RESILIENCE COVERAGE OF GLOBAL SUSTAINABILITY ASSESSMENT FRAMEWORKS: A SYSTEMATIC REVIEW

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ABSTRACT

Sustainable development has been a popular concept since 1987 and the issuance of the Brundtland report. A diverse number of sustainability assessment frameworks are available to examine the environmental performance of buildings and communities. With the current pace of climate change and the increasing threat of stronger, more frequent natural hazards, however, there are doubts that sustainability alone is an effective response. Sustainability assessment frameworks in recent years have been criticized for not incorporating hazard resilience. To better understand the current level of emphasis put on resilience to natural hazards in green building rating systems, this study aims to assess the level of resilience integration in existing sustainability assessment frameworks. The results demonstrate an overall lack of resilience coverage in the frameworks with only four frameworks, CASBEE, LEED, Green Globes, and DGNB having resilience coverage of 27.5%, 15%, 2.6%, and 1.1% respectively. This confirms a need for more systematic integration of resilience indicators into sustainability rating systems to create combined frameworks for sustainability and resilience.

KEYWORDS

sustainability assessment frameworks, green building rating systems, sustainability, resilience, integration, integrated framework, unified framework

1. INTRODUCTION

The modern environmental movement traces back to the mid-19th century, in response to increasing levels of air pollution during the industrial revolution. Marked by the introduction of power-driven machinery and the extensive reliance on coal consumption, the industrial revolution resulted in unprecedented economic growth. The Industrialized West soon realized that the

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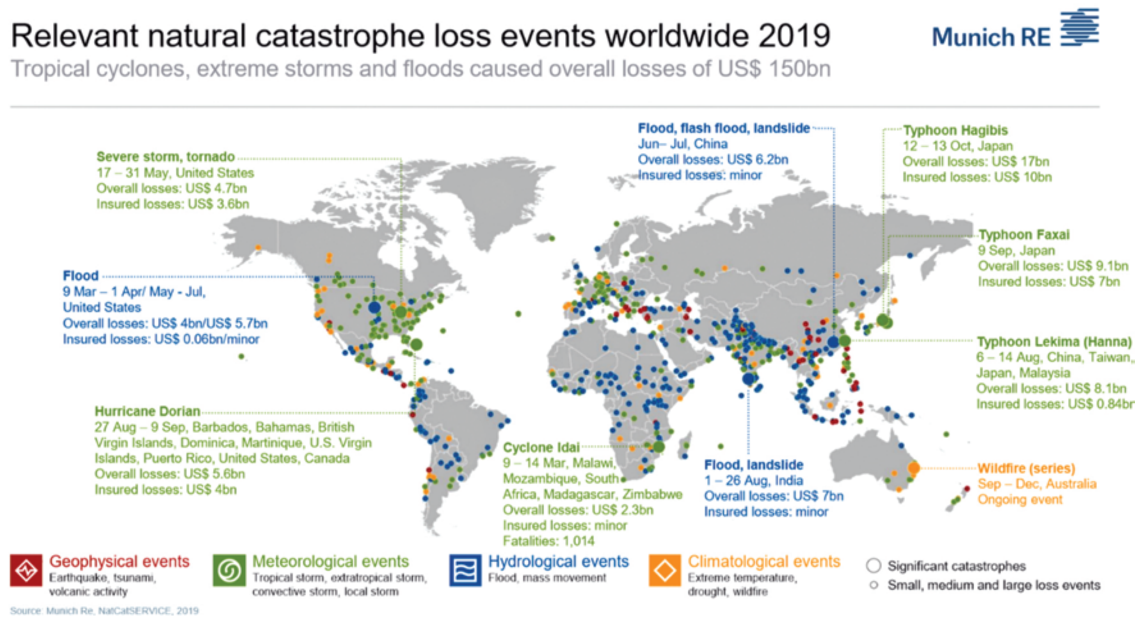
material benefits and great advances in technology come at a heavy cost to the environment. This awareness sparked the development of movements to mitigate air pollution and protect the environment, throughout the 20th century. In the 1970s the term "Sustainable Development' was introduced by Gro Harlem Brundtland. Later in 1987, as the Prime Minister of Norway, she chaired the United Nations Commission for Environment and Development, also known as the "Brundtland Report." The most cited definition of sustainable development came out of this same report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987).

The building sector accounts for the largest share of both global final energy use (IEA and UNEP, 2019). To pursue the principles of sustainable development, the way the buildings were designed and built needed to be reconsidered. In other words, to reduce environmental impacts associated with the buildings, a yardstick for measuring environmental performance was needed (Crawley & Aho, 1999). In this regard, the first commercially available environmental assessment tool for buildings, the Building Research Establishment Environmental Assessment Method (BREEAM) was established in 1990 in the UK. This was the first real attempt to "establish comprehensive means of simultaneously assessing a broad range of environmental considerations in buildings" (Crawley & Aho, 1999). It gave rise to the emergence of many different sustainability rating systems and Life Cycle Assessment (LCA) tools around the world ever since.

