leyden, K. M. (2003). Social capital and the built environment: the importance of walkable neighborhoods. American journal of public health, 93(9), 1546-1551.

Li, J., & Kim, C. (2018). Measuring Individuals' Spatial Access to Healthy Foods by Incorporating Mobility, Time, and Mode: Activity Space Measures. The Professional Geographer, 70(2), 198-208.

Li, J., Song, C., Cao, L., Zhu, F., Meng, X., & Wu, J. (2011). Impacts of landscape structure on surface urban heat islands: A case study of Shanghai, China. Remote Sensing of Environment, 115(12), 3249-3263.

Lightfoot, L. (2015, October 27). Supersize schools: how big is too big…2,000? Or 4,000? The Guardian. Retrieved from https://www.theguardian.com/education/2015/oct/27/supersize-schools-too-big-add-places-pupils

Lin, B. B. (2011). Resilience in agriculture through crop diversification: adaptive management for environmental change. BioScience, 61(3), 183-193.

Lin, B., Li, X., Zhu, Y., & Qin, Y. (2008). Numerical simulation studies of the different vegetation patterns' effects on outdoor pedestrian thermal comfort. Journal of Wind Engineering and Industrial Aerodynamics, 96(10-11), 1707-1718.

Lindenmayer, D. B., Margules, C. R., & Botkin, D. B. (2000). Indicators of biodiversity for ecologically sustainable forest management. Conservation biology, 14(4), 941-950.

Litman, T. (1999). Traffic calming: benefits, costs and equity impacts. Victoria, BC,, Canada: Victoria Transport Policy Institute.

Litman, T. (2003). Integrating public health objectives in transportation decision-making. American Journal of Health Promotion, 18(1), 103-108.

Litman, T. (2016, July). Determining Optimal Urban Expansion, Population and Vehicle Density, and Housing Types for Rapidly Growing Cities. In Proceedings of the World Conference on Transport Research, Shanghai, China (pp. 10-15).

Litman, T. (2017). Evaluating Transportation Diversity. Victoria Transport Policy Institute.

Litman, T. (2018). Economic Value of Walkability. Retrieved from https://www.vtpi.org/walkability.pdf

Litman, T. (2018, November 16). Evaluating Transportation Diversity. Victoria Transport Policy Institute.

Litman, T. (2019). Parking Requirements Impacts on Housing Affordability. Retrieved from http://vtpi.org/park-hou.pdf

Liu, H., Li, F., Li, J., & Zhang, Y. (2017). The relationships between urban parks, residents' physical activity, and mental health benefits: A case study from Beijing, China. Journal of environmental management, 190, 223-230.

Liu, Y., & Cirillo, C. (2015). Measuring transit service impacts on vehicle ownership and use. Public transport, 7(2), 203-222.

Liu, Z., Xiu, C., & Song, W. (2019). Landscape-Based Assessment of Urban Resilience and Its Evolution: A Case Study of the Central City of Shenyang. Sustainability, 11(10), 2964.

London Borough of Croydon. (2009). Landscape Design; Supplementary Planning Guidance No. 12.

London Canada. (2010). Illustrated Urban Design Principles. Retrieved from https://www.london.ca/business/Planning-Development/urban-design/Documents/Illustrated-Urban-Design-Principles.pdf

Loughner, C. P., Allen, D. J., Zhang, D. L., Pickering, K. E., Dickerson, R. R., & Landry, L. (2012). Roles of urban tree canopy and buildings in urban heat island effects: Parameterization and preliminary results. Journal of Applied Meteorology and Climatology, 51(10), 1775-1793.

Loukaitou-Sideris, A. (1993). Privatisation of public open space: The Los Angeles experience. Town Planning Review, 64(2), 139.

Lovasi, G. S., Grady, S., & Rundle, A. (2011). Steps forward: review and recommendations for research on walkability, physical activity and cardiovascular health. Public health reviews, 33(2), 484.

Lovett, G. M., Tear, T. H., Evers, D. C., Findlay, S. E., Cosby, B. J., Dunscomb, J. K., ... & Weathers, K. C. (2009). Effects of air pollution on ecosystems and biological diversity in the eastern United States. Annals of the New York Academy of Sciences, 1162(1), 99-135.

Low, S. (2006). Towards a theory of urban fragmentation: a cross-cultural analysis of fear, privatization, and the state. Cybergeo: European Journal of Geography.

Lowry, S. (1990). Housing and health: Families and flats. BMJ: British Medical Journal, 300(6719), 245.

Lylykangas, K. (2009). Shape factor as an indicator of heating energy demand. In Proceedings of the 15th International Wood Construction Conference (IHF).

Lynch, K., Lynch, K. R., & Hack, G. (1984). Site planning. MIT press.

Maas, J., Verheij, R. A., Groenewegen, P. P., De Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity, and health: how strong is the relation?. Journal of Epidemiology & Community Health, 60(7), 587-592.

Macdonald, E. (2005). Street-facing dwelling units and livability: The impacts of emerging building types in Vancouver's new high-density residential neighbourhoods. Journal of Urban Design, 10(1), 13-38.

Mallo, M. F. L., & Espinoza, O. (2016, January). Cross-laminated timber vs. concrete/steel: cost comparison using a case study. In WCTE 2016–World Conference on Timber Engineering.

Marcus, C. C., & Francis, C. (Eds.). (1997). People places: design guidlines for urban open space. John Wiley & Sons.

Markovich, J., Slovinec, D., & Dinh, T. (2018). Community Wellbeing: A Framework for the Design Professionals. Ottawa: The Conference Board of Canada.

Marquet, O., & Miralles-Guasch, C. (2015). The Walkable city and the importance of the proximity environments for Barcelona's everyday mobility. Cities, 42, 258-266.

Mason, J., Fulton, L., & McDonal, Z. (2015, November). A Global High Shift Cycling Scenario: The Potential For Dramatically Increasing Bicycle and E-bike Use in Cities Around the World with Estimated Energy, C02, and Cost Impacts. Retrieved from https://itdpdotorg.wpengine.com/wp-content/uploads/2015/11/A-Global-High-Shift-Cycling-Scenario_Nov-2015.pdf

Matthews, C. E., Jurj, A. L., Shu, X. O., Li, H. L., Yang, G., Li, Q., ... & Zheng, W. (2007). Influence of exercise, walking, cycling, and overall nonexercise physical activity on mortality in Chinese women. American journal of epidemiology, 165(12), 1343-1350.

May, C. W., Horner, R. R., Karr, J. R., Mar, B. W., & Welch, E. B. (1998). The cumulative effects of urbanization on small streams in the Puget Sound Lowland Ecoregion. In Proceedings of the Puget Sound Research.

McCarthy, D., & Saegert, S. (1978). Residential density, social overload, and social withdrawal. Human Ecology, 6(3), 253-272.

McGill Cycling Working Group. (2014, July). Recommendations. Retrieved from https://www.mcgill.ca/campusplanning/files/campusplanning/pedestrian_cycling_co-existence_final_report.pdf

McGranahan, G., Balk, D., & Anderson, B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environment and urbanization, 19(1), 17-37.

