Net Zero and Resilience: Similarities and Divergence

Ming Hu[1]

[1]School of Architecture, Planning and Preservation, College Park, MD

ABSTRACT: Two important contemporary domains in the built environment are “resilience” and “net zero,” both of which are associated with high-performance design and have their origin in the field of ecology. The energy efficiency and performance of buildings are common measuring indices accepted by multiple fields. The ultimate goal of net zero building has become a hot trend, and off-grid building has become the ultimate “high-performance” standard. Another emerging index is to measure and improve the resilience of buildings, capturing performance attributes such as environment, safety, durability, and functionality. Resilience has a broad range of implications in the built environment, such as recovery time during extreme events, emergency supply storage in buildings, off-grid/stand-alone potential, injuries during construction, and self-deconstruction capability (in order to minimize damage to the surrounding area in extreme events). Each of these categories uses different metrics. This paper provides an overview of research activities on the net zero building movement and the concept of resilience in the building and construction industry over the past 40 years. The purpose of this overview is to determine the main research areas within each domain and gain insight into the size of the different areas; explore how these research areas relate to each other and their intellectual origins; identify the most influential studies and thinkers; and identify potential research gaps. Conclusions are drawn relating to the major difference between the development of the net zero movement and resilience theory in the built environment and their respective relation to their ecological origin.

KEYWORDS: Net zero, resilience, ecology, divergence

INTRODUCTION

The built environment is responsible for a significant use of final energy (62%) and is a major source (55%) of greenhouse gas emissions (Anderson et al., 2015). Achieving environmental goals such as climate change mitigation, risk management, and disaster relief requires comprehensive methodologies to accurately assess the impact of buildings and the construction sector. The research to date focuses on either energy performance or resilience building. A large body of research has addressed quantifying building energy performance, and robust methodologies have been established and developed. With respect to resilience, some methods have been implemented and tested to quantify the ecological impact of large built environments that include multiple buildings. However, the assessment of the environmental impacts of built environments has been largely confined within either the energy field or the resilience field. This paper bases a review of contemporary studies in the net zero building movement and the resilience concept in the built environment on a systematic screening of peer-reviewed articles using title, keywords, and abstract. The purpose of this work is to create an overview of the scientific literature in the resilience and net zero domains within a built environment context, in order to understand its future direction.

1.0 THE CONCEPT AND DEVELOPMENT OF “NET ENERGY”

1.1. 1920–1930

The concept of “net energy” has always had its origin and a close relation to ecology. In 1920, Frederick Soddy, an English chemist and Nobel prize winner, first offered a new perspective on economics rooted in physics—specifically, the law of thermodynamics. Soddy suggested the importance of energy for social progress based on real wealth formation, as distinct from virtual wealth and a debt accumulation process (Hassler, 2014; Spash, 2017). He suggested that detailed accounting for energy use could be a good alternative to the monetary system, since the conventional monetary system treated economics as a perpetual motion machine, while in reality, as with any commodity, the actual wealth flow should obey the laws of thermodynamics (Spash, 2017; Hernandez, 2010). He argued that real wealth derived from the use of energy to transform materials into physical goods and services (Hernandez, 2010; Soddy 1933). However, his theory was largely criticized and ignored in his time, since he came to orthodox economics as a critic instead of a student. The contempt was mutual; in one of review of his book *Wealth, Virtual Wealth, and Debt*, the *Times Literary Supplement* remarked that "it was sad to see a respected chemist ruin his reputation by writing on a subject about which he was quite ignorant…" (Soddy, 1933). The ignorance and criticism of Soddy's theory contributed to the long-term silence of associated research development between 1930 and 1970.

1.2. 1930–1970

There is large gap in relevant literature between 1930 and 1970. The only notable development is the "Technical Alliance," a group of architects, engineers, economists, and ecologists who formed a professional association in 1919 that disbanded in 1921. It started an energy survey of North America with the aim of documenting the wastefulness of the entire society, the first recorded attempt to quantify "net energy" (Rapoport, 1976).

