Urban Form and Energy Resilient Strategies: A Case Study of the Manhattan Grid

Perry P.J. Yang and Steven J. Quan

Abstract The Manhattan grid is known as a testing ground of high-density urban development from the 19th century onward. Its urban form model and regulatory zoning mechanisms provide lessons for global cities in shaping their urban skylines. This chapter describes the physical form and processes that have established and characterize Manhattan's grid, focusing on the grid as a generator and framework for growth. A performance-based urban energy model is used to examine the potential for energy self-sufficiency within the current urban form structure of the Manhattan grid. To make the city more energy resilient, a transformative approach is proposed that centers on the implementation of a performance-based model of urban design, which enhances urban resiliency at the neighborhood level. The concept of panarchy is applied to address complex systems problems such as energy resiliency in cities. To design an energy resilient urban system, it is important to define a community-level action and a medium-scale framework, which allow effective systems integration and coordination among stakeholders. The framework of urban design accommodates finer-scale, bottom-up eco-initiatives, which enable agile responses to unpredictable events, such as climate-induced disasters and environmental changes.

1 Introduction

Urban resilience is becoming an increasingly pressing issue after recent natural or human-induced disasters, such as the Tōhoku earthquake and tsunami that caused the Fukushima disaster in Japan in 2011 and Hurricane Sandy, which led to major flooding and power losses, in New York City in 2012. In this chapter, we address the

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question of how cities should be planned, designed, managed and restructured to be more resilient to future changes caused by potential shocks, using the Manhattan grid as a test case. In order to better prepare for a more tumultuous and unpredictable future, a framework for designing resilient urban forms that adapt to, mitigate or prevent disasters for major cities, like New York and Tokyo, will be needed.

In order to do so, we must understand the urban physical form and structure and the historical and social contexts that have created it. Contemporary cities, however, were not necessarily designed with resiliency in mind. Urban form, street patterns, block structures and building typologies are often produced according to organizational principles other than resilience to climate change, which has only become a major topic in the past several decades. The components of urban form are not only physical, but are also impacted by social, institutional and financial factors. In the case of New York City, the urban grid structure in Manhattan, known as *the Manhattan grid*, was formed through engineering surveys of the land and infrastructure during the early 19th century and formalized in the Commissioner's Plan of 1811 (Bender 2002). Manhattan also created one of the world's earliest zoning ordinances in 1916. The current urban form of the city was influenced by infrastructural interventions, regulatory mechanisms, urban economic developments and real estate finance (see Fig. 1).

However, the events of Hurricane Sandy in 2012 demonstrated the inability of the city's urban form to respond to unexpected shocks, as the city was crippled for several days (see Figs. 2 and 3) by flooding, blackout and other effects of the storm.

Fig. 1 Zoning map of Midtown Manhattan, New York City (New York City Department of City Planning)

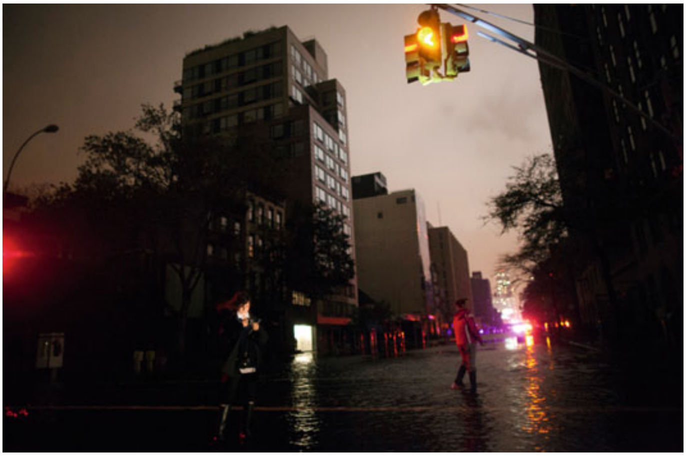

Fig. 2 Black out in New York City (New York Times, October 29, 2012)

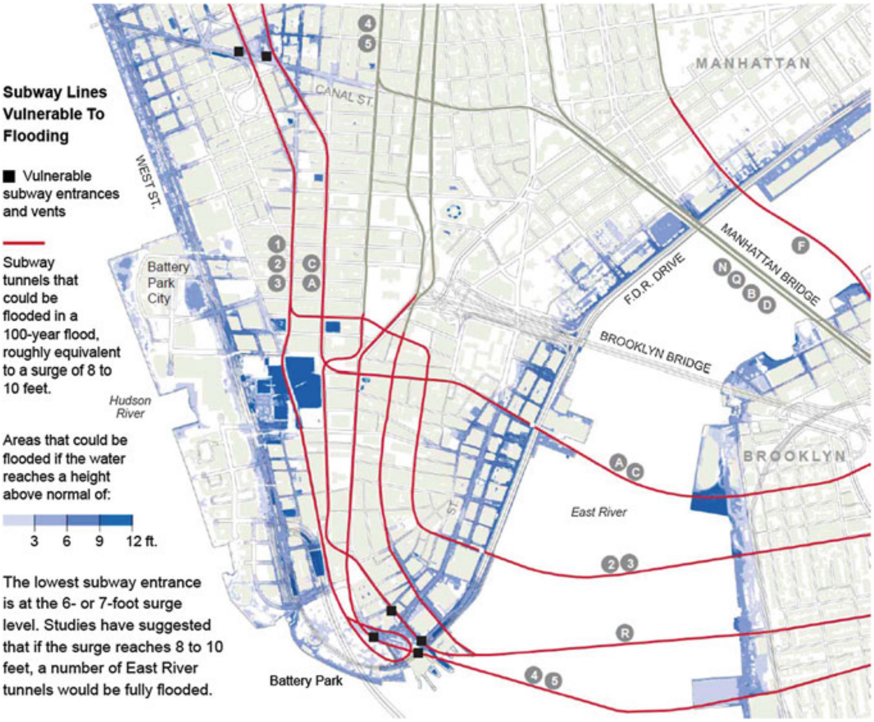

Fig. 3 Flooding over lower Manhattan during the Sandy Hurricane in 2012 (New York Times, October 29, 2012)

The continued development and increases in density within the Manhattan grid that have occurred over the past 200 years have left the city unable to adapt to unpredictable changes induced by major natural or human-made disasters, such as Hurricane Sandy. In order to transition to more resilient and sustainable systems, new organizational principles and mechanisms must be developed for the existing urban form and structure of cities.

