Climate Change Resilience Strategies for the Building Sector: Examining Existing Domains of Resilience Utilized by Design Professionals

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Received: 4 March 2019; Accepted: 16 May 2019; Published: 21 May 2019

Abstract: Recently, climate change resilience efforts in the building sector have increased. Previous studies have examined the theoretical frameworks that have shaped the concept development of resilience. However, little is known about the theoretical approaches adopted by building professionals in their climate change resilience work. A literature review identified climate change resilience across four academic domains: ecology, engineering, disaster risk reduction, and the social sciences. To better understand how resilience is defined in the building sector, we examined eighteen climate change resilience documents developed to provide guidance to building sector professionals in the United States. Our analysis of these documents helps to understand how professionals are framing and possibly incorporating these strategies in their work, though we did not measure the adoption rate of each of the documents. We find that resilience is mostly a discourse on bouncing-back, preserving the status quo, and/or developing emergency responses to major hazards. Fewer documents incorporated an ecological or social science-based logic. This highlights the challenges of translating resilience from four academic domains into building strategies for the professional community. In closing, we discuss how competing conceptions of resilience may impact the implementation and effectiveness of climate change resilience strategies in the built environment.

Keywords: building sector; building codes; building standards; building design; climate adaptation

1. Introduction

Recent climate-related events, such as Hurricane Sandy that struck New York City and the Northeastern United States in 2012, have highlighted the resilience, or lack thereof, of the building sector. Events like Hurricane Sandy, and other weather-related phenomena, illustrate that the climate is shifting rapidly in many parts of the globe; planning for future building stock can no longer rely solely on historical data.

After Hurricane Sandy, the New York City Housing Authority (NYCHA) reported loss of power, heat, and hot water in approximately 35,000 housing units; 94% of the 62,000 damaged properties inspected by the Federal Emergency Management Agency (FEMA) experienced flooding damage [1]. In response, the City of New York proposed a comprehensive plan titled “A Stronger, More Resilient New York”, with the goal of increasing the resilience of infrastructure and buildings in communities across the city.

New York City and New York State are not the only U.S. locations grappling with this threat. Due to multiple large-scale events in recent years, resilience efforts to reduce risks related to the building stock have been deployed by policy- and decision-makers [2]. These organizations are
disseminating reports, toolkits, voluntary standards, and other “how-to” information to build resilience in the built environment.

While the interest in resilience in the public and political sphere has largely been in reaction to climate disasters, literature on climate change resilience in the built environment is growing rapidly. According to Longstaff et al., due to its recent popularity, resilience risks turning into another buzzword with no meaning [3]. Some argue that the diversity and ambiguity in resilience thinking challenges its operationalization [3,4], while others have suggested that resilience’s conceptual vagueness facilitates interdisciplinary communication [5]. Reaching a holistic definition may be difficult, however efforts to explore how different definitions of resilience modify the approach of professionals is important. To this end, this paper examines how resilience is translated from four academic domains into practical guidance currently in use by built environment professionals.

In the following three subsections of this paper, we provide an overview of the concept of resilience across four academic domains identified within the resilience literature. Next, we illustrate how resilience is translated into practice. In the final subsection, we highlight how the building sector approaches and conceptualizes climate change resilience by analyzing existing climate change resilience documents providing guidance to building professionals.

1.1. Understanding Resilience: Four Academic Domains

The word resilience originates from the Latin word “resiliō” meaning to “spring back.” Resilience generally refers to the ability of a system to withstand an array of shocks and stresses. Within the literature, resilience has overlapped with concepts such as stability and robustness [6] and is considered a complementary approach to sustainability [7,8]. Definitions of resilience are grounded in a diverse array of disciplinary perspectives.

While the definitions of resilience across domains overlap, it is important to explore the differences in how resilience is framed in each individual domain. This allows one to grasp how resilience definitions may shape policy and professional efforts to adapt the building stock to climate change. A review of the literature has identified four main academic domains of resilience: ecology, engineering, disaster risk reduction, and the social sciences.

1.1.1. Ecology

Perhaps the most prominent researcher on resilience is Holling, who introduced the concept of resilience to the field of ecology in 1973. Holling defines resilience as a, “measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables” [9]. In this definition, ecological systems are viewed as having multiple equilibrium or stable states; ecological resilience examines the threshold required to move a system from one equilibrium state to another [10,11].

In recent years, literature on ecological resilience has explored notions of constantly changing systems, or nonequilibrium systems. As such, resilience reflects a process of continuous adaptation to stresses and disturbances rather than an attribute or outcome. Nonequilibrium notions of resilience shift from reinforcing the ability to bounce-back towards exploring opportunities for transformation and change or “bouncing forward.”

This literature also acknowledges interactions between social and ecological systems. This conception of resilience in the ecological domain was essential to understanding change in social-ecological systems (SES). Resilience in SES is defined as, “the capacity of linked social-ecological systems to absorb recurrent disturbances such as hurricanes or floods so as to retain essential structures, processes, and feedback … the degree to which a complex adaptive system is capable of self-organization (versus lack of organization or organization forced by external factors) and the degree to which the system can build capacity for learning and adaptation” [12].