McPhearson, T., Andersson, E., Elmqvist, T., & Frantzeskaki, N. (2015). Resilience of and through urban ecosystem services. Ecosystem Services, 12, 152-156.

.

Mead, J., Zegeer, C., Bushell, M. (2014, April). Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research. Retrieved from http://www.pedbikeinfo.org/cms/downloads/PedestrianLitReview_April2014.pdf#page=10&zoom=100,69,326

Medic, G., Wille, M., & Hemels, M. E. (2017). Short-and long-term health consequences of sleep disruption. Nature and science of sleep, 9, 151.

Mehta, V., & Bosson, J. K. (2010). Third places and the social life of streets. Environment and Behavior, 42(6), 779-805.

Mercy Corps. (n.d.). Urban Resilience Measurement: An Approach Guide and Training Curriculum. Retrieved from https://www.mercycorps.org/sites/default/files/Urban%20Resilience%20Measurement_Training%20Guide_FINAL.pdf

Merle, A. (2017, November 9). The Ideal Work Commute Will Make you Happier and Healthier. Huffpost. Retrieved from https://www.huffpost.com/entry/the-ideal-work-commute-will-make-you-happier-and-healthier_b_59b6ca67e4b0bb893fffffd9

Metro Vancouver & Pinna Sustainability. (2016). Climate Projections for Metro Vancouver. Retrieved from http://www.metrovancouver.org/services/air-quality/AirQualityPublications/ClimateProjectionsForMetroVancouver.pdf

Miller, N. (2012). Estimating office space per worker. Burnham-Moores Center for Real Estate University of San Diego.

Milne, G. A., Gehrels, W. R., Hughes, C. W., & Tamisiea, M. E. (2009). Identifying the causes of sea-level change. Nature Geoscience, 2(7), 471.

Mimura, N. (1999). Vulnerability of island countries in the South Pacific to sea level rise and climate change. Climate research, 12(2-3), 137-143.

Minneapolis-Saint Paul Metropolitan Council. (2016). Measuring Employment, How to Measure Employment Intensity and Capacity. In Local Planning Handbook. Retrieved from https://metrocouncil.org/Handbook/Files/Resources/Fact-Sheet/ECONOMIC-COMPETITIVENESS/How-to-Measure-Employment-Intensity-and-Capacity.aspx

Mir, L. (2008). Noise in class: A stress factor for children? Environnement, Risques & Santé, 7(1),5-6.

Miranda-Moreno, L. F., Morency, P., & El-Geneidy, A. M. (2011). The link between built environment, pedestrian activity and pedestrian–vehicle collision occurrence at signalized intersections. Accident Analysis & Prevention, 43(5), 1624-1634.

Mitchell, R., & Popham, F. (2008). Effect of exposure to natural environment on health inequalities: an observational population study. The lancet, 372(9650), 1655-1660.

Miyake, K. K., Maroko, A. R., Grady, K. L., Maantay, J. A., & Arno, P. S. (2010). Not just a walk in the park: Methodological improvements for determining environmental justice implications of park access in New York City for the promotion of physical activity. Cities and the Environment, 3(1), 1.

Modi, S. (2014). Improving the Social Sustainability of High-rises. Council on Tall Buildings and Urban Habitat Journal, (1). Retrieved from http://global.ctbuh.org/resources/papers/download/828-improving-the-social-sustainability-of-high-rises.pdf

Modi, S. (2018). An analysis of high-rise living in terms of provision of appropriate social spaces for children. Journal of Urban Design and Health, 5(4). Retrieved from https://www.urbandesignmentalhealth.com/journal-5---high-rise.html

Mohajeri, N., Upadhyay, G., Gudmundsson, A., Assouline, D., Kämpf, J., & Scartezzini, J. L. (2016). Effects of urban compactness on solar energy potential. Renewable Energy, 93, 469-482.

Mohareb, E., and Row, J. (2014). Improving Energy Efficiency in Alberta's Buildings. Retrieved from https://www.pembina.org/reports/improving-energy-efficiency-in-alberta-buildings.pdf

Mohsen, S., Khodadad, S., and Khodadad, M. (2018). Flexible Urban Public Spaces and their Designing Principles. Journal of Civil Engineering and Urbanism, 8(4), 39-43. Retrieved from http://www.ojceu.ir/main/attachments/article/65/J.%20Civil%20Eng.%20Urban.%208%20(4)%2039-43,%202018.pdf

Monfared, N. S. S., Hashemnejad, H., & Yazdanfar, S. A. (2015). Design principles in sustainable local community with security and socialization approach (Case study: Chizar). Procedia-Social and Behavioral Sciences, 201, 62-70.

Montgomery, C. (2013). Happy city: Transforming our lives through urban design. Macmillan.

Montgomery, J. (1998). Making a city: Urbanity, vitality and urban design. Journal of urban design, 3(1), 93-116.

Moughtin, C. (1992). Urban Design: Street and Square (Oxford, Butterworth).

Muller, M. (2007). Adapting to climate change: water management for urban resilience. Environment and Urbanization, 19(1), 99-113.

Municipal Association of Victoria (MAV). (2015). Shade Design for Public Places. Retrieved from http://www.mav.asn.au/__data/assets/pdf_file/0018/7326/Shade-design-for-public-places.pdf

Murphy, B. L. (2007). Locating social capital in resilient community-level emergency management. Natural Hazards, 41(2), 297-315.

Murray-Tuite, P. M. (2006, December). A comparison of transportation network resilience under simulated system optimum and user equilibrium conditions. In Proceedings of the 2006 Winter Simulation Conference (pp. 1398-1405). IEEE.

Musterd, S., & Van Kempen, R. (2005). Large-scale Housing Estates in European Cities: opinions of residents on recent developments.

Nässén, J., Hedenus, F., Karlsson, S., & Holmberg, J. (2012). Concrete vs. wood in buildings–an energy system approach. Building and environment, 51, 361-369.

Nasution, A. D., & Zahrah, W. (2012). Public open space privatization and quality of life, case study merdeka square medan. Procedia - Social and Behavioral Sciences, 36, 466-475. doi:10.1016/j.sbspro.2012.03.051

Nechyba, T. J., & Walsh, R. P. (2004). Urban sprawl. Journal of economic perspectives, 18(4), 177-200.

Nelessen, A. (1993). Visions for a New American Dream. Chicago, IL: Planners Press.

Németh, J., & Schmidt, S. (2011). The privatization of public space: modeling and measuring publicness. Environment and Planning B: Planning and Design, 38(1), 5-23.

New York City. (2019, April). Climate Resiliency Design Guidelines. Retrieved from https://www1.nyc.gov/assets/orr/pdf/NYC_Climate_Resiliency_Design_

Guidelines_v3-0.pdf

Newman, L. L., & Burnett, K. (2013). Street food and vibrant urban spaces: lessons from Portland, Oregon. Local Environment, 18(2), 233-248.

Newman, P. (1996). Reducing automobile dependence. Environment and urbanization, 8(1), 67-92.

Newman, P. (2010). Resilient infrastructure cities. Developing Living Cities: From Analysis to Action; Kallidaikurichi, S., Yuen, B., Eds, 77-106.

Newman, P., & Kenworthy, J. (2006). Urban design to reduce automobile dependence. Opolis, 2(1).