This paper investigates how the urban form of contemporary cities, such as the Manhattan grid, function in energy performance and how urban form can be altered in order to transition to more resilient systems. We provide a brief history of Manhattan's urban grid structure, focusing on how the well-known Manhattan grid generated consequential urban form through regulatory mechanisms, such as the city's 1916 zoning ordinance and setback requirements.

2 Literature on Resilient Cities

The concept of resilience is broadly defined in many research fields including policy, ecology, engineering and planning. There is also a growing body of literature exploring how resilience is defined and connected to other concepts such as sustainability, adaptation, and transformation. Resilience is defined as the capability to absorb disturbances and impacts, e.g., extreme weather events, and the ability to self-adapt to changes (Walker et al. 2004). In other words, resilience is the ability of a system to withstand large perturbations and enable the generalized recovery from within when the system fails. However, the recovery may or may not restore the system to its original configuration; rather, the system can take on a completely new configuration that is also acceptable to the stakeholders (Maruyama 2013).

To make the concept of resilience operational, it must be translated into an operational system in actual urban contexts. *Urban Resilience* can, therefore, be defined as the ability of a city or an urban system to withstand a wide array of shocks and stresses. In order to adapt to and prepare for the effects of climate change, cities must become resilient to a wider range of shocks and stresses and adopt strategies for mitigation and adaptation to these potential shocks (Leichenko 2011). While mitigation aims to reduce the impacts of climate change, adaptation seeks to adjust the built and social environments to minimize the negative outcomes of climate change (Hamin and Gurran 2009).

The above concepts illustrate three approaches to creating a resilient city: First, urban resilience as an ecosystem is the ability of a city or urban system to absorb disturbances while retaining its identity, structure and key processes. Second, urban resilience as risk reduction focuses on enhancing the capacity of cities and infrastructure systems to quickly and effectively recover from both natural and human-made hazards. Third, urban resilience is affected by different types of institutional arrangements, and in response, resilience thinking can influence the development of improved governance mechanisms that promote adaptation to climate change (Leichenko 2011).

Urban resilience contains two other critical attributes: (1) reliability and efficiency and (2) adaptability and flexibility (McDaniels et al. 2008). The first attribute emphasizes the stability and predictability of functions and services provided by urban infrastructure systems, even under extreme or unforeseen conditions. The second attribute stresses continuous adaptation to conditions that unfold and evolve over the long lifecycle of an infrastructure system or a city (Alberts and Hayes 2003). The prominent urban designer Kevin Lynch reminds us that the meanings of both attributes are ambiguous and hard to attain (Lynch 1981).

In order to avoid this pitfall, an operational method of urban resilience is needed to define the interrelationship between urban form and infrastructure systems. The design and operation of urban infrastructure systems, such as energy systems, need to be considered in light of a city's transformation. Conventional approaches of developing infrastructure systems over fragmented, uncertain, and stochastic processes are inadequate in addressing these challenges. In order to transition to more resilient cities, an understanding of the critical interactions and interdependencies between infrastructure systems and urban compositions (such as urban form) is necessary (ASCE 2009).

To tackle the complex challenge of designing urban systems, a network configuration of buildings, infrastructure, information and behavioral systems, we draw on the concept of *panarchy*. This concept was developed by ecologists to account for the dual characteristics of eco-systems—stability and change—and address the interconnectedness across different levels of scales within cities. It deconstructs this interconnectedness by viewing a webbed, interwoven system as multiple layers of components with different levels of detail (Walker et al. 2004). A research approach based on this concept identifies a focal scale that is manageable for analyzing the relationships between sectorial infrastructures and interactions between the focal scale and its coarser scale and finer scale (Yang 2012). The concept of panarchy also provides a perspective that implies a transformative process in the system. By identifying a focal scale, we are able to form a consensus at the community-level and, therefore, make the system transformation tangible.

In this paper, we focus on building an energy resilient city that is both a resource reservoir and producer of secondary resources, rather than a linear resource-to-waste system. The concept of *urban energy harvesting* can be used as a transformative tool for developing more resilient cities (Agudelo-Vera et al. 2012). Urban design provides an interventional approach to connect fragmented elements of landscapes and material resources for enhancing urban energy harvesting capabilities. The objective of designing a resilient place is to create a system in which the urban (metabolic) functions and the urban form are well fitted to each other (Lynch 1983). Resilient urban design is an approach to enhancing the ability of a place, a community or a city to adapt to future changes in urban metabolic and system functions.

3 The Manhattan Grid: From a Non-resilient Form to a Performance-Based Resilient System?

3.1 The Manhattan Grid as a Generator of Urban Development

Manhattan's urban grid system serves as a test bed for exploring the issue of urban resilience. The grid is one of the earliest urban form structures and has been studied extensively. The well-known *Commissioners' Plan of 1811* for New York platted the city's urban form from Houston Street in the south to 155th Street on the northern end of Manhattan. The plan superimposed a street grid structure of equal-sized blocks in dimensions such as 70 by 200 m over the previous topography (see Fig. 3) (Bridges 1811). The Manhattan grid can be seen as an urban form generator, which set out the rules for the city's future urban development. The grid of streets and blocks gives the city a regular composition but may also result in monotony (Martin and March 1972). The historical development of Manhattan shows that the grid, however, did not produce a completely uniform and homogeneous urban landscape or social organization, instead it enabled extensive urban experimentation by accommodating a complex urban environment of skylines and skyscrapers (Bender 2002).