In this way, resilience in the ecological domain also embraces a potential for change and highlights the capacity of systems to reorganize. Disturbances can create (or force) opportunities for
decision-makers and stakeholders to innovate and adapt [13]. Ecological resilience addresses both acute and chronic stresses, meaning it does not focus primarily on temporary disturbances, but requires a shift in practices that respond to long term impacts and chronic vulnerabilities within a system.

1.1.2. Engineering

Engineering resilience describes the capacity of a system to withstand disturbances and return to a steady state. To engineers, systems have only one equilibrium state that they return to after a shock or disturbance. Engineering resilience thus emphasizes a system’s resistance to disturbances, the speed of return to a resilient state, and its overall ability to bounce back [4,11]. This contrasts with the concept of ecological resilience which recognizes systems as having multiple states of equilibrium. Generally, engineering resilience is appropriate when a stable state is desired; the bearing capacity of building foundations and the robustness of a building’s structure are examples.

While engineering resilience has limitations in capturing the dynamics of a system under stress, because the desired state is defined, the operationalization of resilience may be easier to attain [14]. In the built environment, the idea of recovery and bouncing back, or engineering resilience, underpins many resilience efforts and is well-represented in government documents [2]. For example, the Department of Homeland Security defined resilience as, “the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies” [15].

However, recovery to the norm and speed of return alone are not sufficient measures of resilience [16]. Generally, single-equilibrium viewpoints do not adequately account for multiple pathways that retain essential structures within a system [16]. These other resilience strategies may be better explored under a disaster risk reduction or social science-based approach.

1.1.3. Disaster Risk Reduction

While engineering and ecological resilience are dominant domains of resilience [11,13], resilience has been growing in other fields, notably disaster risk management/reduction and the social sciences. A disaster-risk reduction approach, like engineering, generally adopts a single-state equilibrium viewpoint of resilience [10]. Resilience in the disaster risk reduction domain attempts to quantify the probability of a hazardous event and understand internal and external vulnerabilities of cities/communities/buildings, and measures resilience in terms of economic, physical, and social recovery from a disturbance back to a single state [10,17].

The importance of resilience in disaster risk management/reduction was highlighted by the adoption in 2005 of the Hyogo Declaration: Building the Resilience of Nations and Communities to Disasters, by the United Nations International Strategy for Disaster Risk Reduction (UNISDR). The 10-year Hyogo framework for action provided guidance to various sectors and stakeholders on developing legislative and institutional frameworks to reduce disaster risk. The actions comprised the assessment and monitoring of risks, building a culture of safety and resilience, reducing risk factors, and improving disaster preparedness. In 2015, the strategy was superseded by the 2015–2030 Sendai Framework for Disaster Risk Reduction (DRR).

The Sendai Framework action priorities include understanding disaster risk, strengthening disaster risk governance, investing in DRR for resilience, enhancing disaster preparedness and building back better. The fourth priority in the Sendai Framework highlights a shift from recovery to the norm or status quo (bounce back), to recovery to an improved state by building better and improving response to future risk (bouncing forward).

1.1.4. Social Sciences

Resilience studies in ecological, engineering, and disaster risk reduction domains have yet to account for the underlying socioeconomic inequities that shape the resilience of vulnerable populations to harm and have mostly focused on the physical resilience of infrastructure [18]. As such, resilience in
the social sciences domain emerged to explore the factors that shape how individuals and communities respond to climate change hazards and risks [19].

The emphasis on preserving a steady state frequently shapes how governments, cities, and professionals frame climate change resilience and respond to hazards. It also highlights the need to evaluate if the status quo is meeting the needs of vulnerable populations [20]. Can a community be considered resilient if it bounces back to a state that reinforces structural inequities across race, class, gender, and income levels? For example, research has shown that low-income communities are particularly vulnerable to heatwaves because of limited access to air-conditioning, utility poverty, and low housing quality [21,22]. In this scenario, recovery to a norm where low-income communities remain vulnerable does little to prepare them for future events.

In a study on the relationship between social and ecological resilience, social resilience was defined as, “the ability of groups and communities to cope with external stresses and disturbances as a result of social, political, and environmental change” [19]. Specifically, questions of resilience to what, of what, and for whom are explored. By recognizing differential vulnerabilities to climate change impacts due to existing inequities within communities, resilience efforts move away from only focusing on short-term recovery to “support the immune system of social systems” [14].

1.2. Resilience in Practice

As discussed above, the debate on resilience definitions has mainly emerged from four academic domains: ecology, engineering, disaster risk reduction, and the social sciences. Most efforts currently adopted are driven by one or two resilience academic domains, mainly engineering and disaster risk reduction. However, as Lorenz states, “given the nature of cross-scale problems that do not adhere to system boundaries or can even arise from interacting systems, disciplinary approaches reach their limits” [14].

More specifically, because how we define and understand resilience impacts how we operationalize, apply, measure, and evaluate the resilience of systems, efforts from these four academic domains have resulted in divergent resiliency measurements and applications. As such, understanding the multiple theoretical frameworks (academic domains) of resilience in the development of strategies and guidance tools is critical.

Despite this challenge, there are limited efforts to examine how resilience has translated into practice. Do professionals employ a bouncing-back approach to resilience, as in the engineering and disaster risk domains, or do they adopt other approaches, as in the ecology and social sciences domain?