Since the report of the Brundtland Commission in 1987, sustainable development has remained a popular concept (Anderies et al., 2013; Lew et al., 2016). With the current pace of climate change and the increasing threat of stronger, more frequent natural hazards, however, there are doubts that sustainability alone is an effective response (Lew et al., 2016). Sustainability assessment frameworks such as Leadership in Energy and Environmental Design (LEED) have attracted criticism in recent years as they are said to be an exercise of efficiency (Reed, 2007), focusing mainly on energy consumption and carbon reduction (Kibert, 2007; Lizarralde et al., 2015). New York City, with one of the largest collections of LEED-certified green buildings in the world, suffered more than $19 billion in losses during Hurricane Sandy in 2012 (Zhao et al., 2015). Superstorm Sandy is an example of Extreme Weather Events. Extreme Weather Events and Large Scale Singular Events are among the five key reasons for concern identified by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2018). In recent years these events have taken a heavy toll on the lives of humans and other species, as well as economic development throughout the world. In 2019, the world faced a wide range of extreme events and suffered over 150 billion US dollars in losses (Munich RE, 2019). Among these natural hazards are the Black Summer Australian wildfires, Typhoons Faxai and Hagibis in Japan, Typhoon Lekima in China and Philippines, flood and landslides in India, the cyclone Idai in Africa, and hurricane Dorian in the Bahamas (Figure 1). Tropical Cyclone Idai, for example, made landfall on the east coast of Africa in March 2019, displacing 50,905 people in Zimbabwe, 53,237 in southern Malawi, and 77,019 in Mozambique. It also destroyed about 780,000 hectares (1,927,422 acres) of crops in Malawi, Mozambique, and Zimbabwe, further worsening food security in the region (WMO, 2019). Other, non-climate-related disasters, such as earthquakes and biological events, also cause catastrophic damage due to the increased urbanization and concentration of large populations in regions prone to natural disasters. According to the United Nations (2018), 55% of the world population (about 4.2 billion) resided in urban areas in 2018. This number is projected to go up by 13% by 2050. With the world population expected to go up to 9.7 billion by 2050 (United Nations, 2019) there will be 6.6 billion (an

FIGURE 1. Natural catastrophe loss events worldwide in 2019. Source: (Munich RE, 2019).



additional 2.4 billion) urban dwellers in the world. As the number and severity of risks to the built environment are increasing, the resilience of the built environment becomes more crucial, forcing a transformation in the design and construction of the built environment to minimize these risks, respond to the shocks and maintain functionality.

The need for transforming the way the buildings are designed and built applies to the design of green buildings too. While reducing the environmental footprint of buildings, these green buildings must also withstand external stressors that may arise over the buildings' lifetime (C.L.Aktas & 2016, 2016). In this regard, the majority of the literature acknowledges the need for integrating resilient design indicators into sustainability assessment frameworks (Champagne & Aktas, 2016; Redman, 2014; Roostaie et al., 2019a; Zhao et al., 2015).

Previous studies have investigated this topic with different approaches. Champagne and Aktas (2016), for example, assessed resilience coverage of LEED V4 and concluded that about half of the identified resilience principles are not addressed in LEED V4. Another study analyzed 11 sustainability assessment frameworks including different variations of the same system, for example, the Japanese Comprehensive Assessment System for Building (CASBEE) for New Construction, CASBEE for Home, and CASBEE for Urban development. They reported that resilience is not systematically integrated throughout the selected frameworks. They also recognized a limited coverage of hazards and a weakness in acknowledging the impacts of climate change that may lead to the design of structures and communities vulnerable to extreme events (Matthews et al., 2014). In a different work, Achour et al. (2015) studied 10 international frameworks based on the geographical areas they cover and found CASBEE and the German Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) as the only tools in which resilience had been integrated.

Although prior studies have examined the resilience coverage of green building rating systems, they have usually focused on a handful of frameworks including different variations of a given system. Therefore, this study reviews 34 different global sustainability assessment frameworks and analyzes their level of resilience integration under five resilience assessment themes of Risk Avoidance, Passive Survivability, Durability & Longevity, Redundant Systems, Response & Recovery. By advancing a better understanding of how and to what degree green building rating systems account for resilient design indicators, more successful assessment frameworks can be developed to improve the resiliency of green buildings to external shocks and disturbances.

Resilience in the context of Sustainability Assessment Frameworks

The concept of resilience has been gaining momentum in academia and practice due to the increasing trend of extreme climate events (Roostaie et al., 2019a). Given the complexity surrounding resilience as a concept and its areas of applicability, providing a single definition that fully captures the notion is challenging. First introduced in the field of ecology through Holling's work in 1973, the concept of resilience then evolved and influenced a variety of disciplines. Previous studies have provided a wide range of definitions for resilience in different fields of studies (Brand & Jax, 2007; Roostaie et al., 2019b; Xu et al., 2015). Since this study focuses on the single-building level, it studies the physical dimension of resilience that refers to the design, physical configuration, materials, and engineering aspects of a building to absorb external stresses and retain function in the face of disturbance (Burroughs, 2017; Zhao et al., 2015). Resilience in this context relates to the buildings and their systems including architectural, structural, life safety, mechanical, electrical, plumbing, security, communication, and information technology systems, as well as the connections to external infrastructure and services (Burroughs, 2017).