1.3. 1970–2006

In the 1970s, Romanian-American mathematician and economist Nicholas Georgescu-Roegen further developed ecological economics, or "eco-economics," based on Soddy's concepts. Eco-economics is a transdisciplinary and interdisciplinary field of research that includes ecology, economics, and physics. Georgescu-Roegen proposed the application of entropy law in the field of economics, where, he argued, all natural resource consumption essentially is irreversible. This approach had a profound impact on thinking about net energy flow or the life cycle of natural resources. Georgescu-Roegen was the first economist of some standing to theorize on the premise that all Earth's mineral resources will eventually be exhausted at some point (Boulding 1981); the concept of depletion of natural resources eventually led to the movement now known as sustainable development. He stated, "An unorthodox economist—such as myself—would say that what goes into the economic process represents valuable natural resources, and what is thrown out of it is valueless waste" (Georgescu-Roegen, 1971).

Another important development in the 1970s was the publication of the article "Energy, Ecology, and Economics" and the book *Environment, Power, and Society* by ecologist Howard Odum, who tackled the economic issue using ecological theories based on energy fundamentals. His system of energy economics was based on the concept of energy as the foundation for all forms of life, and transformable: he stated that "the true value of energy to society is the net energy, which is that after the costs of getting and concentrating that energy are subtracted (Odum, 1973). In the latter part of his career, in the 1990s, he developed a concept of "emergy": "emergy is a measure of energy used in the past and thus is different from a measure of energy now. The unit of emergy is the mjoule, as distinguished the evolution of self-organising open systems" (Odum, 1996). Emergy has attracted attention from academic researchers and is being applied to research in the building and construction industry as well as in natural ecosystems (Pulselli et al., 2007; Pulselli et al., 2009).

1.4. 2006–the present

The last recession, which officially lasted from 2007 to 2009, started with the bursting of the housing bubble. The so-called Great Recession played a role in the decline of fossil fuel CO_2 emissions. In the United States, CO_2 emissions decreased by 11 percent between 2007 and 2013. During this period, a variety of federal agencies and industry regulators proposed defined guidelines to measure and quantify net zero energy building across the globe. In 2008, the National Science and Technology Council (NSTC) issued the Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings (NSTC, 2008). The National Institute of Standards and Technology defined net zero energy buildings as those that produce as much energy as they consume, over a defined period, and proposed measurement techniques (NIST, 2010]. Those guidelines set an agreed-upon platform and consistent technical guidelines worldwide so that practitioners, researchers, and regulators could communicate in a common language.

2.0. THE CONCEPT AND DEVELOPMENT OF "RESILIENCE"

2.1. 1940–1970

Resilience emerged in the field of ecology at the same time that net zero studies started to catch researchers' and practitioners' attention. Resilience has since developed into another important emerging concept in built environments. In the 1960s the ecological resilience concept was first introduced in studies of the stability of ecosystems. One of the pioneers was C.S. Holling, who is considered by many to be the father of ecological resilience theory, and who also introduced this use of the word "resilience." Holling believed that extending the ecological framework to other fields would be useful for understanding how society, individuals, and communities interact with natural ecosystems. The origin of this term has deeper roots that may be linked to the origins of ecosystem and systems ecology and attempts to mathematically model dynamic ecosystems in the 1940s and 50s (Lindseth, 2011). The concept of resilience emerged from concepts and approaches that drew from cybernetics and were critical of existing (perceived) simplistic approaches within population ecology. The idea that nature was composed of systems that may have properties such as resilience set the stage for more formal conceptualizations of the term by Holling and colleagues throughout the 1970s and 80s (Lindseth, 2011).

2.2. 1970–the present

Holling describes resilience as dynamic and complex, in juxtaposition to views of a stable and simple nature. This established view defines stability in ecological systems as their ability to return to an equilibrium state following a disturbance. In contrast, Holling suggests that resilience "is 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." In this early formulation by Holling, it is the instability of a system that conveys its resilience.