In their study comparing conceptualizations of urban climate resilience in theory and practices, Meerow and Stults found that amongst practitioners working for local United States governments, resilience was mostly defined through an engineering perspective [23]. They also found that practitioners indicated robustness as an important characteristic of resilience [23]. Similar approaches to resilience were also found in interviews with construction stakeholders and local authorities in the UK [24].

Because of its abstract nature and the challenges in operationalizing the concept, planning for resilience is a significant challenge for decision-makers. In the building sector, researchers have suggested the need for resilience metrics and guidance to inform building stakeholders including building owners, managers, residents, architects, engineers, community organizations, and policymakers.

In his 2008 book, Bosher states that a resilient built environment, “should be designed, located, built, operated and maintained in a way that maximizes the ability of built assets, associated support systems (physical and institutional) and the people that reside or work within the built assets, to withstand, recover from, and mitigate for, the impacts of extreme natural hazards and human induced threats” [25]. Indeed, the use of resilience as a concept for buildings has been rapidly growing. Much work has been directed towards examining the climate resilience of cities and communities, or urban resilience (see for example [26–30]). However, understanding how resilience is conceptualized within the building
sector and how it is translated into practice by building professionals remains unclear and therefore is the focus of this paper.

1.3. Objective of Paper

Approaches to climate change resiliency are varied and grounded in multiple academic domains. For example, in their examination of community resilience definitions, the Community and Regional Resilience Institute listed 46 definitions of resilience [31]. Meerow et al. found 25 definitions for urban resilience [32], while Manyena found 12 definitions of resilience [33]. The variability in definitions is a reflection of current literature on resilience that argues its malleable nature as a concept challenges the development of coherent, consistent, and holistic definitions [4].

However, to date, there have been few efforts to examine how the building sector approaches climate change resiliency. To address this gap, this paper examines eighteen climate change resilience documents providing guidance to the building sector. The primary objective is to better understand the current approaches and limitations to climate change resiliency efforts in the building sector.

Accordingly, we compare conceptualization of resilience in the building sector through a content analysis of recent resilience documents for the building sector in the United States. Specifically, the paper addresses the following research questions:

(1) How do existing resilience guidance documents in the building sector address and incorporate different academic domains of resilience?
(2) Does the building sector employ a bouncing-back or bouncing-forward approach to climate change resilience?

Based on the literature review, we hypothesized that the majority of resilience efforts in the building sector are shaped by the engineering and disaster risk reduction academic domains, thus employing a bouncing-back approach to climate change resilience.

2. Materials and Methods

To examine how the building sector conceptualizes resilience we analyzed climate change resilience documents developed for building professionals in the United States. To identify relevant documents, we screened resilience initiatives, programs and frameworks that directly addressed the resilience of buildings. These included general guidance documents, resilience standards, and building design and construction strategies that could be utilized by stakeholders within the building sector such as architects, building managers and operators, homeowners, building users, and neighborhoods and community organizations. A total of eighteen resilience documents for buildings were identified. Table 1 provides a brief description of each tool.

Table 2 below illustrates the specific characteristics of the documents. Six were categorized as guidance documents, while eleven were categorized as resiliency rating systems or standards in which specific strategies, or credits are implemented to achieve a defined level of resiliency.

Ten of the resilience documents were developed for specific building typologies, mainly residential (three single family and two multifamily housing) and commercial (four). PEER and ENVISION tools addressed resiliency of infrastructures, campuses, and capital projects, while the remaining tools were not specific to any building typology.

For the LEED and RELi tools, resilience strategies that respond to the specific requirements of a building typology were considered a part of the overall resilience process. Generally, all tools recommend that stakeholders examine the needs and vulnerability of their buildings by incorporating typology considerations such as building functions, occupants, operations, and business continuity. Table 2 also illustrates who controls the implementation or operation of the resilience strategies.
Table 1. Description of climate change resilience documents for building professionals.