Newman, P., & Kenworthy, J. (2015). The end of automobile dependence. In The End of Automobile Dependence (pp. 201-226). Island Press, Washington, DC

Newman, P., Beatley, T., & Boyer, H. (2009). Resilient cities. Responding to peak oil and climate change. Washington DC.

Ngui, A. N., & Apparicio, P. (2011). Optimizing the two-step floating catchment area method for measuring spatial accessibility to medical clinics in Montreal. BMC health services research, 11(1), 166.

Ni'mah, N. M., & Lenonb, S. (2017, June). Urban greenspace for resilient city in the future: Case study of Yogyakarta City. In IOP Conference Series: Earth and Environmental Science(Vol. 70, No. 1, p. 012058). IOP Publishing.

NIDCD. (2019, May). Noise-Induced Hearing Loss. Retrieved from https://www.nidcd.nih.gov/health/noise-induced-hearing-loss

Nikolopoulou, M., Baker, N., & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: understanding the human parameter. Solar energy, 70(3), 227-235.

Niskar, A. S., Kieszak, S. M., Holmes, A. E., Esteban, E., Rubin, C., & Brody, D. J. (2001). Estimated prevalence of noise-induced hearing threshold shifts among children 6 to 19 years of age: the Third National Health and Nutrition Examination Survey, 1988–1994, United States. Pediatrics, 108(1), 40-43.

NOAA Office for Coastal Management. (2019, January). Fast Facts: Hurricane Costs. Retrieved from https://coast.noaa.gov/states/fast-facts/hurricane-costs.html

Nordic Forest Research. (n.d.). Urban Tree Diversity for Sustainable Cities, Policy Brief. Retrieved from https://nordicforestresearch.org/wp-content/uploads/2017/09/URBAN-TREE-DIVERSITY3.pdf

Normandin, J. M., Therrien, M. C., & Tanguay, G. A. (2009, June). City strength in times of turbulence: strategic resilience indicators. In Proc. of the Joint Conference on City Futures, Madrid (pp. 4-6).

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. American journal of community psychology, 41(1-2), 127-150.

Nowak, D. J., & Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA. Environmental pollution, 116(3), 381-389.

Nowak, D. J., Greenfield, E. J., Hoehn, R. E., & Lapoint, E. (2013). Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental pollution, 178, 229-236.

Nowak, D., & Heisler, G. (2010). Air quality effects of urban trees and parks. Research Series Monograph. Ashburn, VA: National Recreation and Parks Association Research Series Monograph. 44 p., 1-44.

Oja, P., Titze, S., Bauman, A., De Geus, B., Krenn, P., Reger-Nash, B., & Kohlberger, T. (2011). Health benefits of cycling: a systematic review. Scandinavian journal of medicine & science in sports, 21(4), 496-509.

Oka, T., & Sawachi, T. (2013). Annex 57–evaluation of embodied energy and carbon dioxide emissions for building construction. In Central Europe Towards Sustainable Building Conference, Prague, Czech Republic (pp. 9-12).

Oke, C. (2017, October). Why Cities Should Focus on Biodiversity. Retrieved from https://www.100resilientcities.org/why-cities-should-focus-on-biodiversity/

Oke, R. T. (1997). Urban climate and global environmental change. Applied climatology, 273-287.

Oke, T. R. (2002). Boundary layer climates. Routledge.

Olds, A. D., Connolly, R. M., Pitt, K. A., & Maxwell, P. S. (2012). Habitat connectivity improves reserve performance. Conservation Letters, 5(1), 56-63.

Ontario Ministry of Transportation. (2012). Transit Supportive Guidelines. Retrieved from http://www.mto.gov.on.ca/english/transit/pdfs/transit-supportive-guidelines.pdf

O'Rourke, T. D. (2007). Critical infrastructure, interdependencies, and resilience. BRIDGE-Washington-National Academy of Engineering-, 37(1), 22.

Osama, A., & Sayed, T. (2017). Evaluating the impact of connectivity, continuity, and topography of sidewalk network on pedestrian safety. Accident Analysis & Prevention, 107, 117-125.

Östh, J., Dolciotti, M., Reggiani, A., & Nijkamp, P. (2018). Social capital, resilience and accessibility in urban systems: a study on Sweden. Networks and Spatial Economics, 18(2), 313-336.

Otak, Inc. (2013, May). Hawaii Pedestrian Toolbox, A Guide for Planning, Design, Operations, and Education to Enhance Pedestrian Travel in Hawaii. Retrieved from https://hidot.hawaii.gov/highways/files/2013/07/Pedest-Tbox-Hawaii-Pedestrian-Toolbox-Low-Res.pdf

Ovstedal, L., & Ryeng, E. (2002, September). Understanding pedestrian comfort in European cities: How to improve walking conditions. In European Transport Conference, Cambridge, UK (Vol. 6).

Owen, B. (2005). Air quality impacts of speed-restriction zones for road traffic. Science of The Total Environment, 340(1-3), 13-22.

Pacheco, R., Ordóñez, J., & Martínez, G. (2012). Energy efficient design of building: A review. Renewable and Sustainable Energy Reviews, 16(6), 3559-3573.

Páez, A., & Whalen, K. (2010). Enjoyment of commute: A comparison of different transportation modes. Transportation Research Part A: Policy and Practice, 44(7), 537-549.

Pak, A. (2019). Concrete high rise LCA study, City of Vancouver. Retrieved from https://vancouver.ca/files/cov/cov-concrete-high-rise-study.pdf

Panahi, M., Rezaie, F., & Meshkani, S. A. (2014). Seismic vulnerability assessment of school buildings in Tehran city based on AHP and GIS. Natural Hazards and Earth System Sciences, 14(4), 969-979.

Pandit, R., Polyakov, M., Tapsuwan, S., & Moran, T. (2013). The effect of street trees on property value in Perth, Western Australia. Landscape and Urban Planning, 110, 134-142.

Parasonis, J., Keizikas, A., & Kalibatiene, D. (2012). The relationship between the shape of a building and its energy performance. Architectural Engineering and Design Management, 8(4), 246-256.

Pareto Securities. (n.d.). Project Finance. Retrieved from http://www.paretosec.com/download/compliance/Risk%20Pareto%20Securities%20Project%20Finance.pdf

Patton, C. V. (1988). Jobs and Commercial Office Development: Do New Offices Generate New Jobs?. Economic Development Quarterly, 2(4), 316-325.

Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. Annual review of Ecology and Systematics, 32(1), 333-365.

Peinhardt, K. (2019). Resilience roundup: public spaces fighting climate change. Project for Public Spaces. Retrieved from https://www.pps.org/article/resilience-roundup-public-spaces-fighting-climate-change

Pendall, R., Gainsborough, J., Lowe, K., & Nguyen, M. (2012). Bringing equity to transit-oriented development: Stations, systems, and regional resilience. Building Resilient Regions: Urban and Regional Policy and its Effects, 4, 148-92.

Peng, Z. R. (1997). The jobs-housing balance and urban commuting. Urban studies, 34(8), 1215-1235.

