Chapter 10
Prospects for Urban Morphology in Resilience Assessment

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10.1 Introduction

Literature on urban resilience has been shaped by scholars from an array of disciplines, thus it should be no surprise that it has become “a tapestry of definitions and meanings with little orthodoxy in its conceptualization and application” (Cutter 2016, 742). Chelleri (2012) agrees that, “it is unclear exactly what the catchword ‘resilient city’ means” (p. 288). He reviews how the concept has been understood and evolved in various disciplines from a static concept centering on “maintenance,” “recovery,” and “equilibrium” to “adaptation” and “renewal.” Acknowledging the complexity of the concept, as well as the necessity of a working definition of resilience, this chapter broadly defines the term as the ability of an urban environment to mitigate the impact of shocks on its physical infrastructure and health of its residents, to continue functioning or quickly restore essential functions, and to adapt in ways that will lessen disruptions from future events.

Scholars have moved beyond definitions of resiliency to develop indicators for use in assessing communities and assisting planning and decision-making. These have taken a wide range of forms—albeit with a great deal overlap as much is derivative from early publications. Cutter (2016) has reviewed fourteen case studies in which specific concepts and variables were applied at the community level. In order, from most common to least, these fall under the categories of economic, social, physical/infrastructural, environmental and institutional. This chapter focuses on physical factors, but includes some discussion of the others as relevant. The variables used in these indices were designed to be easily quantified across entire metropolitan areas, while variations within metropolitan areas remain something of a black box. As a result, many of the factors considered are of questionable value,

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i.e. percent of housing stock that are not mobile homes, number of hotels/motels per square mile, principle arterial miles per square mile, and number of public schools per square mile (Cutter 2010). The distinction between mobile homes and other housing may be useful for hurricanes, but less so for earthquakes. Types of housing other than mobile homes vary widely in their vulnerability to any hazard. In a major catastrophe, the number of hotels and motels per square mile in a metropolitan area is of little benefit, while those in nearby areas or states may be crucial. Miles of arterial road tells little, but the capacity of all modes of transport exiting the city, and variations in the vulnerability to different hazards are essential. Trains can far more rapidly remove people from a city than roadways. Bridges may collapse where ferry service is available. Schools may be useful shelters if built in a place and manner to be more resistant than housing, and so are other types of building. The durability, capacity and distribution of all shelter-buildings is key.

In response to the tendency to aggregate data for entire areas, a number of researchers have directly asserted the importance of addressing urban resilience at multiple scales. Yet, here too, there is no agreement as to what form this should take. Alberti and Marzluff (2004) focus on ecological resilience in urban ecosystems, suggesting that studies should move beyond simple aggregated measures of urbanization such as population density and percent impervious surface to examine land cover patterns. Pickett et al. (2004) offer lessons from the study of ecological systems for application to resilient cities, pointing to a need to examine variation within metropolis, to examine the components of this "integrated ecological-social-infrastructural system" (p. 378). They offer a "summary of tactical insights promoting dialogue between ecology, planning, and design," notably more interdisciplinary dialogue. Vogel and O'Brien (2004) note that vulnerability is scale dependent and consider the levels of the individual, household, region and system. Novotny et al. (2010) proposes five urban planning and design strategies for building urban resilience, one being "multiscale networks." Their "strategies for building urban resilience capacity" include green streets, stormwater wetlands, gray water recycling, and urban bioreserves to name a few. Chelleri (2012) suggests adopting the Panarchy concept to address the "complex cross-scale effects between neighborhoods, suburbs, and the metropolitan region" (p. 295).

In fact, there are ready-made methods for breaking the metropolitan continuum into discrete units of analysis. The field of urban morphology has already done so. Like resiliency, this field has drawn researchers from diverse academic disciplines, who have generated an array of methods and purposes. Nonetheless, it is dominated by a few schools of thought and many attributes are widespread within the literature. Urban morphology offers a ready-made hierarchy of elements for examining the middle-scales that have received little attention in the study of resiliency. Though morphology examines the physical attributes of a city, data on social or economic variables can be keyed to these. The next section will review some fundamental aspects of urban morphology. The section after this will examine how some work in resiliency has already worked with these scales, and suggests how this could be fit into a standardized framework.