| Document                                  | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| LEED [Resilient Design Pilot Credits]     | Developed by the U.S. Green Building Council (USGBC), the Leadership in Energy and Environmental Design, or LEED, rating system is one of the most popular green building rating systems in the world. In 2015, the LEED pilot credits on resilient design were adopted. Three pilot credits were incorporated in the LEED rating system and fall into the Integrative Process category of LEED. The three pilot credits are: (1) assessment and planning for resilience (climate change assessment or emergency planning); (2) design for enhanced resilience (design for top three hazards); and (3) design for passive survivability (choose two of thermal resilience, back-up power, and access to water). |
| PEER [Performance Excellence in Electricity Renewal] | Administered by Green Business Certification Inc. (GBCI) (Washington, DC, USA), the PEER standards evaluate the performance of power systems in seven categories: reliability and resilience; operations, management and safety; energy efficiency and environment; grid services; innovation and exemplary performance; regional priority; and education. There are four levels of certification including certified, silver, gold, and platinum certification. PEER standards aim at integrating buildings with the energy and power industry by improving the efficiency, reliability, and resiliency of power systems in campuses, critical infrastructural, transit, and utilities and cities. A total of 39 credits were examined. |
| RELi [Resilience Action List and Credit Catalog] | Developed by the RELi Resilience Collaborative (Perkins and Will, U.S. Green Building Council, AREA Research, C3 Living Design, The Capital Markets Partnership’s National Safety and Resiliency Committee, AIA Minnesota, and the University of Minnesota School of Architecture), RELi is a resilient rating system providing certification for buildings, neighborhoods, homes, and infrastructure. The RELi action list is divided into four main categories including: panoramic approach; risk adaptation and mitigation for acute events; comprehensive adaptation and mitigation for a resilience present and future; and applied creativity and contextual factors for resiliency. A total of 62 requisites, policy-requisites, policy-credits, and credits were examined (including sub-credits, the credit catalog consists of over 190 credits). |
| ENVISION                                | Developed and administered by the Institute for Sustainable Infrastructure, the ENVISION rating system is a framework of sustainability criteria, or credits, for infrastructure projects. The objective of ENVISION is to improve the performance and resiliency of physical infrastructure. Credits are divided into five overarching categories: quality of life; leadership; resource allocation; natural world; and climate and risk. A total of 60 credits were examined. |
| B-READY                                 | Developed by DNV-GL (Oslo, Norway), the B-READY building resilience assessment tool incorporates an assessment of local climatic hazards and a building’s vulnerability and resilience to provide a resiliency index (based on a 0–100 scale). The assessment tool also provides recommendations for resilience measures based on best-practices in the industry. The resilience measures cover twelve building systems including envelope and structure; mechanical systems and controls; electrical and lighting; communication and security; interior, equipment, and furnishing; energy generation and storage; fire suppression; plumbing; site; conveying equipment; and operations, and community. A total of 130 resilience measures were examined. |
Table 1. Cont.

| Document Description                                      | Description                                                                                                                                                                                                                                                                                                                                 |
|-----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BRLA [Building Resilience Los Angeles]                    | Developed by the USGBC Los Angeles chapter, the BRLA primer for facilities offers guidance for organizations and buildings to become more resilient. It provides a framework for developing an effective resilience building process at the building and campus level. The primer includes multiple regional, national, and international case studies and sample resilience strategies divided into six categories including shelter, water, energy, food, natural and outdoor spaces, and communication. A total of 94 sample strategies were examined. |
| ENTERPRISE [Strategies for Multifamily Building Resilience] | Developed by Enterprise Community Partners, Inc. (New York, NY, USA), the Strategies for Multifamily Buildings Resilience provides guidance for existing multifamily buildings through several retrofit and mitigation strategies. The manual includes guidance on identifying a building’s exposure to hazards, assessing risks, and determining resilience strategies. The proposed strategies are grouped into four categories including protection, adaptation, backup, and community. A total of 19 resilience strategies were explored. |
| USGBC [Green Building and Climate Resilience]              | This guidance report titled “Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions” was developed by the USGBC and the University of Michigan. The report highlights research on the projected impacts of climate change by region, and explores design, construction, and operation strategies that improve a building’s resilience. The strategies include no-regrets and resilience strategies which are divided into six categories including envelope; siting and landscape; heating, cooling, lighting; water and waste; equipment; and process and operations. A total of 81 strategies were examined. |
| NIST [Community Resilience Planning Guide]                | Developed by the National Institute of Standards and Technology, the Community Resilience Planning Guide for Buildings and Infrastructure Systems consists of two volumes. The first volume illustrates a six-step process for planning for resilience, while the second volume provides tools to characterize the social and built community and identify dependencies, and highlights examples of community resilience metrics. Unlike other documents, this guide addresses climate change resilience at the community level and identifies strategies for different sectors, including buildings, transportation, energy, communication, and water and wastewater. Strategies that explore the resilience of buildings were examined. This included references to existing best practices for wind and flood resistant design and construction and solutions for future and existing construction. While the NIST guide incorporates a vulnerability assessment to identify potential climate change impacts, the building strategies included only address flooding, wind, and rain hazards. 16 strategies were examined. |
| NYSERDA [Climate Change Impacts on New York’s Building Sector] | Developed by the University at Buffalo for the New York State Energy Research and Development Authority, this document provides guidance to owners and operators, policymakers and planners, and architects and engineers on how to prepare buildings for the expected impacts of climate change in New York State. The document features 25 strategies that were examined. |
| BOSTON [Enhancing Resilience in Boston]                    | Developed by A Better City (ABC), this guide for large buildings and institutions examined the resilience of commercial buildings. The report illustrates climate-related risks and identifies resilience actions, or strategies, for buildings inside and outside of projected floodplains in Boston. The strategies are group into three main categories including permeable pavement, dry floodproofing, and permanent flood barriers. A total of 32 strategies were examined. |
| Document                                                                 | Description                                                                                                                                                                                                 |
|------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| New York City [Preliminary Climate Resiliency Design Guidelines]        | Develop by the New York City (NYC) Mayor’s Office of Recovery and Resiliency, the goal of the guidelines is to incorporate forward-looking climate data in the design of infrastructure and buildings. The guidelines are grouped to address three main hazards including increasing heat, increasing precipitation, and sea level rise. A total of 16 guidelines were examined. |
| FORTIFIED COMMERCIAL [Hail and High Wind]                              | The Insurance Institute for Business and Home Safety’s (IBHS) FORTIFIED programs provide recommendations for reducing damage caused by specific natural hazards for existing and new buildings (programs are designated for either commercial buildings or homes). The program offers three levels of FORTIFIED designations, bronze, silver, and gold based on the intended resilience goals. A total of 13 guidelines for reducing hail and high wind damage to commercial buildings were examined. |
| FORTIFIED COMMERCIAL [Hurricane]                                      | (see FORTIFIED COMMERCIAL for Hail and High Wind above). A total of 14 guidelines for reducing hurricane damage to commercial buildings were examined.                                                            |
| FORTIFIED HOME [Hail and High Wind]                                    | (see FORTIFIED COMMERCIAL for Hail and High Wind above). A total of 16 guidelines for reducing hail and high wind damage to homes were examined.                                                                    |
| FORTIFIED HOME [High Wind]                                            | (see FORTIFIED COMMERCIAL for Hail and High Wind above). A total of 16 guidelines for reducing high wind damage to homes were examined.                                                                          |
| FORTIFIED HOME [Hurricanes]                                           | (see FORTIFIED COMMERCIAL for Hail and High Wind above). A total of 22 guidelines for reducing hurricane damage to homes were examined.                                                                        |
| REDi [Resilience-based Earthquake Design Initiative]                  | A three-level resilience rating system with silver, gold, and platinum ratings. The rating system, developed by Arup (London, UK), is based on four overarching guidelines and criteria: organizational resilience, building resilience, ambient resilience, and loss assessment. A total of 65 resilience criteria were examined. |
Table 2. Characteristics of climate change resilience tools for buildings.