The urban grid of Manhattan laid out in the 1811 plan provided a framework of urbanization. It is a controlling factor that dictates how the city was and continues to be built. The scale and pattern of the framework affects the possible building arrangements within it. It supports the growth of overlapping patterns of human activities, which allow for different choices. The grid can accept and respond to growth and change, and accommodates organic growth without turning future urban development over to chaos. It is only through the understanding of the grid as a structuring framework that we can open up the full range of choices and opportunities (Martin and March 1972) (Fig. 4).

In what way does the grid operate as a generator or a controlling instrument in relation to urban form? How does the grid system, as a flexible framework of a city, accommodate urban growth and adapt to future change, both socially and

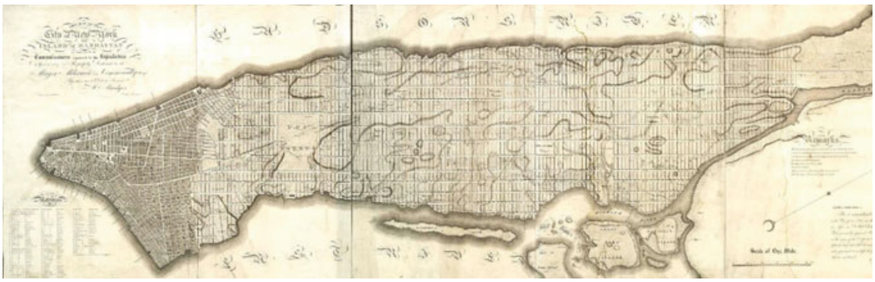

Fig. 4 The Commissioners' plan of 1811, Manhattan, New York City (Bridges 1811)

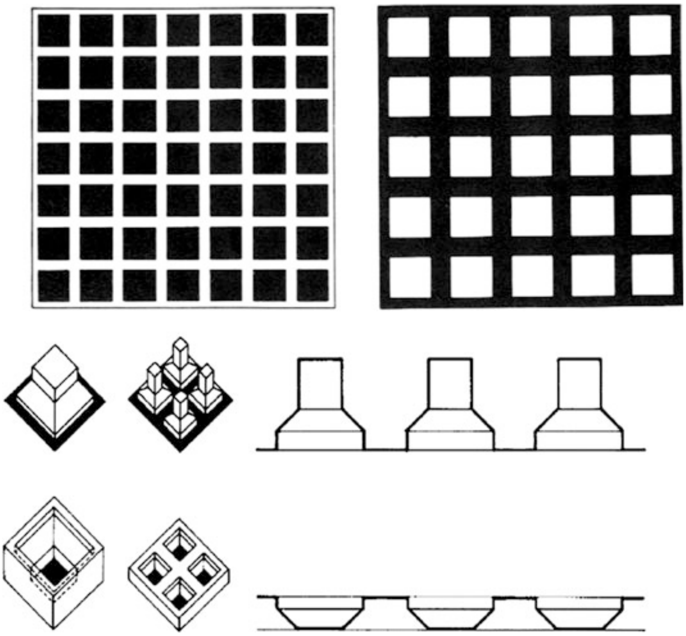

Fig. 5 The forty nine block structure and two building typologies (Martin and March 1972)

environmentally? Martin and March provided an approach to investigating geometric attributes of urban spaces and understanding the relationship between density and spatial typology. Given equal density, various urban typologies generate different effects and consequences. A simple experiment regarding the Manhattan grid was conducted to examine how the grid accommodates two distinct building typologies: the pavilion and the court, based on a fixed building density or floor area ratio (FAR). A grid system of forty nine blocks can be laid out according to the two different building typologies using the same 50 % building cover ratio (see Fig. 5). The relationship among density, urban typology and its social or environmental consequences can then be tested on the performance of urban design.

The simple experiment leads to a question of how the urban grid influences the built form of cities, which, in turn, influences their social and environmental consequences. The current Manhattan grid has developed a specific urban form with a dense skyline of tall skyscrapers from 42nd to 57th Street. What if the same total amount of building floor area were laid out using a different typology, like the courtyard type in which building blocks are arranged around the edge of an enlarged grid. Using this building typology, the original tower blocks could be lowered to an average of 7-story high courtyard blocks that accommodate the same building density (see Fig. 6) (Martin and March 1972).

The hypothetical scenarios for reforming the Manhattan grid reveal the link between urban form typology and its social and environmental impacts. However,

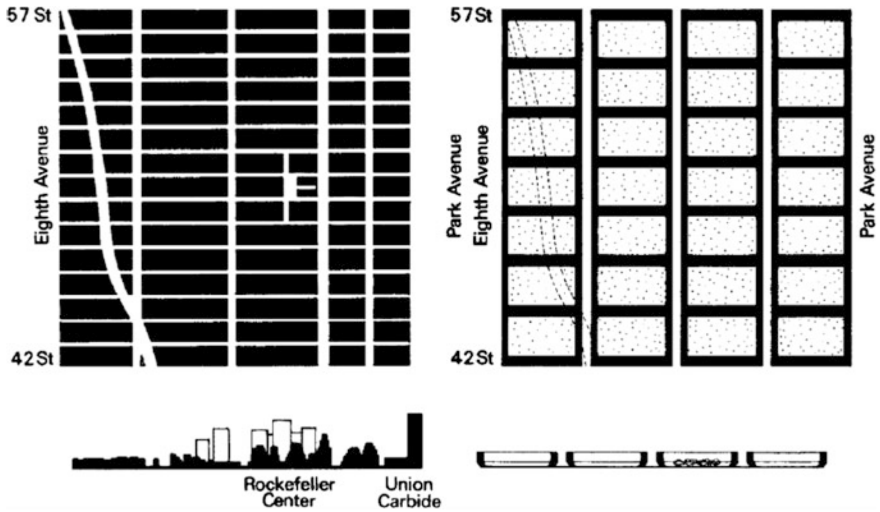

Fig. 6 The Manhattan proposal by Martin and March in the Urban Space Structure book (Martin and March 1972)

the opportunities to redesign the urban form and building typologies in Manhattan are constrained by its grid structure.