10.2 Urban Morphology

Gauthier and Gillard (2006) provide an overview of the extremely diverse field of urban morphology, including “scientific studies concerned with the city as an artifact and spatial form” to “urban design normative contributions [that] aim at devising an urban form that has yet to be built” (pp. 46–47). Urban morphology has been found applicable to such diverse fields as architecture, urban design, historic preservation, archaeology, urban history, and economics. The range of methodologies is extreme, from very general concepts for global application (Lynch) to the development of a system of notation for a specific topic (Satoh 1997). Despite a variety of techniques, and some completely unique approaches, two schools of thought have dominated the field. The English school heavily shaped by its most prominent theoretician, Conzen, and the Italian school, heavily shaped by the work of Muratori and Caniggia. Both work with a hierarchy of scales, and there is considerable overlap, but also some significant differences. In Conzen’s approach:

> The town plan consists of the street system, plot pattern and building arrangement. The plot pattern corresponds to an arrangement of contiguous plots, divided into street-blocks bounded partly or wholly by street lines. Conzen’s system also includes the plot series, a row of plots each with its own frontage placed contiguously along the same street line. … Combinations of streets, plots and block plans form plan-units characterized by morphological homogeneity, but also taking account of land use and era of origin. Plan divisions are groups of plan units with similar characteristics, again including land use and age. (Osmond 2010, 7)

In contrast, Caniggia emphasizes the emergence of building types, examining several scales comprising buildings (elements, elementary structures, and structure systems), and how building types constitute urban tissue (lot, street and pertinent strip) which in turn constitutes districts. The importance of working through multiple-scales and their relations is emphasized. A city cannot be comprehended as an agglomeration of beams and bricks. Effective interpretation for a given purpose depends on choosing the correct scale(s) to work with for the given purpose (Caniggia and Maffei 2001).

A recent application of morphological technique that illustrates this point is the development of form-based codes as an alternative to zoning for land use in the Europe and the United States (Parolek et al. 2008). While several approaches are evident, they all focus on smaller scales, from the neighborhood down to building volumes, some including architectural details, such as fenestration patterns. Some center on building types and work to larger and smaller scales. Others center on the interface between the public and private realm, with street types that guide development from building facade to building facade, leaving the design of the spaces behind the facade with great flexibility. Neither is inherently superior, but either could be advantageous depending on the context and the goal of the code.

Thus, the potential application of morphological techniques to the study of resilience must consider purpose and scale. Caniggia’s statement on scale is of particular interest regarding resilience assessment tools as they typically define variables at the metropolitan level only (i.e. miles of arterial road and number of public schools per square mile for a metropolitan area) and lack any middle-scales. A review of the field of urban morphology reveals that the approach—including the scales incorporated and the definition of formal elements—is shaped by the purpose of the study. Thus, the ideal solution would not be to copy an existing format, but to use these as a base. McGlynn and Samuels (2000) touch on this issue regarding the potential use of morphology to inform planners and builders who seek to regulate development to retain local character. They suggest "sieving" information about the local environment through frameworks of morphology to identify what is important and how it is inter-related. Factors affecting resilience are complex and their definition remains a work in progress. Thus, the approach taken here is to examine some of the literature addressing substantive issues in resilience and urban form and perform a simple "sieving" process to suggest directions for the potential application of scale and hierarchy to both the study of resilience and planning for resilience. It is not possible to examine all threats to urban resiliency, so three have been chosen for demonstrative purposes.

10.3 Morphology and Resiliency

Researchers have examined various dimensions of threats to urban life and property, such as earthquakes, fires, severe wind events, tsunamis, river flooding, and heat waves. A subset of this work focuses on changes to the physical city that could help reduce impacts, enable evacuation or provide safe havens, or facilitate recovery. This section reviews literature on resiliency and three natural phenomena: heat waves, flooding, and wind events. There is considerable evidence for the significance of interventions at multiple scales, their inter-relatedness and the potential of morphological frameworks for organizing data.