| RESILIENCE TOOLS                                      | Type          | Building Typology | Control of Strategy |
|-------------------------------------------------------|---------------|-------------------|---------------------|
|                                                      | Rating/Standard | Guidance doc.     | Residential | Commercial | Campuses | Infrastructure | General | New Buildings | Existing Structures | Owner | Occupant | O&M | Passive |
| LEED [Resiliency Design Pilot Credits]                | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| PEER [Performance Excellence in Electricity Renewal]  | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| RELi [Resilience Action List + Credit Catalog]        | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| ENVISION                                              | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| B-READY                                               | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| BRLA [Building Resilience Los Angeles]                | ○             | ●○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| ENTERPRISE [Strategies for Multifamily Building Resilience] | ○             | ●○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| USGBC [Green Building & Climate Resilience]           | ○             | ●○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| NIST [Community Resilience Planning Guide]            | ○             | ●○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| NYSERDA [Climate Change Impacts on NY’s Building Sector] | ○             | ●○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| BOSTON [Enhancing Resilience in Boston]               | ○             | ●○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| NYC [Climate Resiliency Design Guidelines]            | ○             | ●○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| FORTIFIED COMMERCIAL [Hail & High Wind]               | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| FORTIFIED COMMERCIAL [Hurricane]                      | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| FORTIFIED HOME [Hail & High Wind]                     | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| FORTIFIED HOME [High Wind]                           | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| FORTIFIED HOME [Hurricanes]                           | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |
| REDi [Resilience-based Earthquake Design Initiative]  | ●             | ○○○○○○○○○○○○○○○ | M          | ●          | ○        | ●        | ○        | ●        | ●        | ●        | ●        | ●        |

1 Residential building typologies were categorized into single family (S) and multifamily homes (M).
Data Analysis

A content analysis was performed on the eighteen building resilience documents and the strategies proposed. The analysis consisted of coding the text and strategies based on the research objectives including climate change hazards addressed (resilience to what?) and the resilience academic domain adopted within each tool (ecology, engineering, disaster risk reduction, and social sciences). Examining the variety of climate change hazards addressed provides a better understanding of the scope of hazards that are prioritized by the building sector. This theme builds on research that argues hazards which have resulted in visible physical and fiscal damage are prioritized in climate change responses [34].

The resilience academic domains adopted are examined to gain a better understanding of how resilience is shaped within the building sector. This was conducted by coding all building strategies proposed based on the intended outcome of that strategy. For example, resilience strategies that addressed social cohesion and community empowerment were coded as social sciences resilience and as bouncing-forward resilience, while strategies for bracing reinforcements and roof strengthening were coded as engineering resilience and bouncing-back resilience. The tools were thus categorized according to the four academic domains identified in the literature section, engineering, ecology, disaster risk reduction, and social sciences.

3. Results

3.1. Resilience to What?

A total of 724 resilience strategies were identified from eighteen building climate change resilience tools. To examine the climate change hazards addressed, strategies were grouped into 12 hazard categories based on the coding results (Table 3). The documents ranged from being hazard specific (developed to address one or two types of hazards) to having an all-hazard approach in which a vulnerability assessment was part of the resilience building process. Only three documents were developed to address a specific context including BOSTON (Boston), NYSERDA (New York State), and BRLA (Los Angeles). This means that the resilience strategies proposed within those documents were developed to address the climate change hazards specific to a region.