These ecological origins for the modern concept of resilience are in some ways at odds with notions of resilience from other disciplinary uses. Engineering resilience refers to how a system responds to disturbances in light of the system's stability with respect to an equilibrium steady state (Holling, 1996; Liao, 2012; Wang & Blackmore, 2009). Engineering resilience derives from notions of resistance to and recovery from disturbances, focusing on the ability and speed of a system to bounce back to its initial, equilibrium conditions following a disturbance event (Liao, 2012; Wang & Blackmore, 2009).

The ecological concept of resilience has seen extension of its domain to include both social-ecological resilience and a paradigm that is applicable to resource management (Berkes & Folke, 1998; Folke, 2006). This evolution parallels the development of the Resilience Alliance, a collective of institutions and researchers that implement "resilience thinking" for the study and management of systems from an interdisciplinary perspective. Here, resilience extends from a concept focused on buffering stress and maintaining function to one where the focus is on the adaptive capacity to transform and innovate a system to sustain and reorganize in the face of stress and disturbance (Folke, 2006). These principles can be put into practice to manage a system for resilience (Adger, Hughes, Folke, Carpenter, & Rockstrom, 2005; Biggs et al., 2012; Walker & Salt, 2006).

3.0. LITERATURE REVIEW METHOD AND MATERIALS

Academic research documents on resilience and net zero within the built environment were reviewed to: 1) identify the main research areas within the domains; 2) gain insight into the size of the different areas; 3) gain insight into how the areas relate to one another; and 4) identify any research gaps. The screening and review entailed three steps. First, key search terms on the net zero movement and resilience concept were used to scan the Web of Science database and Elsevier's Scopus database. The screening excluded non-scientific or technological literature, and multiple combinations of the search terms were used. Combinations of terms included "resilience" with "city," "building," and "built environment," and "net zero" with "buildings" and "built environment." Articles, conference proceedings, books, and book chapters were included. In total, 1821 papers were found from a variety of disciplines in the resilience research domain, and 592 papers were found in the net zero research domain.

After screening, a computer program (VOSviewer) was used to analyze and determine influential studies, thinkers, and concentrated research topics and their correlations. VOSviewer is a tool used for citation analysis, a method used to quantitatively evaluate scientific and academic literature to assess the quality of an article or the impact of an author, journal, or institution. Citation analysis is also the "examination of the frequency, patterns, and graphs of citations in documents" (Wikipedia). For this project, VOSviewer was chosen for its ability to create a two-dimensional distance-based map based on a co-occurrence matrix; this process consists of three steps. The first step is to obtain a similarity matrix; in the second step, a map is constructed by applying the VOS mapping technique to the similarity matrix; and in the final step, the map is translated and reflected (Van Eck et al., 2010). In this review several types of maps were created: 1) Map of terms: Use all text data to generate a term map based on the frequency of the occurrence of specific text, in order to understand the research topics/clusters in one domain; 2) Map of keywords: Use co-occurrence of keywords data to construct a map representing the relationships between knowledge groups and different research fields; 3) Map of authors: Use citation data to construct a map to identify the influential thinkers in research domains; 4) Map of journal: Use citation data to construct a map to identify the influential journals/sources in the research domains.

As a last step, after creating an overview of research activities, more selective and focused reviews were carried out on 20 of the most influential papers in each track, as a means of drawing conclusions.

4.0. FINDINGS

4.1. Research topics on resilience

First, in order to identify the research focus areas, a term map was created based on a corpus of scientific publications amounting to 1821 articles. The co-occurrence frequencies of terms (text) of these articles were determined based on a minimum number of 20 occurrences of a term (10 is the default and recommended number, according to program manual; in order to narrow down the research, we used double the default number); out of the 39,855 terms, 496 met the threshold. For each of the 496 terms, a relevance score was then calculated, based on this score, the most relevant terms were selected; the default choice in the program is to select the 60 percent most relevant terms. Altogether, 275 terms were selected for the resilience research study; the result is shown in Fig. 1. Based on the VOSviewer clustering technique, the terms in the data set were divided into four clusters, with the colors indicating the different research clusters.