10.3.1 Heat Waves

The potential for improved urban form to reduce heat-wave related deaths was already speculated upon in the 1970s. Schuman (1972) concluded his examination of heat wave deaths in New York and St. Louis with the suggestion that loss of life could be reduced through well-spaced parks and ponds, building design that enabled cross-ventilation in case air conditioning failed or power was rationed. More recently, the topic has attracted considerable interest due to the impending threat of increased events due to global warming. Wilhelmi and Hayes (2010) have noted:

> Spatial assessments, common in vulnerability research, often result in vulnerability index maps, where indices are constructed as cumulative composites of multiple factors. They highlight relative vulnerability within an urban boundary, but do not often provide sufficient information for communities and policy makers on specific intervention and vulnerability reduction actions. (p. 5)

They recommend examining physical, social and organizational factors in more detail than the current “broad homogenous units,” instead examining the “patchwork mosaics of neighborhoods and households within their regional context” (p. 5).

Other research delves into the details of the impact of urban form on temperature at various scales. At the largest scale, urban patterns of expansion directly contribute to the metropolitan heat island effect, with temperatures in the United States most sprawling metropolitan areas increasing at twice the rate of its most compact metropolitan areas (Stone et al. 2010). Additionally, micro-urban heat islands are evident in the most densely built areas. Hence, the most environmentally beneficial form of development on a global scale suffers the highest temperatures (Brazel 2007; Gill et al. 2007; Smargasi et al. 2009). At the district or neighborhood level, proximity to large-scale green (vegetation) and blue (water) areas reduces temperatures and heat wave-related deaths (Burkardt et al. 2016). The benefits of strategically placed medium and large green areas with development are obvious, but less intuitive is the impact of urban form on this relationship. Tall buildings and surface roughness (abrupt changes in topography, building height and gaps between buildings) can divert or slow the winds that bring cooler air through the city. Hence, building volume along with street orientation and design can limit this effect, and even create “ventilation paths” into the city from green and blue areas (Alcoforado et al. 2009; Smith and Levermore 2008). Within districts, public streets and privately-owned plazas and parking lots (parcel level) can have significantly different impacts on local temperatures depending upon their material, color and shading. Even in high density town centers, extensive tree planting can significantly reduce peak temperatures (Gill et al. 2007). Sky view factor (essentially the percent of the sky visible from the ground) also impacts the amount of cooling that occurs at night, indicating the importance of street canyon design. Buildings also contribute to local heating, particularly their roofs. Reflective surfaces, or better yet, green roofs (where drought is not an issue) can reduce these effects and the internal temperature of the building (Gill et al. 2007; Takebayashi and Moriyama 2007). Though attention has been focused on roofs in this regard, there has been increasing interest in the potential of natural green facades across the exterior walls of buildings to serve the same purposes (Köhler 2008). Fenestration pattern and design is also significant for its potential contribution to the cooling of interior spaces (Smith and Levermore 2008) and when improperly designed, its potential contribution to overheated interiors (Kim and Ryu 2015).

It is clear from this review that a range of scales are essential to limiting the impact of heat waves on the city and its residents:

(1) Building: wall & roof materials, shading elements, planting; fenestration quantity and pattern.

(2) Parcel: paving amount, materials, shading; vegetation amount and type
(3) Street & small open space: street, plaza and parking lot size, proportion, materials and planting
(4) Neighborhood and district: pattern of building heights and sizes, location of large parks and water bodies, ventilation corridors

While the urban heat island accumulates from the sum effect of all development, great variations may be evident in small areas and these have immediate impacts on residents' health and energy demands.

10.3.2 Fire

Fittingly, research and government policy on the threat to property and human life from fire has centered on individual buildings (Hadjisophocleous et al. 1998; Yung 2008) and on achieving quick response times across a city through effective fire station placement (Murray 2013; Başar et al. 2012). A secondary concern with catastrophic fires has received increased interest, particularly as a dimension of urban resilience. One focal point of interest on this topic is fire fueled by dried vegetation near the wildland-urban interface, for which the parcel is the most crucial scale. Cohen (2010) observes that the "home ignition zone," the 100′ surrounding a home where flammable vegetation and debris can accumulate is usually private property in the United States. The City of Los Angeles, which has grown into canyons deemed "very high fire hazard severity zones" has implemented a brush clearance program requiring property owners to comply with standards for maintaining vegetation on their property (City of Los Angeles 2016). In Australia, Blanci et al. (2006) have determined that trees and shrubs near residences pose a significant threat. They also found that building envelope configuration can create crevices where embers can lodge and eventually ignite the structure. Complex roof shapes with multiple ridges and valleys, re-entrant corners, decks and balconies, and unprotected windows are all points of vulnerability. Also, outbuildings and fences made of flammable material can ignite readily and transfer embers to the main building.