What are the advantages of the urban grid in supporting urban energy resilience, in terms of renewable energy harvesting, building energy consumption and energy distribution through the smart grid infrastructure? The form and orientation of urban blocks and buildings affects energy flows in cities, including solar availability, shading and the microclimate that affects the heat transfer between building envelopes. For example, the Manhattan grid contains a large number of east-west oriented blocks, and creates relatively wider south facing building frontage. But the climatic consequences and potential of the grid structure are not fully considered or organized to create a more resilient city.

3.2 Zoning and Setback Controls for Shaping the Urban Street Canyon

Manhattan's urban form is not solely determined by the physical grid structure. Zoning and other regulatory mechanisms also influenced the development of the city's urban form. In the early 20th century, Manhattan was plagued by congested streets, incompatible land uses, and a lack of light and clean air, the results of its intensive urban development. In order for the city to continue to grow and function efficiently, new requirements were needed to address these problems. In response to these issues, New York City created the first zoning ordinance in the United States in 1916. The zoning ordinance established three categories of land uses: residential, business and unrestricted. Zoning demonstrates the ability of regulatory mechanisms, rather than direct architectural design and engineering, to dictate urban form. The principles of zoning, land use control, restriction of building height, setback and building envelopes formed the rules that would determine future urban growth (Loukaitou and Banerjee 1998). Among them, the zoning envelope, or an imaginary spatial envelope beyond which a building could not extend, shapes the three-dimensional urban geometry of New York City. The urban form was determined or affected by the zoning envelope through land assembly and height control.

The setback control, or how building heights are limited in proportion to the width of adjoining streets, shaped the city's urban street canyons, which greatly affect urban climate. The original purpose of setback controls in Manhattan, however, was for aesthetic purpose to create horizontal monumentality within the traditional "five-story building wall" along the streets and to keep towers separate from the street wall (Bender 2002). The setback controls and desire for horizontal monumentality led architects to incorporate decorative bands and ornamental treatments on the buildings' edges, which would become key features of the Art Deco style, also known as "setback style" or "New York style" (Loukaitou and Banerjee 1998). Downtown urban form can be viewed as a container composed of functional cells. The division of downtown into functional cells, defined by zoning, ensured the stable and orderly development of the most prime land in the city, which benefits well established corporations and institutions. As a result, the downtown skylines, streetscapes and canyon-like urban geometries were defined by setback controls in many ways, which produce variation in patterns of microclimate, and would influence total performance of building energy use.

New York City's setback controls, or the width/height ratio (W/H Ratio) to use to width of the road to determine the limit of building heights, act as form-based prescriptive guidelines, and become a global model of urban form control that has been applied to many cities across the globe (see Fig. 7). But the controls impact on buildings' energy performance has received little attention. The performance of the urban form has never been measured in quantitative way or by computing tools until very recently.

Does the current Manhattan urban form contain properties of resilience, e.g. the passive resilience such as redundancy, diversity and adaptability, the active resilience like anticipatory design, modeling or business planning or the capacity for transformative recovery as was defined in the book (Maruyama 2013, 2016)? There is an inconsistency or incompatibility between the historical mechanisms such as the setback control and zoning ordinance that shaped the city's form, and the future mechanisms that will be needed to create a more resilient urban form for adapting to future climate-induced shocks and changes.

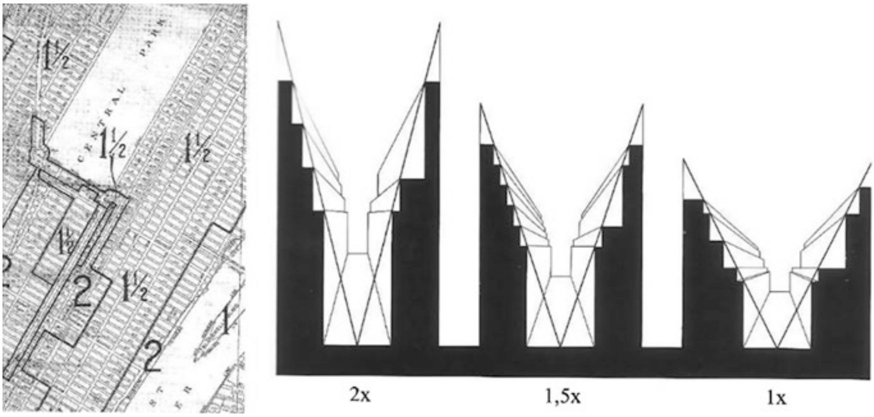

Fig. 7 *Left* Manhattan's setback control map in 1960s; *Right* Street canyons according to the setback ratio (Lehnerer 2009)

4 Urban Energy Modeling of the Manhattan Grid: Moving from a Form-Based Width/Height Ratio to a Performance-Based Energy Resiliency Ratio

4.1 Urban Energy Modeling

Streets, blocks and buildings are the elements of the urban grid system. In Manhattan's grid, the spatial arrangement of these elements reflects similarities and differences, in which the measurability of geometry, scale, performance and their transformation are critical to the making of resilient urban system. How are cities organized in space, time and across different scales? How does the design and organization of cities affect elements of system performance, such as efficiency, complexity and resilience?