- Cluster 1 (red): technology, application, energy efficiency, performance, event (left)
- Cluster 2 (blue): factor, finding, relationship, health (right)
- Cluster 3 (green): urban resilience, governance, understanding/theory, ecosystem/eco service (middle)
- Cluster 4 (yellow): disaster, hazard, mitigation (upper)

These clusters represent four separate focus areas across different scales, which may be referred to as ***techniques and application of resilient practice*** (cluster 1), ***cause and relation of resilient factors*** (cluster 2), ***the understanding of the mutual influence of urban resilience and ecosystem*** (cluster 3), and ***disaster and hazard relief*** (cluster 4). The four focus areas can be tied to Hollings's clearly described resilience definitions: cluster 2 is derived from ecological resilience, cluster 3 is a continuation of social-ecological resilience, and cluster 4 is related to engineering resilience. Cluster 1 is about the translation or transformation of theory to application.

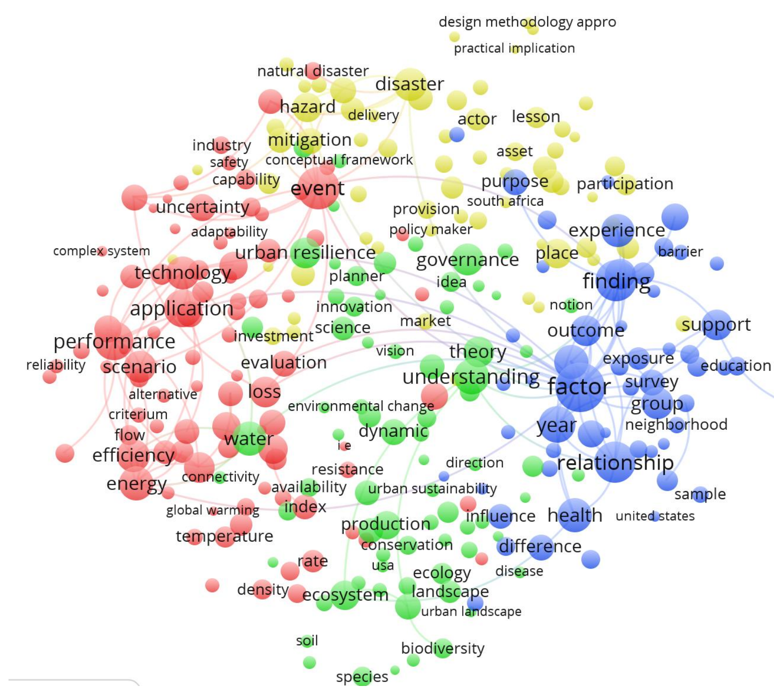

Figure 1: Term map representing the main research areas on resilience in the built environment.

4.2. Research topics on net zero

The same process used in studying the research domain on resilience was applied to the net zero research domain. A term map was first created based on a corpus of scientific publications, using keywords, titles, and abstracts from 519 documents: articles, book chapters, and books. This is many fewer than the quantity of research activities in the resilience domain. The co-occurrence frequencies of terms (text) of journals were determined based on a minimum number of 15 occurrences of a term, out of the 15,438 terms, which is only half of the terms associated with resilience; 167 met the threshold. For each of the 167 terms, a relevance score was then calculated. Based on this score, the most relevant terms were selected; again, the default choice in the program is to select the 60 percent most relevant terms. Altogether, 100 terms were selected for net zero research; the result is shown in Fig. 7. Based on the VOSviewer clustering technique, the terms in the data set were divided into four clusters, and the colors indicate the different research clusters.