Five resilience documents (LEED, PEER, RELi, ENVISION, and B-READY) address climate change hazards as part of a vulnerability assessment, or all-hazards approach. The documents provide guidelines on the process of conducting a vulnerability assessment to inform the development of appropriate resilience strategies. Resilience strategies in these tools were considered as pathways that support a building’s resilience regardless of the projected hazards or expected risks. For example, strategies such as maintaining backup power to critical systems, building community ties, providing areas of refuge, developing emergency management plans, planning for long-term monitoring and maintenance, and system redundancy are not hazard-specific and can be applied to improve the overall resilience of a building.

Eight tools (BOSTON, NYC, FORTIFIED COMMERCIAL, FORTIFIED HOME, and REDi) were identified as hazard specific. Building strategies were developed to improve a building’s resilience to a defined hazard including seismic activity, rising sea levels, flooding, hurricanes, severe storms, winter storms, and heatwaves. The remaining documents were general resilience guidance documents that incorporated strategies to address a range of climate change hazards either directly or indirectly.

Table 3 above illustrates that flooding, heatwaves, severe storms, and hurricanes encompassed the focus of most climate change resilience tool in the building sector. Other hazards such as air and water quality, drought, wildfires, and pest infestation were not as extensively covered. This pattern is consistent with literature in which current climate change efforts are concentrated on visible hazards or hazards that have resulted in extensive physical and economical damage [34].
Table 3. Hazards addressed in climate change resilience documents for buildings.

| Resilience Tool | Water Quality | Air Quality | Seismic Activity | Drought | Wildfires | Pest Infestation | Rising Sea Levels | Flooding | Hurricanes | Severe Storms | Winter Storms | Heatwaves |
|-----------------|---------------|-------------|------------------|---------|-----------|------------------|-------------------|----------|------------|--------------|--------------|-----------|
| LEED            | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| PEER            | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| RELi            | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| ENVISION        | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| B-READY         | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |

For Multiple Hazards:

| Resilience Tool | Water Quality | Air Quality | Seismic Activity | Drought | Wildfires | Pest Infestation | Rising Sea Levels | Flooding | Hurricanes | Severe Storms | Winter Storms | Heatwaves |
|-----------------|---------------|-------------|------------------|---------|-----------|------------------|-------------------|----------|------------|--------------|--------------|-----------|
| BRLA            | ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ | ○               | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| ENTERPRISE      | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| USGBC           | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| NIST            | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| NYSERDA         | ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ | ○               | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |

For Hazard Specific:

| Resilience Tool | Water Quality | Air Quality | Seismic Activity | Drought | Wildfires | Pest Infestation | Rising Sea Levels | Flooding | Hurricanes | Severe Storms | Winter Storms | Heatwaves |
|-----------------|---------------|-------------|------------------|---------|-----------|------------------|-------------------|----------|------------|--------------|--------------|-----------|
| BOSTON          | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| NYC             | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| FORTIFIED COMMERCIAL (High Wind & Hail) | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| FORTIFIED COMMERCIAL (Hurricanes) | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| FORTIFIED HOME (High Wind) | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| FORTIFIED HOME (High Wind & Hail) | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| FORTIFIED HOME (Hurricanes) | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |
| REDi            | ○             | ○           | ○                | ○       | ○         | ○                | ○                 |          |            |              |              | ○         |

Key: ●: Document directly addresses hazard. ○: Document addresses hazard as part of an all-hazard approach/vulnerability assessment. ⊙: Document indirectly addresses hazard. ⊙: Document does not address hazard.

3.2. Resilience Approach

To examine the resilience academic domains adopted within each tool, a total of 724 resilience strategies for the building sector were coded based on the intended outcome of that strategy as explained in the previous section. All documents were also coded based on the overall approach to climate change resilience they described. It is important to note that some resilience strategies may fall under more than one resilience academic domain. For example, elevating a building on piles can be considered as an engineering and disaster risk reduction approach to resilience. Similarly, extreme heat awareness can be categorized as a disaster risk reduction and social sciences approach.

Based on the coding results, Figure 1 illustrates the variability of resilience approaches. The figure highlights the representation of the four academic domains of climate change resilience. While some of the documents may have addressed the importance of a conducting vulnerability assessment to identify the appropriate resilience pathways for buildings, most strategies introduced represented narrow conceptualizations of climate change resilience. Specifically, engineering resilience and disaster risk resilience were represented in all documents. Accordingly, the majority of strategies reinforced bouncing-back and robustness after a disturbance or shock. This finding aligns with current resilience literature that states the predominance of engineering resilience in current climate change policy, programs, and initiatives [2,23].

Ecological resilience was adopted in eleven resilience documents but not as extensively as engineering and disaster risk resilience. Ecological resilience strategies addressed adaptation to change and uncertainty and the need for transformation in current practices mainly through passive design approaches.
The social sciences resilience was the least represented resilience approach. Resilience strategies within this approach support social cohesion, community ties, information flow, and the empowerment of individuals and communities. Strategies included extreme heat awareness, fostering collaboration and teamwork, and providing bilingual communication.

Figure 1. Framing of resilience across the eighteen resilience documents.
4. Discussion

While this analysis does not explore how professionals themselves define resilience, the findings provide crucial insights on the applications and definitions of climate change resilience being used by guidance documents for the building sector. Based on the findings above, resilience practice in the building sector is driven by engineering-related resilience. Consequently, the focus on the ability of buildings to bounce-back after a disaster to an equilibrium state has reduced resilience building efforts to the development of emergency responses, or disaster risk reduction.