We conducted urban energy modeling for the Manhattan grid to test how much total solar energy can be assimilated in the city in different locations and at different times of year. We examined 45,900 buildings within the Manhattan grid to demonstrate how the new modeling assesses each building's energy use, solar potential and energy balance in 2012, using a GIS-based urban energy balance modeling system. This method integrates the building energy modeling and solar potential modeling to provide energy consumption and production estimates and also estimates the energy balance using the self-supply ratio (solar energy production/energy use) and surplus ratio (surplus solar energy/energy use) (Quan et al. 2015b).

This modeling method expands the field of analysis from a single building to many buildings in the urban context. Overall urban energy performance cannot be estimated simply by aggregating individual building performance, as the influence of shading, microclimate changes and occupancy variations must be considered

(Quan et al. 2015b). This model accounts for the interaction between buildings and topographies through obstructions, which influence solar radiation on rooftops, as well as the buildings' energy performance (Ok 1992). Buildings' energy use are also impacted by the building's microclimates. Local air temperature and winds are modified by urban form through the increased thermal storage within buildings and impervious surfaces (Oke et al. 1991). Occupant density and behavioral patterns, which reflects the interaction between buildings and social and economic conditions, also lead to building energy variations (Al-Homoud 2001). This model accounts for all of these factors by developing three engines: a shading engine, a microclimate engine, and an occupancy engine, to estimate hourly variations in building energy use and solar energy production across Manhattan.

The urban energy modeling consists of four models: the Data Integration Model, Urban Building Energy Model, Urban Roof Solar Energy Model and Energy Balance Model. Through these models, the urban scale data are organized and refined to provide inputs for simulations. The resulting data are coupled to examine the energy balance of urban buildings, which leads to the Energy Resilience Ratio, defined as the total solar energy produced by rooftop solar panels divided by the total building energy use (see Fig. 8).

The core *Urban Building Energy Model* is based on a modified EPC calculator (Energy Performance Calculator) in ISO standards. EPC uses simplified calculation to simulate the thermodynamic processes, assuming a quasi-steady-state conditions for heat balance in each hour. It includes heat gain from internal load and solar radiation, and heat loss from ventilation, infiltration and transmission that go through the building envelope (ISO 2006; Lee 2012). Three engines in this model simulated the final inputs. The shading engine generated a set of lines of sight from each sample window point, along which maximum obstruction angles were

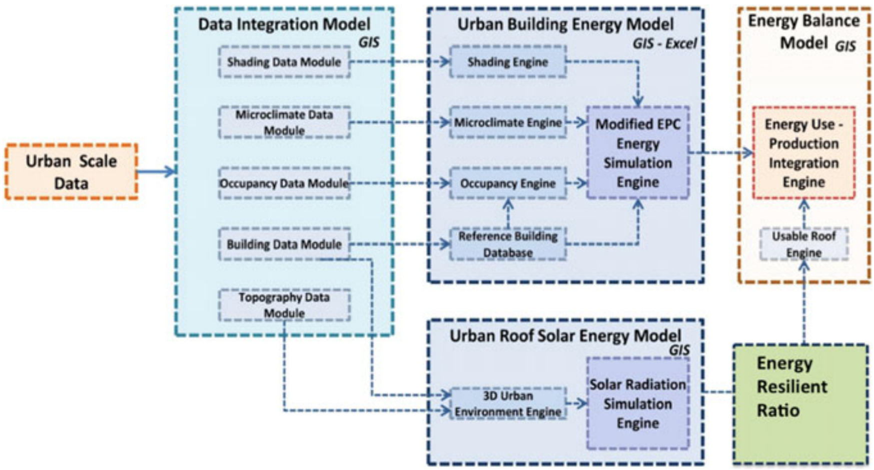

Fig. 8 A process of urban energy modeling for Manhattan grid (revised from Quan et al. 2015b)

Fig. 9 Urban energy modeling in Manhattan. *Left* Annual building energy use mapping; *Middle* Annual solar radiation mapping; *Top Right* Sample window points on the facades and the lines of sight in Gramercy neighborhood; *Bottom Right* Aggregated hourly energy balance of solar buildings in Gramercy neighborhood (Quan et al. 2015a)

calculated according to the intersection between the lines and surrounding buildings, resulting in the shading factor for each facade. The microclimate engine used parameters from the urban canyon and land cover to simulate the hourly temperature representing microclimate for each microclimate zone (Sun and Augenbroe 2014). The occupancy engine used the residence and employment information from census data to adjust the occupant density for each building based on the reference building database. With the output data from those three engines, the modified EPC engine were used to simulate the hourly energy use including electricity use and gas use of each building in Manhattan during a year. The results were then collected and further visualized in GIS to show annual energy use distribution (see Fig. 9).

The *Urban Roof Solar Energy Model* uses the tool of "Area Solar Radiation" based on the Solar Analyst in ArcGIS 10.2 as the core engine. In this model, the 3D modeling engine first transformed the buildings and topography into GIS raster files to represent the 3D urban environment. Then the tool of "Area Solar Radiation" in ArcGIS 10.2 were used to simulate the potentials of solar energy productions from solar PV panels on building rooftops and grounds with different temporal scales from annual, monthly to hourly (see Fig. 9) (Quan et al. 2015b).

Finally, *the Urban Energy Balance Model* examines the balance between the building energy use and rooftop solar energy production. This case study takes the assumption that 50 % of building roofs are used for solar energy production. The usable roof engine first identified the area of 50 % of each roof that has the most solar radiation potentials. Then the potential solar energy production was estimated assuming solar panel efficiency of 20 %. With the solar energy potentials and energy use results, the average building Energy Resilience Ratio through the year was 0.0269, meaning 2.69 % of the overall building energy demands could be met with solar energy from the buildings. However, the energy balance varies at different locations. In the case of the Gramercy neighborhood in Manhattan, the annual Energy Resilience Ratio is 0.0295, which is only a little higher than Manhattan's average as a whole. The model also demonstrates that the Energy Resilience Ratio could increase in the summer with increased solar energy production. For example, during the simulation the daily Energy Resilience Ratio in the Gramercy neighborhood on June 21 was estimated at 0.1015, significantly higher than its average ratio of 0.0295 for the entire year.