Peprah, C., Oduro, C. Y., & Afi Ocloo, K. (2014). On-street parking and pedestrian safety in the Kumasi metropolis: issues of culture and attitude. Dev Country Stud, 4(20), 85-94.

Perlman, D. L., & Milder, J. (2005). Practical ecology for planners, developers, and citizens. Island Press.

Perovic, S., & Folic, N. K. (2012). Visual perception of public open spaces in Niksic. Procedia-Social and Behavioral Sciences, 68, 921-933.

Petal, M., Baral, S., Giri, S, Rajbanshi, S., Gajurel, S., Green, R.P., Pandey, B., & Shoaf, K. (2017, April). Causes of Deaths and Injuries in the 2015 Gorkha (Nepal) Earthquake, Research Report. Retrieved from https://resourcecentre.savethechildren.net/node/14168/pdf/causes_of_deaths_and_injuries_nepal_earthquake_report_eng_2017.pdf

Peters, K., Elands, B., & Buijs, A. (2010). Social interactions in urban parks: stimulating social cohesion?. Urban forestry & Urban greening, 9(2), 93-100.

Pickett, S. T., Cadenasso, M. L., & McGrath, B. (Eds.). (2013). Resilience in ecology and urban design: linking theory and practice for sustainable cities (Vol. 3). Springer Science & Business Media.

Planning Institute of Australia. (2009, June 10). Connectivity and Permeability. Healthy Spaces & Places. Retrieved from https://www.healthyplaces.org.au/userfiles/file/Connectivity%20June09.pdf

Polzin, S. E., Pendyala, R. M., & Navari, S. (2002). Development of time-of-day–based transit accessibility analysis tool. Transportation Research Record, 1799(1), 35-41.

Portland Bureau of Planning and Sustainability. (2012). Cost of Onsite Parking and Impacts on Affordability.

Portland Sustainability Institute. (2011). EcoDistricts Toolkit: Assessment.

Poskitt, M. (2017). Shaping urban resilience: An analysis of post-earthquake recovery in Christchurch.

Potter, S. H., Becker, J. S., Johnston, D. M., & Rossiter, K. P. (2015). An overview of the impacts of the 2010-2011 Canterbury earthquakes. International Journal of Disaster Risk Reduction, 14, 6-14.

Pouyat, R. V., Yesilonis, I. D., & Nowak, D. J. (2006). Carbon storage by urban soils in the United States. Journal of environmental quality, 35(4), 1566-1575.

Powell, L. M., Slater, S., Mirtcheva, D., Bao, Y., & Chaloupka, F. J. (2007). Food store availability and neighborhood characteristics in the United States. Preventive medicine, 44(3), 189-195.

Preservation Green Lab. (2016, November). The Atlas of ReUrbanism, Buildings and blocks in American cities. Retrieved from https://forum.savingplaces.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=4219579b-fd10-8cea-1fd1-c8763bb07d81&forceDialog=0

Proffitt, D. G., Bartholomew, K., Ewing, R., & Miller, H. J. (2019). Accessibility planning in American metropolitan areas: Are we there yet?. Urban Studies, 56(1), 167-192.

Pushkar, A. O., Hollingworth, B. J., & Miller, E. J. (2000). A multivariate regression model for estimating greenhouse gas emissions from alternative neighborhood designs. In 79th annual meeting of the Transportation Research Board, Washington, DC.

Quastel, N. (2009). Political ecologies of gentrification. Urban Geography, 30(7), 694-725.

Quigley, J. M. (1998). Urban diversity and economic growth. Journal of Economic perspectives, 12(2), 127-138.

Rabianski, J., Gibler, K., Tidwell, O. A., & Clements III, J. S. (2009). Mixed-use development: A call for research. Journal of Real Estate Literature, 17(2), 205-230.

Rafferty, J. (2015). Nepal earthquake of 2015. In Enyclopedia Britannica. Retrieved from https://www.britannica.com/topic/Nepal-earthquake-of-2015

Rajagopalan, P., Lim, K. C., & Jamei, E. (2014). Urban heat island and wind flow characteristics of a tropical city. Solar Energy, 107, 159-170.

Rakowska, A., Wong, K. C., Townsend, T., Chan, K. L., Westerdahl, D., Ng, S., ... & Ning, Z. (2014). Impact of traffic volume and composition on the air quality and pedestrian exposure in urban street canyon. Atmospheric Environment, 98, 260-270.

Ramanathan, V., & Feng, Y. (2009). Air pollution, greenhouse gases and climate change: Global and regional perspectives. Atmospheric environment, 43(1), 37-50.

Raven, J. (2011). Cooling the public realm: climate-resilient urban design. In Resilient Cities (pp. 451-463). Springer, Dordrecht.

Redmond, L. S., & Mokhtarian, P. L. (2001). The positive utility of the commute: modeling ideal commute time and relative desired commute amount. Transportation, 28(2), 179-205.

Reinmoeller, P., & Van Baardwijk, N. (2005). The link between diversity and resilience. MIT Sloan Management Review, 46(4), 61.

Reklaitiene, R., Grazuleviciene, R., Dedele, A., Virviciute, D., Vensloviene, J., Tamosiunas, A., ... & Bernotiene, G. (2014). The relationship of green space, depressive symptoms and perceived general health in urban population. Scandinavian journal of public health, 42(7), 669-676.

Renne, J. L., Tolford, T., Hamidi, S., & Ewing, R. (2016). The cost and affordability paradox of transit-oriented development: A comparison of housing and transportation costs across transit-oriented development, hybrid and transit-adjacent development station typologies. Housing Policy Debate, 26(4-5), 819-834.

Rentals.ca & Bullpen Consulting (2019, July). July 2019 Rent Report. Retrieved from https://rentals.ca/national-rent-report#municipal-rental-rates

Resch, E., Bohne, R. A., Kvamsdal, T., & Lohne, J. (2016). Impact of urban density and building height on energy use in cities. Energy Procedia, 96, 800-814.

Rethink Wood. (2015, April). Evaluating the Carbon Footprint of Wood Buildings: Reducing greenhouse gases with high-performance structures. Retrieved from https://www.awc.org/pdf/education/gb/ReThinkMag-GB500A-EvaluatingCarbonFootprint-1810.pdf

Reymão, M. S. F., Cury, P. M., Lichtenfels, A. J. F. C., Lemos, M., Battlehner, C. N., Conceição, G. M. S., ... & Böhm, G. M. (1997). Urban air pollution enhances the formation of urethane-induced lung tumors in mice. Environmental research, 74(2), 150-158.

Riddell, T. (2017, August). Why Recycling Construction Materials is Important for Your Business. Retrieved from https://esub.com/recycling-construction-materials-important-business/

Rizwan, A. M., Dennis, L. Y., & Chunho, L. I. U. (2008). A review on the generation, determination and mitigation of Urban Heat Island. Journal of Environmental Sciences, 20(1), 120-128.

Rockström, J. (2003). Resilience building and water demand management for drought mitigation. Physics and Chemistry of the Earth, Parts A/B/C, 28(20-27), 869-877.

Roe, J., Thompson, C., Aspinall, P., Brewer, M., Duff, E., Miller, D., ... & Clow, A. (2013). Green space and stress: evidence from cortisol measures in deprived urban communities. International journal of environmental research and public health, 10(9), 4086-4103.