In addition, the building sector emphasizes strategies that reduce the time scale of recovery after a disaster or shock. Specifically, resilience strategies on the ground and at the local level represent strategies that reinforce building stability and emergency responses. Current resilience tools reflect a focus on the physical resilience of buildings with minimal attention to underlying inequities facing building users and community residents. This finding aligns with current literature on the predominance of engineering resilience in practice [2,23], and the need to explore the factors that shape how individuals and communities respond to climate change hazards and risks [19].

In addition to its narrow implementation, resilience is often employed to address specified hazards, leaving the responsibility to address other hazards to other disciplines. However, increasing the resilience of one component of a system to one specific shock may leave it vulnerable to other types of disturbances. As such, resilience efforts must recognize the importance of addressing the interrelation of all system components and their system’s response to varying climate change impacts.

Generally, the buildings’ resilience tools draw on no clear empirical evidence to efficiently validate the development of climate change resilience strategies. While some employ case studies, community knowledge through participatory techniques, and/or stakeholder consultation, discussions on the theoretical background of resilience in the built environment were not evident.

In response to current limitations, we find that new alliances and fields have emerged that provide more holistic framing of resilience. The Resilience Alliance was established to provide an interdisciplinary ‘Resilience Thinking’ framework for understanding transformation in socio-ecological systems. The Resilience Engineering Association has introduced a subspecialty of engineering, resilience engineering, as a new way of thinking about safety. Additionally, the American Society of Adaptation Professionals was recently established to support and connect climate adaptation professionals working to improve the climate change adaptation and resilience of cities and communities across the country. These new fields reflect an increasing awareness of the challenges professionals faces in conceptualizing and implementing climate change resilience in the built environment.

Diversity is a key theme in resilience; diversity of impacts, of system components, of measurement, and as explored in this paper, of definitions and applications. As a multifaceted concept, current discourse on climate change resilience in the building sector requires more critical and constructive action. Having insights on the different conceptualizations of resilience and the associated building strategies helps stakeholders select appropriate approaches and make informed decisions. Specifically, stakeholders can identify the limitations and opportunities provided within different conceptualizations of resilience and develop context- and system-sensitive climate change resilience strategies for their own buildings.

5. Conclusions

The goal of this paper was to examine how resilience is translated into practice within the building sector by examining existing climate change resilience tools for buildings. The findings highlight the need for new approaches that addresses the variability of resilience definitions. While each academic domain brings unique contributions to the practice of resilience in the building sector, it is important to acknowledge that each body of literature alone cannot comprehensively address all aspects of resilience. As a complex challenge for the building sector, addressing climate change and resilience will require integrative and transdisciplinary efforts.
This may be achieved by providing platforms for authentic dialogue and stakeholder engagement to build a deep understanding of impacts, hazards and risks across sectors, and facilitating cross-disciplinary collaboration and co-development of new resilience guidance, strategies, and standards. Further research on the barriers to collaboration among domains and professionals, and how resilience is approached on individual projects is a critical next step.

Finally, this research also shows that adopting climate change resilience strategies is not as simple as selecting an existing resilience guidance document produced by others. At this early stage of climate resilience practice, building professionals must acknowledge the limitations of existing literature, guidance, codes, and standards to avoid maladaptation and undermining of long-term climate-related resilience.

**Author Contributions:** Both authors contributed to the development of the research design, analysis, and writing of this manuscript.

**Funding:** This research was supported by the New York State Energy Research and Development Authority (NYSERDA).

**Acknowledgments:** We would like to thank Kara Allen and Amanda Stevens of NYSERDA for reviewing earlier drafts of the manuscript. We would also like to thank Jim Leahy of DNV GL for providing feedback on the overall approach to the research design and for reviewing drafts.