4.2 Moving from the Form-Based Width/Height Ratio to the Performance-Based Energy Resilience Ratio

The previous results show that the current energy self-supply ratio for Manhattan's grid is still low with the utilization of solar energy. During unpredictable shocks, such as hurricanes that may cause power blackouts and infrastructure breakdowns, the city and its infrastructural systems are unreliable and lack the ability to react and respond to extreme or unforeseen conditions.

How can cities be reorganized and restructured to increase adaptability and resilience? How can the urban form be transformed to be more resilient and robust, given that the current urban grid is far from self-reliant or energy resilient? The urban energy modeling demonstrates that there are variations in energy balance over space of the island and time of a year. Understanding how to exploit these variations, in order to best harvest renewable energy and increase energy performance, will be an important aspect of creating resilient and adaptable cities. The urban grid structure should be adapted to be more climate-sensitive and energy-responsive, rather than simply a form-based structure. The control of urban form making should move from prescriptive urban design guidelines to performance-oriented criteria.

The following analysis uses the previous urban energy modeling to compare the W/H Ratio as the prescriptive form-based guideline and the Energy Resilience Ratio as the performance-based indicator within the Manhattan grid.

The system boundary of the urban district for computing energy balance is defined based on the census tracts and the urban block. Census tract is a geographic unit used for census on demographic characteristics. It links geographic areas with population and societal datasets, but it also reflects the clustering of neighborhoods or districts of homogeneous urban form regulated by current zoning ordinances. The urban block is a physical territory bounded by streets. It is often used to calculate building density such as Floor Area Ratio (FAR). According to the 2010 Census, Manhattan is divided into 288 census tracts and 2870 urban blocks based on the PLUTO (Primary Land Use Tax Lot Output). Given the inconsistency between the two kinds of spatial units, the system boundary of energy performance computing is modified and combined to be 257 district units.

The advantages of defining the above district unit include: (1) the census tract is officially used to document the population change and related to the estimation of occupancy, including the occupant density and occupant behavior (United States Census Bureau 2012) which influence building energy use greatly, and therefore can be used as a spatial unit to cluster building energy use; (2) the census tract was established based on topography, housing and drainage (Krieger 2006). The district unit combines both the census tract and the urban block that imply homogeneous urban geometry, and corresponding microclimate within each district that affect building energy use and renewable energy production; (3) the size of district unit in Manhattan is close to the local climate zones (LCZ) of a classification system proposed by Stewart and Oke that are associated with the homogeneous urban form (Stewart and Oke 2012). It can be linked to wider applications such as the World Urban Database and Access Portal Tools (WUDAPT 2016). The microclimate zone is of great importance in urban building energy performance studies (Li et al. 2015). In this case study, the district unit for analysis serves as the local climate zone to keep the microclimate regime constant within each district. Steward and Oke suggested that the radius of the microclimate zone should be at least 200–500 m so that the boundary layers of adjacent microclimate zones won't overlap with each other (Stewart and Oke 2012), which is equivalent to the minimum area of microclimate zone of 125,600–785,000 m^2. In the total of 257 districts in Manhattan, 76 % of them meet the area requirement of the local climate zone.

The 257 district units are used for calculating the two indicators in those districts: (1) the W/H Ratio measured and calculated in GIS, and (2) the annual Energy Resilience Ratio calculated based on the urban energy modeling described above.

The W/H Ratio computed in our model is based on the existing urban form, in which the discontinuous facades and various building heights in blocks of actual architectural designs are far more complex than the hypothetical envelop controls or the setback controls by the urban design guidelines (see Fig. 9). The computation of the actual W/H Ratio in this study follows the method commonly used in microclimate studies as the average building height in a certain spatial unit (Bueno et al. 2013). In this case study, the W/H Ratio of each district is measured as the average distance between buildings on two sides of all the streets included in the district divided by the average height of buildings of the district (Fig. 10).

As discussed in previous paragraph, the Energy Resilient Ratio is calculated using the above Urban Energy Modeling to simulate how much energy production from rooftop PVs would meet the demand of building energy use within the district over certain period of time. Districts with higher resilience ratio are more self-sufficient and therefore more able to handle and adapt to the effects of unpredicted shocks such as blackouts. Different from the W/H Ratio, the Energy Resilient Ratio varies not only spatially but also temporally, which can be measured based on annual, monthly, daily or hourly average. To evaluate the capability of self-sufficiency and resilience of urban district, the Energy Resilient Ratio should be measured according to when and how long the problems would be caused by the shocks.