Roehr, D., Laurenz, J., & Kong, Y. (2008). Green Envelopes. In Proceedings of the 2008 International LID Conference (pp. 16-19).

Roh, S., & Tae, S. (2016). Building Simplified Life Cycle CO2 Emissions Assessment Tool (B-SCAT) to Support Low-Carbon Building Design in South Korea. Sustainability, 8(6), 567.

Rozworski, M. (2019, June 14). The roots of our housing crisis: Austerity, debt and extreme speculation. Retrieved from https://www.policynote.ca/the-roots-of-our-housing-crisis-austerity-debt-and-extreme-speculation/

Rueda, S. (2012). Ecological Urbanism. Retrieved from https://www.vitoria-gasteiz.org/wb021/http/contenidosEstaticos/adjuntos/es/80/86/38086.pdf

Rupasingha, A. (2013). Locally owned: Do local business ownership and size matter for local economic well-being? (No. 2013-01). Federal Reserve Bank of Atlanta.

Sailer, K., & McCulloh, I. (2012). Social networks and spatial configuration—How office layouts drive social interaction. Social networks, 34(1), 47-58.

Sallis, J. F., Frank, L. D., Saelens, B. E., & Kraft, M. K. (2004). Active transportation and physical activity: opportunities for collaboration on transportation and public health research. Transportation Research Part A: Policy and Practice, 38(4), 249-268.

Sallis, J. F., Saelens, B. E., Frank, L. D., Conway, T. L., Slymen, D. J., Cain, K. L., ... & Kerr, J. (2009). Neighborhood built environment and income: examining multiple health outcomes. Social science & medicine, 68(7), 1285-1293.

Salviati, C. (2018, September). What Can Old Housing Tell Us About the Future of Affordability? Rentonomics. Retrieved from https://www.apartmentlist.com/rentonomics/older-buildings-losing-affordability/

Sarkar, S. (2003). Qualitative evaluation of comfort needs in urban walkways in major activity centers. Transportation Quarterly, 57(4), 39-59.

Schroeder, H. W. (2011). Does beauty still matter? Experiential and utilitarian values of urban trees. In In: Trees, people and the built environment. Proceedings of the Urban Trees Research Conference; 2011 April 13-14; Edgbaston, Birmingham, UK. Institute of Chartered Foresters: 159-165.(pp. 159-165).

Schueler, T. (1994). The importance of imperviousness. Watershed protection techniques, 1(3), 100-101.

Schultheiss, B., Sanders, R., Judelman, B., Boudart, J., Blackburn, L., Brookshire, K., … & Embry, M. (2018). Literature Review: Resource Guide for Separating Bicyclists from Traffic. Retrieved from https://safety.fhwa.dot.gov/ped_bike/tools_solve/docs/fhwasa18030.pdf

Schwela, D. H. (2001). The new world health organization guidelines for community noise. Noise Control Engineering Journal, 49(4), 193-198. doi:10.3397/1.2839659

Seagate Structures Ltd. (2017). Mass timber vs. concrete comparison chart. Retrieved from https://seagatestructures.com/wp-content/uploads/2017/10/Seagate-Structures-Mass-Timber-vs-Concrete-Comparison-Chart-TaskChecklist-28129.pdf?ct=t(Come_Join_Us5_9_2017)

Searle, G. (2010). Too concentrated? The planned distribution of residential density in SEQ. Australian Planner, 47(3), 135-141.

Seinfeld, J. H., & Pandis, S. N. (2016). Atmospheric chemistry and physics: from air pollution to climate change. John Wiley & Sons.

Shams, S., Mahmud, K., & Al-Amin, M. (2011). A comparative analysis of building materials for sustainable construction with emphasis on CO 2 reduction. International Journal of Environment and Sustainable Development, 10(4), 364-374.

Sharifi, A., & Yamagata, Y. (2014). Resilient urban planning: Major principles and criteria. Energy Procedia, 61, 1491-1495.

Sharifi, A., & Yamagata, Y. (2016). Principles and criteria for assessing urban energy resilience: A literature review. Renewable and Sustainable Energy Reviews, 60, 1654-1677.

Sharifi, A., Chelleri, L., Fox-Lent, C., Grafakos, S., Pathak, M., Olazabal, M., ... & Yamagata, Y. (2017). Conceptualizing dimensions and characteristics of urban resilience: insights from a co-design process. Sustainability, 9(6), 1032.

Shashank, A. (2017). Walking and connectivity: unpacking measures of the built environment. Retrieved from https://pdfs.semanticscholar.org/b710/ad9ef205ea95a4e3a21ef1bab4327ab2b473.pdf

Shield, B. M., & Dockrell, J. E. (2008). The effects of environmental and classroom noise on the academic attainments of primary school children. The Journal of the Acoustical Society of America, 123(1), 133-144.

Siavash, Y. S. (2016). Achieving Urban Resilience: Through Urban Design and Planning Principles (Doctoral dissertation, Oxford Brookes University).

Siemens. (2013). Toolkit for Resilient Cities. Retrieved from https://assets.new.siemens.com/siemens/assets/public.1543066657.641ee2256c5a0d5919d1aa3094a701f6ec9c3f90.toolkit-for-resilient-cities.pdf

Siemers, B. M., & Schaub, A. (2010). Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. Proceedings of the Royal Society B: Biological Sciences, 278(1712), 1646-1652.

Sing, N.S. (2016). Effectiveness of Density Bonusing in Securing Affordable Housing: A study of Toronto Downtown and waterfront area. Retrieved from https://ecologicaldesignlab.ca/site/uploads/2018/02/Shakya-Singh-Nisha-1.pdf

Singh, N., & Davar, S. C. (2004). Noise pollution-sources, effects and control. Journal of Human Ecology, 16(3), 181-187.

Singh, V. S., Pandey, D. N., & Chaudhry, P. (2010). Urban forests and open green spaces: lessons for Jaipur, Rajasthan India (pp. 1-18). Jaipur: Rajasthan State Pollution Control Board.

Sivell, P. M., Reeves, S. J., Baldachin, L., & Brightman, T. G. (2008). Climate change resilience indicators. Client project report CPR, 117.

Smith, R., Griffin, G. and Rice, T. (2015). Solid Timber Construction Process Practice Performance. OffSite Studies. Retrieved from: https://cdn.ymaws.com/www.nibs.org/resource/resmgr/OSCC/OffSite_Studies_STC.pdf

Somerville, C. T., & Holmes, C. (2001). Dynamics of the affordable housing stock: Microdata analysis of filtering. Journal of Housing Research, 12(1), 115-140.

Sozer, H. (2010). Improving energy efficiency through the design of the building envelope. Building and environment, 45(12), 2581-2593.

Staddon, C., Ward, S., De Vito, L., Zuniga-Teran, A., Gerlak, A. K., Schoeman, Y., ... & Booth, G. (2018). Contributions of green infrastructure to enhancing urban resilience. Environment Systems and Decisions, 38(3), 330-338.

Stamen, T. (1993). Graffiti deterrent proposed by horticulturalist [Press release]. Riverside: University of California, Riverside.