**Conflicts of Interest:** The authors declare no conflict of interest.

**References**

1. PlaNYC. *A Stronger, More Resilient New York*; New York City Economic Development Corporation: New York, NY, USA, 2013.
2. Davoudi, S. Resilience: A bridging concept or a dead end? *Plan. Theory Pract.* 2012, 13, 299–307. [CrossRef]
3. Longstaff, P.H.; Koslowski, T.; Geoghegan, W. Translating resilience: A framework to enhance communication and implementation. In Proceedings of the Symposium on Resilience Engineering, Soesterberg, The Netherlands, 25–27 June 2013; pp. 12–23.
4. Martin-Breen, P.; Anderies, J.M. *Resilience: A Literature Review*; Rockefeller Foundation: New York, NY, USA, 2011.
5. Brand, F.; Jax, K. Focusing the meaning(s) of resilience: Resilience as a descriptive concept and a boundary object. *Ecol. Soc.* 2007, 12, 23. [CrossRef]
6. Hosseini, S.; Barker, K.; Ramirez-Marquez, J.E. A review of definitions and measures of system resilience. *Reliab. Eng. Syst. Saf.* 2016, 145, 47–61. [CrossRef]
7. Redman, C.L. Should sustainability and resilience be combined or remain distinct pursuits? *Ecol. Soc.* 2014, 19, 1. [CrossRef]
8. Rees, W.E. Sustainability vs. REsilience. Available online: https://www.resilience.org/stories/2014-07-16/sustainability-vs-resilience/ (accessed on 20 May 2019).
9. Holling, C.S. Resilience and Stability of Ecological Systems. *Annu. Rev. Ecol. Syst.* 1973, 4, 1–23. [CrossRef]
10. Pendall, R.; Foster, K.A.; Cowell, M. Resilience and regions: Building understanding of the metaphor. *Camb. J. Reg. Econ. Soc.* 2010, 3, 71–84. [CrossRef]
11. Holling, C.S. Engineering resilience versus ecological resilience. *Eng. Ecol. Constraints* 1996, 31, 32.
12. Adger, W.N.; Hughes, T.P.; Folke, C.; Carpenter, S.R.; Rockström, J. Social-Ecological Resilience to Coastal Disasters. *Science* 2005, 309, 1036–1039. [CrossRef]
13. Folke, C. Resilience: The emergence of a perspective for social–ecological systems analyses. *Glob. Environ. Chang.* 2006, 16, 253–267. [CrossRef]
14. Lorenz, D.F. The diversity of resilience: Contributions from a social science perspective. *Nat. Hazards* 2013, 67, 7–24. [CrossRef]
15. DHS. Resilience. Available online: https://www.dhs.gov/topic/resilience (accessed on 20 May 2019).
16. Walker, B.; Holling, C.S.; Carpenter, S.R.; Kinzig, A. Resilience, Adaptability and Transformability in Social–Ecological Systems. *Ecol. Soc.* 2004, 9, 5. [CrossRef]
17. Vale, L.J.; Campanella, T.J. *The Resilient City: How Modern Cities Recover from Disaster*; Oxford University Press: New York, NY, USA, 2005.
18. Kaswan, A. Seven principles for equitable adaptation. *Sustain. Dev. Law Policy* 2013, 13, 41.
19. Adger, W.N. Social and ecological resilience: Are they related? *Prog. Hum. Geogr.* 2000, 24, 347–364. [CrossRef]
20. Vale, L.J. The politics of resilient cities: Whose resilience and whose city? *Build. Res. Inform.* 2014, 42, 191–201. [CrossRef]
21. Mees, H.L.P.; Driessen, P.P.J.; Runhaar, H.A.C. “Cool” governance of a “hot” climate issue: Public and private responsibilities for the protection of vulnerable citizens against extreme heat. *Reg. Environ. Chang.* 2015, 15, 1065–1079. [CrossRef]
22. Sampson, N.R.; Gronlund, C.J.; Buxton, M.A.; Catalano, L.; White-Newsome, J.L.; Conlon, K.C.; O’Neill, M.S.; McCormick, S.; Parker, E.A. Staying cool in a changing climate: Reaching vulnerable populations during heat events. *Glob. Environ. Chang.* 2013, 23, 475–484. [CrossRef]
23. Meerow, S.; Stults, M. Comparing Conceptualizations of Urban Climate Resilience in Theory and Practice. *Sustainability* 2016, 8, 701. [CrossRef]
24. Lizzarralde, G.; Chmutina, K.; Bosher, L.; Dainty, A. Sustainability and resilience in the built environment: The challenges of establishing a turquoise agenda in the UK. *Sustain. Cities Soc.* 2015, 15, 96–104. [CrossRef]
25. Bosher, L. *Hazards and the Built Environment: Attaining Built-In Resilience*; Taylor & Francis: London, UK; New York, NY, USA, 2008. [CrossRef]
26. Prasad, N.; Shah, F.; Trohanis, Z.; Kessler, E.; Sinha, R. *Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disasters*; World Bank Group: Herndon, VA, USA, 2009. [CrossRef]
27. Newman, P.; Beatley, T.; Boyer, H. *Resilient Cities: Responding to Peak Oil and Climate Change*; Island Press: Washington, DC, USA, 2009.
28. Blakely, E.J.; Carbonell, A. *Resilient Coastal City Regions: Planning for Climate Change in the United States and Australia*; Lincoln Institute of Land Policy: Cambridge, MA, USA, 2012.
29. Torres, H.; Alsharif, K. What It Means to Become “More Resilient”: An Analysis of Local Resilience-Building Approaches in Three Florida Communities. *Weather Clim. Soc.* 2017, 9, 405–419. [CrossRef]
30. Desouza, K.C.; Flanery, T.H. Designing, planning, and managing resilient cities: A conceptual framework. *Cities* 2013, 35, 89–99. [CrossRef]
31. CARRI. *Definitions of Community Resilience: An Analysis*; Community and Regional Resilience Institute: Washington, DC, USA, 2013.
32. Meerow, S.; Newell, J.P.; Stults, M. Defining urban resilience: A review. *Landsc. Urban Plan.* 2016, 147, 38–49. [CrossRef]
33. Manyena, S.B. The concept of resilience revisited. *Disasters* 2006, 30, 434–450. [CrossRef] [PubMed]
34. Moser, S.; Ekstrom, J. A framework to diagnose barriers to climate change adaptation. *Proc. Natl. Acad. Sci. USA* 2010, 107, 22026–22031. [CrossRef] [PubMed]

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