The spatial distributions of the W/H Ratio and the annual Energy Resilience Ratio in Manhattan are shown in Fig. 11. The Energy Resilience Ratio was also

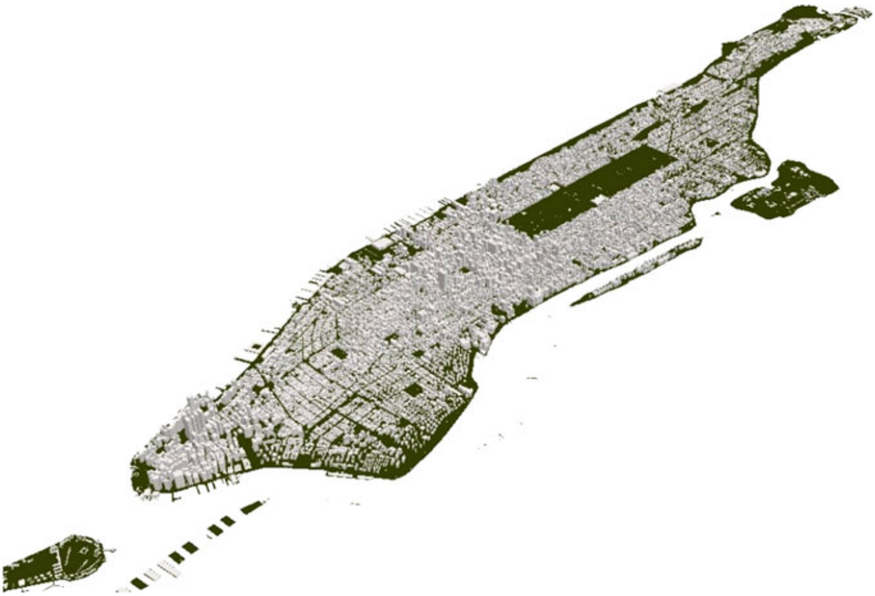

Fig. 10 Highly complex building shapes in Manhattan regulated by set-back and W/H controls

plotted against the W/H Ratio to show their relationship in Fig. 12. Observations from these two figures suggest a seemingly positive correlation between the two variables.

In order to verify this hypothesis, this case study conducted a simple linear regression to test 257 districts with the Energy Resilience Ratio as the dependent variable and the W/H Ratio as the independent variable. The results in Table 1 show that the W/H Ratio is significantly and positively correlated with the Energy Resilience Ratio with the significant level of 0.000, which verifies the hypothesis on the correlation between the two variables. Such result suggests that the W/H Ratio as a prescriptive form-based urban design control can still take effects in addressing the energy resilience variations. However, the R-Square of the regression is only 0.213, which means that the form-based indicator of the W/H Ratio can only explains 21.3 % of the variation in energy resilience. The limited R-square can be observed from the plotting in Fig. 13, in which a number of district units seem to be outliers for the linear relationship between the two variables. It points out that the W/H Ratio as a form-based prescriptive control does not ensure the energy resilience of all district units. The W/H Ratio cannot address the temporal dynamics of the system or the variation of the energy resilience over time. The performance modeling approach proposed in the chapter provides an alternative to addresses the energy resilience problem with better accuracy for adaptable strategies.