Stangl, P., & Guinn, J. M. (2011). Neighborhood design, connectivity assessment and obstruction. URBAN DESIGN International, 16(4), 285-296. doi:10.1057/udi.2011.14

Stansfeld, S. A., & Matheson, M. P. (2003). Noise pollution: non-auditory effects on health. British medical bulletin, 68(1), 243-257.

Statista. (2019). Monthly average insurance cost of owned home in British Columbia 2016 value. Retrieved from https://www.statista.com/statistics/580597/owned-home-insurance-cost-bc-by-home-value/

Statistics Canada. (2017). Journey to work: Key results from the 2016 Census. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/171129/dq171129c-eng.htm#targetText=Commuters%20spent%20an%20average%20of,minutes%20for%20public%20transit%20commuters.

Statistics Canada. (2018). Survey of Household Spending, 2017. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/181212/dq181212a-eng.htm

Statistics Canada. (2019). Labour force characteristics by province, monthly, seasonally adjusted. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1410028703

Stephens, K., Graham, P., & Reid, D. (2002). Stormwater Planning: A Guidebook for British Columbia. Retrieved from file:///C:/Users/pok51/Downloads/stormwater_planning_guidebook_for_bc.pdf

Stewart, G. H., Meurk, C. D., Ignatieva, M. E., Buckley, H. L., Magueur, A., Case, B. S., ... & Parker, M. (2009). Urban biotopes of Aotearoa New Zealand (URBANZ) II: floristics, biodiversity and conservation values of urban residential and public woodlands, Christchurch. Urban Forestry & Urban Greening, 8(3), 149-162.

Stewart, I. D. (2011). A systematic review and scientific critique of methodology in modern urban heat island literature. International Journal of Climatology, 31(2), 200-217.

Stiefel, L., Iatarola, P., Fruchter, N., & Berne, R. (1998). The Effects of Size of Student Body on School Costs and Performance in New York City High Schools.

St-Louis, E., Manaugh, K., van Lierop, D., & El-Geneidy, A. (2014). The happy commuter: A comparison of commuter satisfaction across modes. Transportation research part F: traffic psychology and behaviour, 26, 160-170.

Stone Jr, B., Mednick, A. C., Holloway, T., & Spak, S. N. (2007). Is compact growth good for air quality?. Journal of the American Planning Association, 73(4), 404-418.

Stone, B., & Norman, J. M. (2006). Land use planning and surface heat island formation: A parcel-based radiation flux approach. Atmospheric Environment, 40(19), 3561-3573.

Stone, J., Brian, & Rodgers, M. O. (2001). Urban form and thermal efficiency. Journal of the American Planning Association, 67(2), 186.

Stoy, C., & Schalcher, H. R. (2007). Residential building projects: Building cost indicators and drivers. Journal of construction engineering and management, 133(2), 139-145.

Sturm, R., & Cohen, D. (2014). Proximity to urban parks and mental health. The journal of mental health policy and economics, 17(1), 19.

Suárez, M., Gómez-Baggethun, E., Benayas, J., & Tilbury, D. (2016). Towards an urban resilience Index: a case study in 50 Spanish cities. Sustainability, 8(8), 774.

Subramani, T., Kavitha, M., & Sivaraj, K. P. (2012). Modelling of traffic noise pollution. International journal of Engineering research and applications, 2(3), 3175-3182.

Sugiyama, T., Cerin, E., Owen, N., Oyeyemi, A. L., Conway, T. L., Van Dyck, D., ... & Mitáš, J. (2014). Perceived neighbourhood environmental attributes associated with adults′ recreational walking: IPEN Adult study in 12 countries. Health & place, 28, 22-30.

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2008). Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships?. Journal of Epidemiology & Community Health, 62(5), e9-e9.

Sullivan, W. C., Kuo, F. E., & Depooter, S. F. (2004). The fruit of urban nature: Vital neighborhood spaces. Environment and behavior, 36(5), 678-700.

SWA. (2019). Field Guide to Life in Urban Plazas: A Study of New York City. Retrieved from https://live-swa-2019.pantheonsite.io/wp-content/uploads/2019/08/Field-Guide-to-Life-in-Urban-Plazas_digital1.pdf

Sweden Green Building Council. (2018). CityLab Action Guide – Version 2.0. Retrieved from http://www.decodeprojektet.se/media/1167/eng-citylabactionguide-180516-webb_com.pdf

Swift, P., Painter, D., & Goldstein, M. (1997). Residential street typology and injury accident frequency. Swift and Associates.

Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. Energy and buildings, 25(2), 99-103.

Talen, E., & Knaap, G. (2003). Legalizing smart growth: An empirical study of land use regulation in Illinois. Journal of Planning Education and Research, 22(4), 345-359.

Talen, E., & Koschinsky, J. (2014). Compact, walkable, diverse neighborhoods: Assessing effects on residents. Housing Policy Debate, 24(4), 717-750.

Tam, V. W. (2011). Rate of reusable and recyclable waste in construction. Open Waste Management Journal, 4(1), 28-32.

Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., ... & Chen, H. (2010). The urban heat island and its impact on heat waves and human health in Shanghai. International journal of biometeorology, 54(1), 75-84.

Tang, J., McNabola, A., Misstear, B., Pilla, F., & Alam, M. (2019). Assessing the impact of vehicle speed limits and fleet composition on air quality near a school. International journal of environmental research and public health, 16(1), 149.

Tang, U. W., & Wang, Z. S. (2007). Influences of urban forms on traffic-induced noise and air pollution: Results from a modelling system. Environmental Modelling & Software, 22(12), 1750-1764.

Tanner, T., Mitchell, T., Polack, E., & Guenther, B. (2009). Urban governance for adaptation: assessing climate change resilience in ten Asian cities. IDS Working Papers, 2009(315), 01-47.

Taslim, S., Parapari, D. M., & Shafaghat, A. (2015). Urban Design Guidelines to Mitigate Urban Heat Island (UHI) Effects In Hot-Dry Cities. Jurnal Teknologi, 74(4).

Tavakoli, A. (2017). Supporting friendlier, more neighbourly multi-unit buildings in Vancouver. Retrieved from https://sustain.ubc.ca/sites/sustain.ubc.ca/files/GCS/2017_GCS/Final_Reports/Supporting%20friendlier%20more%20neighbourly%20multi-unit%20buildings%20in%20Vancouver_Tavakoli_%202017%20GCS.pdf

Taylor, A. F., Kuo, F. E., Spencer, C., & Blades, M. (2006). Is contact with nature important for healthy child development? State of the evidence. Children and their environments: Learning, using and designing spaces, 124.

Taylorsville City, Utah. (2019). Chapter 13.12: Traditional Neighbourhood Development Overlay Zone. In Taylorsville, Utah: City Code. Retrieved from https://www.sterlingcodifiers.com/codebook/m_index.php?book_id=540

Tebaldi, C., Strauss, B. H., & Zervas, C. E. (2012). Modelling sea level rise impacts on storm surges along US coasts. Environmental Research Letters, 7(1), 014032.

Tejera, G., Rodríguez, B., Armas, C., & Rodríguez, A. (2018). Wildlife-vehicle collisions in Lanzarote Biosphere Reserve, Canary Islands. PloS one, 13(3), e0192731.