Another major area of concern involves fires in densely settled districts, where earthquakes or terrorism can damage water supply systems essential for fighting fires (Scawthorn et al. 2006). Navitas (2013) suggests the potential for urban design to improve fire safety in dense urban areas in Indonesia, hindering the spread of fire with building spacing and providing emergency escape paths. In Japan, similar concerns have emerged for urban areas with extensive, densely packed wooden houses (Satoh 2013). In the 1960s and 70s, planning centered on six proposed large-scale "disaster prevention bases." Each would have a minimum of 10 ha of open space protected by fireproof high-rises, and provided with emergency infrastructure (Fluchter 2003). Broad streets serving as evacuation routes to the shelters would be protected by fireproof, highrise buildings. As that approach has proven impractical, planning shifted a series of smaller refuge bases, but the evacuation issue remained problematic. Recent planning has called for 816 small-scale “disaster-proof living zones” that would enable residents to remain in or near their homes. This eliminates the need to travel for safety, preserves desirable urban fabric, and reinforce community-level organization. Zones of traditional wooden houses with narrow streets and small blocks would be surrounded by slightly taller, more fire-resistant structures separated from adjoining blocks by fire-breaks, comprised of roads, railways, waterways and greenways, capitalizing on existing structures as much as possible. The program interconnects infrastructural improvements (roads, water/green areas, buildings, disaster prevention equipment) and human activities at five scales: the house (50–300 m^2), the neighborhood (0.5–1 ha), the district (10–30 ha), the radius of daily life (living zone size, 60–80 ha), and the city (10 km^2 plus). Parks and designated community buildings are retrofit to become emergency refuges. Key routes into the zones are identified and if necessary, adapted to allow access to fire trucks. Local water storage areas ensure access if city-wide lines are damaged in an earthquake.

While the building scale has justly received a great deal of attention for fire safety, other scales are important, too:

(1) Building: materials, configuration, fenestration,
(2) Parcel: amount and type of vegetation
(3) Neighborhood and district: fire breaks, escape paths, shelters, emergency crew access paths, on-site water storage
(4) City: fire station distribution, water lines

While fireproofing buildings is an essential focus, it is clear that the spread of fire, efforts to combat it, and to protect lives involve the interplay of factors at multiple scales.

10.3.3 Flooding

Urban flooding may result from storm surges or tsunamis in coastal cities, from overflowing banks in river cities, and excess storm runoff in any city. Recent thinking in this area has called for less reliance on large infrastructure projects to protect an entire city from water in favor of a multi-tiered approach (Carbonell and Meffert 2009; Watson and Adams 2010). Rather than eliminating city-scale efforts, redundancy is obtained through measures implemented at several scales. Liao (2012) suggests the key variable is percent of land that can be flooded without damage, which may include residential areas if structures are flood proof, but may exclude open space if the soils are contaminated. Thus, the provision of open space and flood-proofing buildings are essential to improving resilience. White (2008) suggests a multi-tiered approach including blue areas for water retention, green areas for recreation doubling as water retention sites when needed, intense development in urbanized areas, limited paving on private parcels in less dense areas, flood-proofing buildings, and constructing green roofs for water retention. Lennon et al. (2014) reiterate some of these ideas, and add others. New neighborhoods could be built on raised plinths, green streets and parking areas can be designed to double as water retention areas. A design charrette for the Greenpoint section of Brooklyn, New York included blue-green corridors at the water's edge, a new esplanade, and floodable streets, making water a feature rather than a barrier (Watson and Adams 2010, 241). In response to catastrophic flooding, Mumbai has implemented a range of measures, including the designation of 120 temporary shelters for stranded people in existing schools, which are by design distributed throughout the city (Guptha 2007). The Netherlands seems to have the most developed approach to managing flood waters, with detention in compartments (areas designated for water storage with different probabilities of flooding) and green rivers (flood plains and compartments with a high probability of flooding as a first line of defense) (Vis et al. 2003). Managing flooding removes the element of surprise for residents, because when left to nature, flooding could proceed in multiple directions at once with unpredictable consequences. Rotterdam has designed an underground car park to retain 10 million liters of water, and "water plazas," public squares in which modest storms result in "streams, brooklets, and small ponds" as play areas for children, the entire plaza fills as a retention area (Mackenzie 2010).