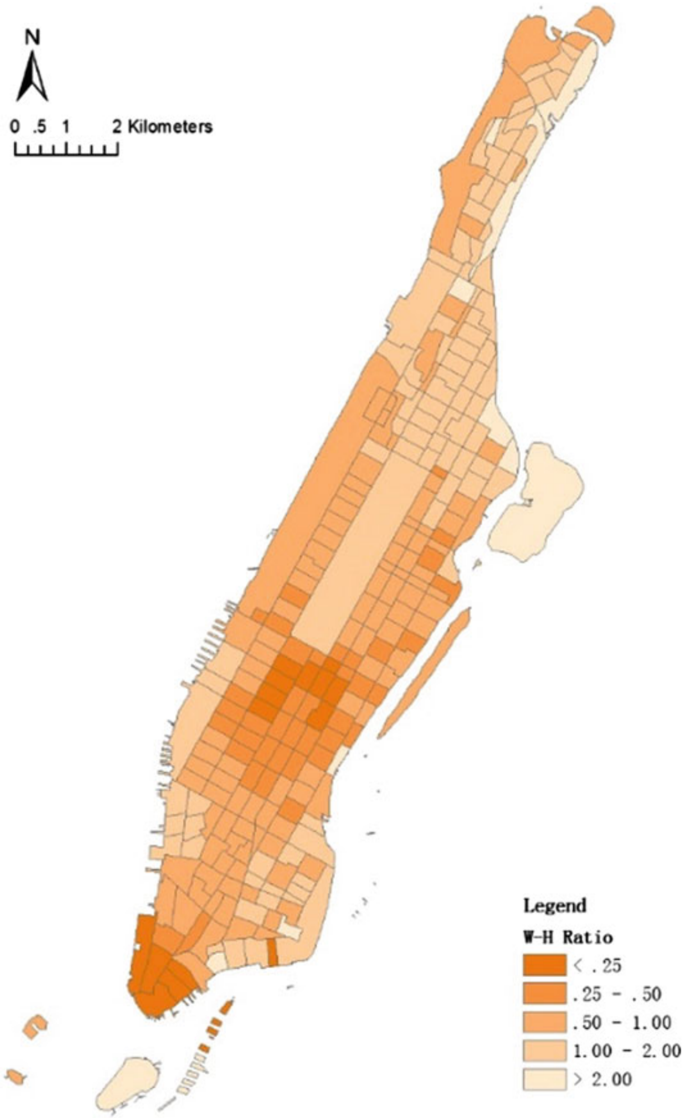

Fig. 11 W/H Ratio mapping in Manhattan

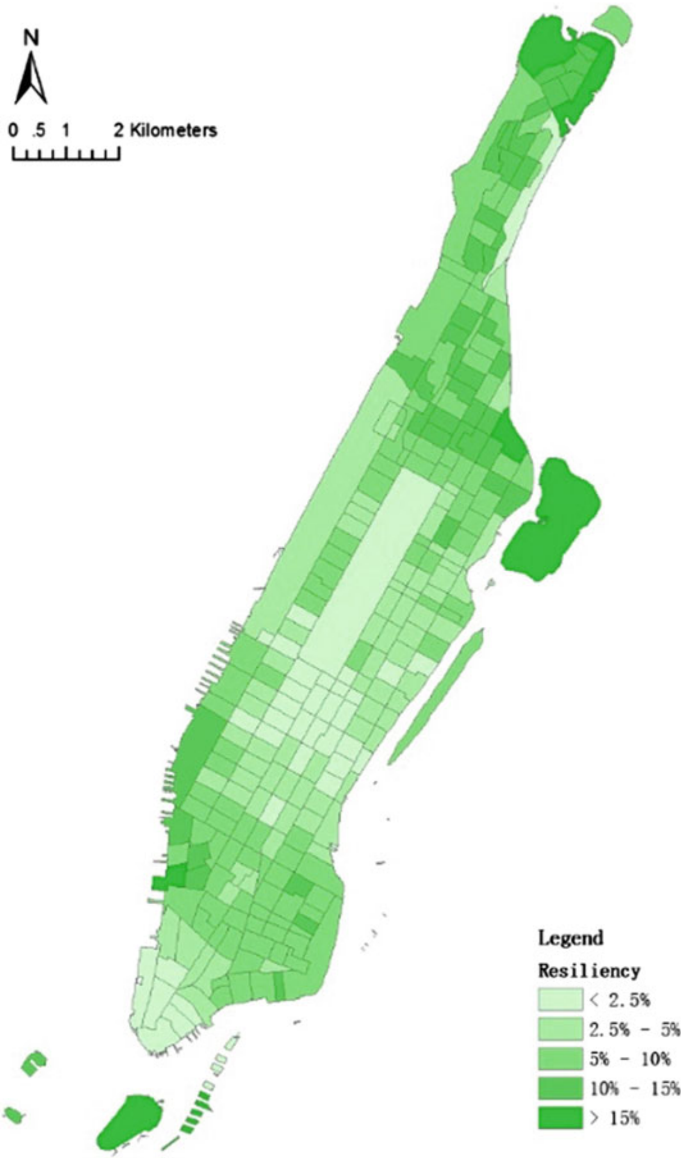

Fig. 12 Energy resilience ratio of defined 257 districts in Manhattan in 2012

Table 1 Coefficients of the linear regression with the dependent variable of the resiliency and the independent variable of the W/H Ratio

Predictors	B	Std. error	t	Sig.
(Constant)	0.045	0.005	9.731	0.000
W/H Ratio	0.026	0.003	8.304	0.000

Dependent variable: energy resilience ratio
R-square: 0.213; std. error of the estimate: 0.056

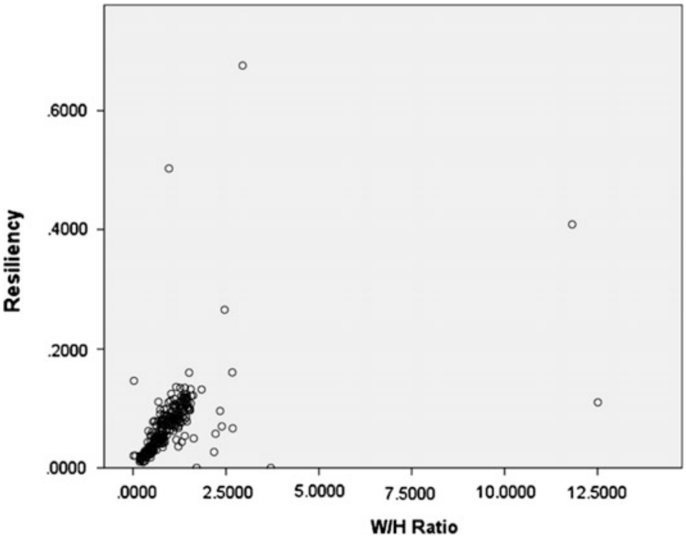

Fig. 13 Plotting of the resiliency against W/H Ratio

5 Conclusion

This chapter investigates the Manhattan grid, a world-renowned high-density urban form structure in place since 1811, and its relationship to resiliency, with a special focus on energy performance. We raise two fundamental questions: (1) to what extent is the Manhattan grid a resilient urban form, and (2) how can the urban form be transformed to create a more energy resilient future city?

The traditional zoning ordinance uses the W/H Ratio, a form-based prescriptive guideline, to form the streetscape and ensured access to sunlight in the case of New York City. The W/H Ratio resulted in the setback control, the setback style or Art-Deco style seen across New York's urban streetscape. The zoning ordinance was intended to control day lighting and ventilation in the urban environment, however, it only indirectly affects buildings' energy performance at the urban-scale.

The above results show that the current Manhattan grid contains very low energy self-supply ratios, which are insufficient for responding to unpredictable shocks, such as hurricanes, that may cause power blackouts and infrastructure breakdowns. A concept of *performance-based* modeling and the Energy Resilient Ratio is proposed to further predict and manage buildings' energy consumption and energy production in real time. There is a need to transition from the current prescriptive-based setback controls, such as W/H Ratio, to a performance-based real time assessment model.

A comparative analysis and mapping of the W/H Ratio and the Energy Resilience Ratio based on 257 districts or local climate zones of the island and over a year in Manhattan are conducted. The result shoes that the W/H Ratio as a form-based prescriptive control does not ensure the energy resilience of all district units. The W/H Ratio lacks the temporal dynamics for responding to the problems of energy resilience over time. By adopting the performance-based model and developing strategies for the increase of energy resilient ratios, the urban form can then be transformed to better adapt to shocks and blackouts caused by the hazardous effects of climate change.

To what degree can the urban form of Manhattan be transformed for more energy resilient, given the physical and institutional constraints of the grid structure? If the current urban form, grid structure and infrastructural systems are not resilient, or was not designed as for being resilient, how do we undo the mistaken parts? What is the reversibility for the system, or in other words, the ability of a system to make recovery? This paper examines a transition from form-based control to performance modeling for strategies to increase energy resilience. Further research should examine transformative paths to increase energy self-sufficient and resilient urban form through linking modeling and urban systems design.

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