Teshnizi, Z. (2019). Policy Research on Reducing the Embodied Emissions of New Buildings in Vancouver. Retrieved from https://vancouver.ca/files/cov/cov-embodied-carbon-policy-review-report.pdf

The Mortgage Group. (2019, May 8). Compare Canadian Mortgage Rates. Retrieved from https://www.superbrokers.ca/tools/mortgage-rates-comparison/

Thompson, C. W., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. Landscape and urban planning, 105(3), 221-229.

Thompson, C. W., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. Landscape and urban planning, 105(3), 221-229.

Thormark, C. (2000). Environmental analysis of a building with reused building materials. International Journal of Low Energy & Sustainable Building, 1.

Thwaites, K., Helleur, E., & Simkins, I. M. (2005). Restorative urban open space: Exploring the spatial configuration of human emotional fulfilment in urban open space. Landscape Research, 30(4), 525-547.

Tischendorf, L., & Fahrig, L. (2000). On the usage and measurement of landscape connectivity. Oikos, 90(1), 7-19.

Toderian, B. (2015, October 21). There aren't many #placemaking tools that are as cheap, simple & effective as #movablechairs. #BryantPark #SummitNYC. Retrieved from https://twitter.com/BrentToderian/status/658751071720837120

Toftager, M., Ekholm, O., Schipperijn, J., Stigsdotter, U., Bentsen, P., Grønbæk, M., ... & Kamper-Jørgensen, F. (2011). Distance to green space and physical activity: a Danish national representative survey. Journal of Physical Activity and Health, 8(6), 741-749.

Tong, Z., Baldauf, R. W., Isakov, V., Deshmukh, P., & Zhang, K. M. (2016). Roadside vegetation barrier designs to mitigate near-road air pollution impacts. Science of the Total Environment, 541, 920-927.

Towers, G. (2002). The implications of housing density. Challenges and Opportunities in Housing: New Concepts, Policies and Initiatives, CIB WC, 69.

TransLink. (2012). Transit-Orientated Communities Design Guidelines: Creating more livable places around transit in Metro Vancouver. Retrieved from https://www.translink.ca/~/media/documents/plans_and_projects/transit_oriented_communities/transit_oriented_communities_design_guidelines.ashx

Transport for London. (2011). Stricter emissions standards for central or inner London: A provisional assessment of potential feasibility and effectiveness.

Treado, C. D., & Giarratani, F. (2008). Intermediate steel-industry suppliers in the Pittsburgh region: a cluster-based analysis of regional economic resilience. Economic Development Quarterly, 22(1), 63-75.

Treloar, G. J., Fay, R., Ilozor, B., & Love, P. E. (2001). An analysis of the embodied energy of office buildings by height. Facilities, 19(5/6), 204-214.

Tumlin, J., & Millard-Ball, A. (2003). How to make transit-oriented development work. PLANNING-CHICAGO-, 69(5), 14-19.

Tyler, S., & Moench, M. (2012). A framework for urban climate resilience. Climate and development, 4(4), 311-326.

U.S. Department of Transportation. (2015). Traffic Calming to Slow Vehicle Speeds. https://www.transportation.gov/mission/health/Traffic-Calming-to-Slow-Vehicle-Speeds

U.S. Energy Information Administration (EIA). (2016). Commercial Buildings Energy Consumption Survey (CBECS). Retrieved from https://www.eia.gov/consumption/commercial/data/2012/bc/cfm/b2.php

U.S. Green Building Council. (2019). LEED v4.1 Cities and Communities: Plan and Design. Retrieved from https://new.usgbc.org/leed-v41#cities-and-communities

Uejio, C. K., Wilhelmi, O. V., Golden, J. S., Mills, D. M., Gulino, S. P., & Samenow, J. P. (2011). Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability. Health & Place, 17(2), 498-507.

Ulmer, J. M., Wolf, K. L., Backman, D. R., Tretheway, R. L., Blain, C. J., O'Neil-Dunne, J. P., & Frank, L. D. (2016). Multiple health benefits of urban tree canopy: The mounting evidence for a green prescription. Health & Place, 42, 54-62.

UN Environment and International Energy Agency (UNIEP) .(2017). Towards a zero-emission, efficient, and resilient buildings and construction sector, Global Status Report 2017

UN-Habitat. (2013). The relevance of street patterns and public space in urban areas. UN-Habitat Working Paper April 2013. Retrieved from http://mirror.unhabitat.org/downloads/docs/StreetPatterns.pdf

UN-Habitat. (n.d.). City Resilience Profiling Tool: Guide, Retrieved from http://urbanresiliencehub.org/wp-content/uploads/2018/02/CRPT-Guide.pdf

United Nations Environment Programme (UNEP). (n.d.). Energy Efficiency For Buildings. Retrieved from http://www.studiocollantin.eu/pdf/UNEP%20Info%20sheet%20-%20EE%20Buildings.pdf

United Nations. (2015). 2030 Agenda for Sustainable Development. Retrieved from https://sustainabledevelopment.un.org/sdgs

Urban Land Institute. (n.d.). Resilience Parks and Open Spaces. Delveoping Urban Resilience. Retrieved from https://developingresilience.uli.org/themes/resilient-parks-and-open-spaces/

Urban Strategies Inc. (2008). Sustainable Community Design. Vaughan Tomorrow: Background Paper. Retrieved from https://www.vaughan.ca/projects/policy_planning_projects/General%20Documents/Background%20Papers/Additional%20Studies%20and%20Presentations/18Sustainability2.pdf

US Green Building Council. (2009). LEED 2009 for Neighbourhood Development.

Van Dyck, D., Cardon, G., Deforche, B., Sallis, J. F., Owen, N., & De Bourdeaudhuij, I. (2010). Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. Preventive medicine, 50, S74-S79.

Van Eck, J. R., & Koomen, E. (2008). Characterising urban concentration and land-use diversity in simulations of future land use. The Annals of Regional Science, 42(1), 123-140.

Van Kamp, I., & Davies, H. (2013). Noise and health in vulnerable groups: a review. Noise and health, 15(64), 153.

Vanaken, G. J., & Danckaerts, M. (2018). Impact of green space exposure on children's and adolescents' mental health: A systematic review. International journal of environmental research and public health, 15(12), 2668.

Vancouver Coastal Health. (2018). Design Resource for Child Care Facilities. Retrieved from http://www.vch.ca/Documents/Design-resource-for-Child-care-facilities.pdf#targetText=Adjacent%20Uses%20%2D%20Where%20possible%2C%20it,%2C%20schools%2C%20libraries%20and%20parks.

Vandell, D. L., Belsky, J., Burchinal, M., Steinberg, L., Vandergrift, N., & NICHD Early Child Care Research Network. (2010). Do effects of early child care extend to age 15 years? Results from the NICHD study of early child care and youth development. Child development, 81(3), 737-756.

Vander Ark, T. (2002). The case for small high schools. Educational Leadership, 59(5), 55-59.

Vårheim, A. (2016). A note on resilience perspectives in public library research: Paths towards research agendas. Proceedings from the Document Academy, 3(2), 12.