Like the other hazards considered, flooding is most effectively addressed at multiple scales:

(1) Building: height above grade, materials, water retention (i.e. green roof, cistern)
(2) Parcel: permeability of surface, on-site retention features (i.e. swales, ponds)
(3) Street & Open Space: green streets, floodable streets, water plazas, floodable parking
(4) Neighborhood & District: flood-proof shelters, green rivers, compartmentalized areas for water control & flood storage
(5) City: undeveloped buffer areas on urban periphery, seawalls, dikes, spillways for overflow

At first glance it may appear that one could solve the issue entirely at the city-scale or building scale. Yet in the first case, any breach of the city-defenses would leave the city flooded, hence the Dutch approach at multiple-scales, and it does not address the issue of runoff generated by rainfall in the city. Solely raising every building, apart from excess expense, would not prevent flooding of city streets, halting transportation. As flooding increases and decreases incrementally, actions to retain water at multiple-scales would reduce the necessary height of buildings. Most significantly, the patchwork patterns of severe flooding and damage resulting from Hurricanes (Harvey & Katrina) in Houston and New Orleans, demonstrate great variations in vulnerability that emerge from the interplay of factors at all scales.

This brief review of literature on three hazards reveals the significance of urban form at multiple scales, and their impact upon each other. The field of urban morphology provides a vocabulary to categorize and analyze these physical elements and their relations (Table 10.1). It offers a means of breaking the urban continuum into a nested hierarchy of discrete units. Floods and fires cut amorphous,

Table 10.1 Relationship between urban form elements and hazards

	Heat wave	Fire	Flood
Fenestration	Percent glazing, orientation, shading, relation to interior spaces	Recessed, frame material & size, screening (ignition, building entry)	x
Facade	Material, surface reflectivity, shading devices, vegetative cover—green facade (increase or decrease ext. & int. temperature)	Material, re-entrant corners, projected or recessed elements, i.e. balconies, arcades (ignition)	(see building scale)
Roof	Material, surface reflectivity, vegetative cover—green roof (increase or decrease ext.& int. temperature)	Material, number and length of valleys (ignition)	Vegetative covering—green roof (reduce/slow runoff)
Building	See facade and roof scales	Fire-proofing (see facade and roof), sealable interior spaces & escape routes; Fireproof safe havens	Raised, flood-proofed, floatable
Parcel	Type and amount of vegetative cover, type and amount of paving	Type, amount & location of vegetation, debris, outbuildings (ignition)	Permeable and impermeable surface, vegetative cover
Street	Material, surface reflectivity, shading, sky view factor, ventilation path	Fire break, protected escape route	Floodable for water retention
Open spaces	Size, material, surface reflectivity, vegetative cover, water, sky view factor	Fire-proof safe havens	Permeable, impermeable, vegetative cover, floodable (runoff vs. retention)
Neighborhood/ District	Distribution of open space, distance & ventilation paths to large blue & green spaces	Station placement, backup water storage, safe haven placement	Placement in/out of flood plain, location & amount of smaller scale control measures
City	Emergency treatment facilities	Station placement, emergency treatment facilities	Large-scale infrastructure (levees, dams, spillways), emergency treatment facilities

variable paths across a city, and heat waves display irregular patterns that are suitable to depiction as an overlay on a city map. However, their interaction with the built environment, its susceptibility to damage, its potential contribution to worsening a disaster, and adaptations for improved resilience can be thought of in terms of morphological units. This seems essential to sound planning for resilience, and there are cases illustrating how a simple morphological framework can be applied in this regard. For instance, a study by the Greater London Authority determined that the urban heat island must be approached at the scale of the building & street, urban design, and city, and lists existing polity frameworks that apply to each, i.e. building regulations, area action plan, and regional spatial strategy (GLA 2006). The potential to improve resilience indices, which currently focus on entire metropolitan areas with some attention to the building scale, would seem immense, but difficult to attain.