- Cluster 1 (yellow): effect, rate/period (left)
- Cluster 2 (red): project/standard, net zero energy/practice, home (right)
- Cluster 3 (green): emission, energy source, water (middle)
- Cluster 4 (blue): zero energy building, heating/cooling/temperature, ventilation (upper)

These clusters represent four focus areas across different disciplines related to net zero research activities, which may be referred to as ***net zero impact*** (cluster 1), ***net zero energy practice in industry (***cluster 2), ***net zero emission*** (cluster 3), and ***techniques to achieve net zero energy building*** (cluster 4). Cluster 4 has the most research activities, which center around net zero building and temperature control. It is commonly known that net zero energy building mainly focuses on operating energy reduction, as heating and cooling together account for more than 50 percent of overall operating energy consumption, and the outside ambient temperature has a large influence on building heating and cooling load. Those factors could explain why heating, cooling, and temperature appear as critical sub-topics in cluster 4. Cluster 2 and cluster 3 are almost the same size, with cluster 2 containing more items and cluster 3 having items aggregating towards one major focus area: "emission." Cluster 1 has the fewest research items and is connected to both cluster 3 and 4, but has no connection to cluster 2. The disconnection between clusters 1 and 2 indicates the limited verification and measurement of the effectiveness of net zero development, particularly in the building industry. This lack of verification and measurement causes some suspicion and challenge to the validity of net zero building design and approach, which present a challenge and a gap as well as opportunities.

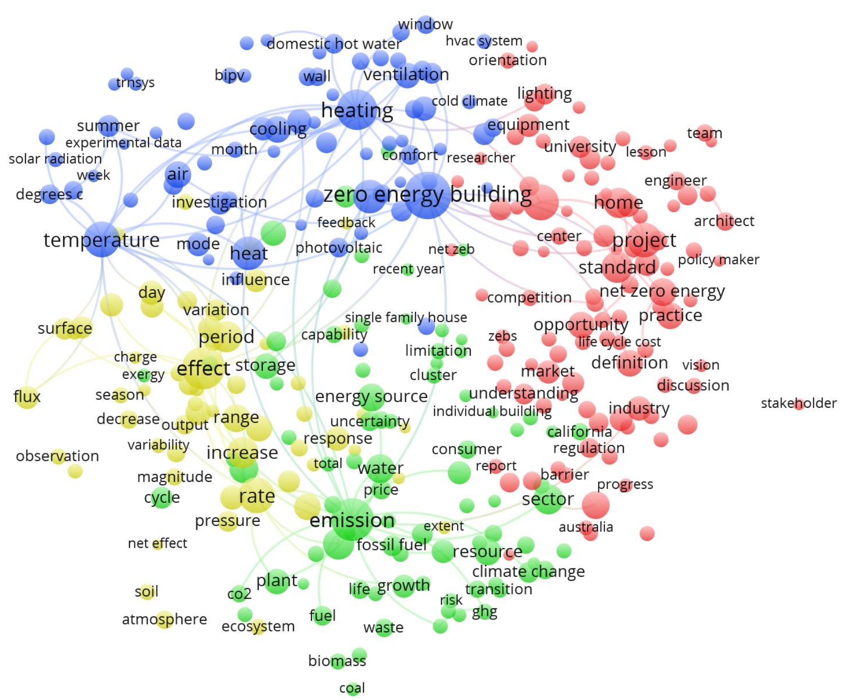

Figure 2. Term map representing the main research areas on net zero in the built environment.

5.0 Findings and discussion

The major findings from the review are as follows:

- A substantial gap exists between disaster mitigation, ecosystem service, and green infrastructure development.
- There is a disconnection between scientific understanding of resilience theory and translation of resilience attributes into practice.
- There is limited verification and measurement of the effectiveness of net zero development and practice, particularly in the building industry.
- The search for a consistent and commonly accepted definition of net zero building has been a singular focus in the past five years due to the strong interest and the quantity of new construction projects around the world.