Velasco, E., Roth, M., Norford, L., & Molina, L. T. (2016). Does urban vegetation enhance carbon sequestration?. Landscape and urban planning, 148, 99-107.

Villanueva, K., Badland, H., Hooper, P., Koohsari, M. J., Mavoa, S., Davern, M., ... & Giles-Corti, B. (2015). Developing indicators of public open space to promote health and wellbeing in communities. Applied geography, 57, 112-119.

Voicu, I., & Been, V. (2008). The effect of community gardens on neighboring property values. Real Estate Economics, 36(2), 241-283.

Voogt, J. A. (2004). Urban heat islands: hotter cities.

W. H. O. (2010). Urban Planning, Environment and Health: From Evidence to Policy Action, meeting report. Copenhagen: World Health Organization.

Wachs, M., Taylor, B. D., Levine, N., & Ong, P. (1993). The changing commute: A case-study of the jobs-housing relationship over time. Urban studies, 30(10), 1711-1729.

Wakefield Acoustics Ltd. (2005, March 30). Traffic noise levels and traffic noise composition on arterial roads study: summary of unmanned noise monitoring. Retrieved from https://vancouver.ca/files/cov/2017-525-release_Part1.pdf

Wakefield Acoustics Ltd. (n.d.). City of Vancouver Noise Control Manual. Retrieved from https://vancouver.ca/files/cov/noise-control-manual.pdf

Walker, C. The Public Value of Urban Parks. Beyond Recreation: A Broader View of Urban Parks. Retrieved from https://www.wallacefoundation.org/knowledge-center/Documents/The-Public-Value-of-Urban-Parks.pdf

Walker, J. (n.d.). Wood solutions in mid-rise construction. Retrieved from http://wood-works.ca/wp-content/uploads/Wood-Solutions-in-Mid-Rise-Construction-Walker-Condensed-Report-FINAL.pdf

Wang, L., & Kanehl, P. (2003). Influences of watershed urbanization and instream habitat on macroinvertebrates in cold water streams1. Journal of the American Water Resources Association, 39(5), 1181

Wang, L., Lyons, J., Kanehi, P., Bannerman, R., & Emmons, E. (2000). watershed urbanization and changes in fish communities in southeastern wisconsin streams. Journal of the American Water Resources Association, 36(5), 1173-1189. doi:10.1111/j.1752-1688.2000.tb05719.x

Wang, Y., & Akbari, H. (2016). The effects of street tree planting on urban heat island mitigation in montreal. Sustainable Cities and Society, 27, 122-128. doi:10.1016/j.scs.2016.04.013

Warburton, D. E., Nicol, C. W., & Bredin, S. S. (2006). Health benefits of physical activity: the evidence. Cmaj, 174(6), 801-809.

Wardekker, J. A., de Jong, A., Knoop, J. M., & van der Sluijs, J. P. (2010). Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. Technological Forecasting and Social Change, 77(6), 987-998.

WCCD. (2016). ISO 37120 Indicators for Certification by the WCCD Global Cities Registry.

Weitz, J., A. P. Association, et al. (2003). “Jobs-housing balance.” American Planning Association Chicago, IL.

Wetmore, F., & Jamieson, G. (1999). Flood mitigation planning: The CRS approach. University of Boulder, Natural Hazards Research and Applications Information Center.

WHO. (2018). Air Pollution. Retrieved from https://www.who.int/airpollution/en/

Whyte, W. H. (1980). The social life of small urban spaces.

Wickens, S. (2018, May 1). Jane Jacobs: Honoured in the breach. The Globe and Mail. Retrieved from https://www.theglobeandmail.com/arts/jane-jacobs-honoured-in-the-breach/article597904/

Williams, J. (2005). Designing neighbourhoods for social interaction: The case of cohousing. Journal of Urban Design, 10(2), 195-227. doi:10.1080/13574800500086998

Wisconsin Department of Transportation. (2010). Wisconsin Guide to Pedestrian Best Practices. Retrieved from https://wisconsindot.gov/Pages/projects/multimodal/ped.aspx

Wolf, K. L. (2007). City trees and property values. Arborist News, 16(4), 34-36.

Wong, B., Snijders, A., & McClung, L. (2006, May). Recent inter-seasonal underground thermal energy storage applications in Canada. In 2006 IEEE EIC Climate Change Conference (pp. 1-7). IEEE

Wood, L., Frank, L. D., & Giles-Corti, B. (2010). Sense of community and its relationship with walking and neighborhood design. Social science & medicine, 70(9), 1381-1390.

Wood, N. (2018). Planning for Privately Owned Public Space in the Greater Toronto Area. Retrieved from https://yorkspace.library.yorku.ca/xmlui/bitstream/handle/10315/34832/MESMP02839.pdf?sequence=1&isAllowed=y

Woodcock, J., Banister, D., Edwards, P., Prentice, A. M., & Roberts, I. (2007). Energy and transport. The Lancet, 370(9592), 1078-1088.

World Health Organization (WHO). (2011). Burden of disease from environmental noise: Quantification of healthy life years lost in Europe. Retrieved from https://www.who.int/quantifying_ehimpacts/publications/e94888/en/

Wroclaw. (2016, February 10). NMF underground parking fees from Feb 15. Retrieved from https://www.wroclaw.pl/en/nmf-underground-parking-fees-from-feb-15-prices

Wu, Q., Zhang, M., & Yang, D. (2015). Jobs-housing balance: the right ratio for the right place. In Recent Developments in Chinese Urban Planning (pp. 311-333). Springer, Cham.

Wu, Z., Kong, F., Wang, Y., Sun, R., & Chen, L. (2016). The impact of greenspace on thermal comfort in a residential quarter of Beijing, China. International journal of environmental research and public health, 13(12), 1217.

Xiao, Y., & Drucker, J. (2013). Does economic diversity enhance regional disaster resilience?. Journal of the American Planning Association, 79(2), 148-160.

Yamada, I., Brown, B. B., Smith, K. R., Zick, C. D., Kowaleski-Jones, L., & Fan, J. X. (2012). Mixed land use and obesity: an empirical comparison of alternative land use measures and geographic scales. The Professional Geographer, 64(2), 157-177.

Yin, H., & Xu, J. G. (2009). Spatial accessibility and equity of parks in Shanghai. Urban Studies, 16(6), 71-76.

Yuan, F., & Bauer, M. E. (2007). Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. Remote Sensing of environment, 106(3), 375-386.

Zaff, J., & Devlin, A. S. (1998). Sense of community in housing for the elderly. Journal of community psychology, 26(4), 381-398.

Zhao, P., Chapman, R., Randal, E., & Howden-Chapman, P. (2013). Understanding resilient urban futures: a systemic modelling approach. Sustainability, 5(7), 3202-3223.

Zizzo, R., Kyriazis, J. Goodland, H. (2017). Embodied Carbon of Buildings and Infrastructure – International Policy Review. Retrieved from https://www.naturallywood.com/sites/default/files/documents/resources/embodied_carbon_in_construction_and_infrastructure_-_international_policy_review.pdf

Zolo. (2019, August). Vancouver Real Estate Trends, Housing Market Report for August 2019. Retrieved from https://www.zolo.ca/vancouver-real-estate/trends