One of the main factors limiting the application of a morphological approach for resilience indices is the ability to link data on key attributes of the built environment to hazard impacts. Yet, some researchers have started making inroads. Researchers in England have developed 29 "urban morphology types" compatible with the UK National Land Use Database and identifiable through aerial photographs. These were applied to a study of the urban heat island in Greater Manchester (population 2.5 million), along with 9 "surface cover types" as green cover does not always correspond with morphology (i.e. extensive street tree planting in a town center). Modelling the existing city and various scenarios (addition of street trees, green roofs, and other green infrastructure) demonstrated the capacity to moderate climate change impacts on the urban area (Gill et al. 2007, 2008).

Yet, the "urban morphological types" are for the most part, defined by land use, i.e. farmland, residential, retail, industry and business, transport. Subcategories attempt to deal with form. Retail is divided into two categories, "town center" and "retail," suggesting a difference between traditional urban and suburban forms. Residential is divided in low, medium and high density, which makes an essential distinction, and may be effective for the Manchester case study, but fails to effectively encompass differences in form that may be essential elsewhere. For instance, a district comprised of town houses (attached houses) may have the same density as a district comprised of garden apartments (walk-up apartments separated by swaths of parking/and/or greenspace), but the consequence of each for the heat island could vary considerably. Further, though form emerges in response to use, the latter is flexible and may change over time. A street of residential row houses may be converted to mixed use with retail and offices (Sheer 2010).

Researchers have also examined forest fire risk management in Mediterranean areas by classifying types of settlement "according to their morphology" and "types of landscape" and then combining the two into one typology (Galiana-Martin et al. 2011). This approach focused more directly on form rather than use, measuring distance between houses and extent of settlement area to define three types: towns (concentrated layout and high building density, clear differentiation from surrounding agrarian space), urbanizations (groups of residential developments removed from agrarian use) and scattered rural settlements (sets of residential buildings of low density, not necessarily forming an urban structure). The authors point out that this local scale data provides valuable information to planning for fire wildfire resilience on the regional scale.

Both of these cases rely on remote sensing to obtain smaller scale detail and link it to a larger scale analysis. The data remains course and the focus is just one hazard, but they suggest a path forward. Remote sensing and aerial photography can rather quickly deliver a great deal of information on horizontal surfaces, such as roofs, streets and open spaces. Local government plans and building records require more effort to glean information, but can provide essential complimentary data about building construction, building heights, placement of emergency facilities, etc. Combining these sources would provide detailed knowledge on urban morphology at multiple-scales, as pertinent to resilience. This would require an extensive effort and the result may never be all-encompassing. However, it would certainly advance resilience indices beyond their current state. Exploratory work is essential to move towards a standardized framework of analysis. The field of urban morphology provides a vocabulary, or multiple vocabularies, for this task. Further research is required to sieve through the details and determine which units of analysis are most important and how they relate to each other in the study of resilience.

10.4 Conclusion

Literature on planning for resilience is highly fragmented and attempts to measure metropolitan resilience remain superficial. Many researchers agree on the need to analyze resilience at multiple scales and examine their impact upon each other. Literature on resilience has examined the impacts of specific hazards multiple-scales, but individual studies remain isolated from each other. This work speaks to the importance of urban form, but lacks a vocabulary for comprehensively studying its relationship to resilience. The field of urban morphology has highly developed frameworks for studying urban form that can be used to assemble data on resilience, its aggregation and disaggregation, and impacts on smaller and larger-scale units of analysis. A few studies have begun to draw connections between these fields, opening the door to more thorough analyses. As the ability to analyze data in GIS systems has become more powerful, the potential to examine the impact of forces and responses at multiple scales exists, yet a great deal of work remains in order to realize this possibility.

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