The major differences between the research domains in net zero and resilience are: 1) singular versus transdisciplinary focus; 2) the distance and separation from the ecological origin; 3) developing countries versus global countries; and 4) top-down versus bottom-up. Each is discussed below.

Singular versus transdisciplinary focus: In terms of research activities, resilience studies in the built environment cover a variety of disciplines with a holistic approach, and the major activities and development have not shifted or moved away from its ecological origin. With the exception of building resilience, most studies and findings are, at a high level, aiming to provide a framework to respond to major natural disasters and man-made events. Beyond this high-level framework, some research activities focus on measurement, performance, and applicable strategies, which are the response to natural events happening in the built environment (urban context). One big gap discovered in this review is that there is a large disconnection between ecosystem and disaster relief: green infrastructure and ecosystem services have not been systematically integrated in future disaster mitigation and management work. Future research could bridge this gap. Unlike resilience studies, research activities on net zero have moved away from its ecological origin, and currently have a relatively narrow focus on operating energy and related environmental impact. The life cycle approach of the original net energy concept developed from ecology has been replaced by a performance-driven, building-types-driven engineering approach. In general, resilience studies in the built environment take a more holistic and comprehensive approach and incorporate long-term strategies, while net zero studies has a more limited scope. In urban resilience studies, the research recognizes the urban ecosystem's vulnerability and the necessity to adapt to the impact of climate change. In net zero studies, the research only addresses the CO_2 emissions from buildings that impact climate change, and does not consider the influence of climate change on the building industry; the net zero work also has limited attention to how climate change or ecosystem change could affect net zero building design strategies.

Developing countries versus global trends: With respect to influential studies, thinkers, and regions, the United States is the most active country in the past 45 years, particularly in the resilience domain, as the resilience theory was originated in the US. Net zero research is most distributed in developed countries, including the United States and western European countries. The United States does not have a clear lead in net zero research for two reasons: policy mandates and available resources. Unlike the EU countries, with their clear net zero building goals and objectives to be met, the United States still operates on a voluntary basis with any target related to high performance and net zero building: LEED, the living building challenge, and the 2030 challenges are all voluntary programs. It appears that resilience not only covers a wide range of fields, but also has research contributions from both developing and developed countries, since the developing countries are more vulnerable to natural disasters due to their lack of robust infrastructure and prevention methods. The dependence on active systems and photovoltaics as renewable energy sources makes it difficult and expensive to promote net zero energy building in developing countries. Integrating the holistic and multi-disciplinary resilient approach in net zero development will be helpful.

Top-down versus bottom-up: Current resilience practice in the building and construction industry follows a top-down approach, with the aim to solve immediate and short-term problems and respond to immediate shocks and stresses. The US Department of Housing and Urban Development (HUD) leads the initiative to incorporate resilient building codes into housing programs. HUD published a climate change adaptation plan in 2014 and identified major vulnerability and risks related to climate change (HUD, 2014). The Federal Emergency Management Agency (FEMA) is exploring strategies to incentivize the adoption and enforcement of building codes at a state and local level through a variety of programs. The National Institute of Standards and Technology (NIST) has organized and conducted research and published results to be shared with the building industry, such as tornado hazard maps; NIST hopes to better equip design and construction teams with sufficient information in order to build more resilient cities. The US Army Corps of Engineers launched a website to promote the latest building regulations and codes in the hope that the information will be integrated into urban and town planning. In 2016, the Department of Homeland Security released a toolkit to help communities develop a resilient infrastructure building plan in order to reduce the risks and damage caused by natural disasters. Other federal agencies such as the Department of Energy, Environmental Protection Agency, and US Department of Agriculture have their own resilience initiatives and activities. This kind of top-down approach has inherent limits, however, including inflexibility and lack of integration of adaptive capacity development. Also, the broad definitions of resilience suggest multiple methods to measure the resilience of built environment, which have not yet been synchronized. Furthermore, there is no clear outline of a path for practicing resilience in building design, and the outcome of resilience is difficult to define and measure.

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