To evaluate the resilience coverage of selected green building rating systems in this study five resilience assessment themes were selected namely, Risk Avoidance, Passive Survivability, Durability & Longevity, Redundant Systems, Response & Recovery. These five themes are adopted from a study done by Phillips and colleagues (2017) in which they used these five themes to investigate 88 strategies driven from four resilient design frameworks, for their potential conflict with sustainability criteria. There are different approaches to categorize resilient design measures that usually cover individual themes and use different terminologies. RELi for example uses Hazard Preparedness which covers Hazard Adaptation and Mitigation (RELi Guidebook, 2015). There are also other models including Mitigation Model, Recovery Model, Structural-cognitive Model described by Tobin (1999) that have partial overlaps with the themes adopted in this study. However, we found the categories suggested by Phillips and colleagues (2017) more comprehensive and therefore a better fit for our study. These five assessment themes are defined below:

Risk Avoidance (RA): Falls under the mitigation model in adopting resilience through which exposure to risks is reduced (Tobin, 1999). Design strategies such as elevating mechanical systems, breakaway systems, or site selection out of floodplains, are examples of risk avoidance measures that reduce or eliminate the inherent risk from hazard damage (Phillips et al., 2017).

Passive Survivability (PS): Refers to the ability of a building to maintain critical life-support conditions for its occupants if services such as power, heating fuel, or water are lost for an extended period. It can be achieved by incorporating design features such as cooling-load avoidance strategies, capabilities for natural ventilation, a highly efficient thermal envelope, passive solar gain, and natural daylighting (Wilson, 2005). Such strategies allow the building to operate with minimal external input (Phillips et al., 2017).

Durability and Longevity (DL): Have to do with the capacity of buildings to offer functionally valuable spaces for a long time, and depends on factors such as the function of the building, applied technology, environmental conditions, local culture, and economic and political situation (Wacław, 2014). Durability and longevity are also referred to as the buildings' ability to absorb and adapt to disturbances and changes in the program and associate them with designing for structural robustness and flexibility of use (Phillips et al., 2017).

Redundant Systems (RS): Is the ability to switch between numerous available choices beyond optimal design (Stevenson, F et al., 2016). In other words, redundant systems are systems such as backup generators and water supply systems that support the main functions of the building if the primary systems are disrupted (Phillips et al., 2017).

Response and Recovery (RR): Response refers to a series of actions that happen during or immediately after the disaster to save lives, protect property and the environment, and meet basic human needs. Recovery begins right after the emergency has passed and is comprised of activities to return the building systems to normal, including restoring essential services, and repairing damages caused by the event (Lindsay, 2012).

2. METHODOLOGY

The ATHENA Sustainable Material classifies green building and Life Cycle Assessment (LCA) tools into three different categories of product comparison tools, whole building design or decision support tools, and whole building assessment frameworks or systems (Trusty, 2000).

The International Energy Agency (IEA) in its ANNEX 31 project categorizes the assessment tools into five classes combined with the ATHENA classification. The five classes of IEA ANNEX 31 include Energy Modelling software, Environmental LCA Tools for Buildings and Building Stocks, Environmental Assessment Frameworks and Rating Systems, Environmental Guidelines or Checklists for Design and Management of Buildings, and Environmental Product Declarations, Catalogues, Reference Information, Certifications and Labels.

TABLE 1. Athena Classification of green building and (LCA) tools.

Level	Tool Type	Examples
1	Product comparison tools and information sources	BEES, the Environmental Resource Guide, LCExplorer, SimPro, TEAM
2	Whole building design or decision support tools	ATHENATM, EcoQuantum, Envest, DoE2, E10, Radiance
3	Whole building assessment frameworks or systems	BREEAM, EcoEffect, EcoProfile, Environmental Status Model, ESCALE, LEED, Green Globe

TABLE 2. IEA ANNEX 31 Classification of Assessment Tools with Respect to Athena Classification.

Class	Tool Type	
1	Energy Modelling softwares	
2	Environmental LCA Tools for Buildings and Building Stocks	BEES 3.0 and TEAM (ATHENA's Level 1)
		ATHENA, BEAT 2002, BeCost, EcoQuantum, Envest 2, EQUER, LEGEP and PAPOOSE (ATHENA's Level 2)
		EcoEffect and ESCALE (ATHENA's Level 3)
3	Environmental Assessment Frameworks and Rating Systems	BREEAM, EcoEffect, EcoProfile, Environmental Status Model, ESCALE, LEED (ATHENA's Level 3)
4	Environmental Guidelines or Checklists for Design and Management of Buildings	
5	Environmental Product Declarations, Catalogues, Reference Information, Certifications and Labels	

This analysis focuses on ATHENA's Level 3, whole building assessment frameworks that are in line with class three of the IEA ANNEX 31 classification. In order to identify the most applicable rating systems for this study, the following review approach was used:

2.1 Identification of sustainable building rating systems

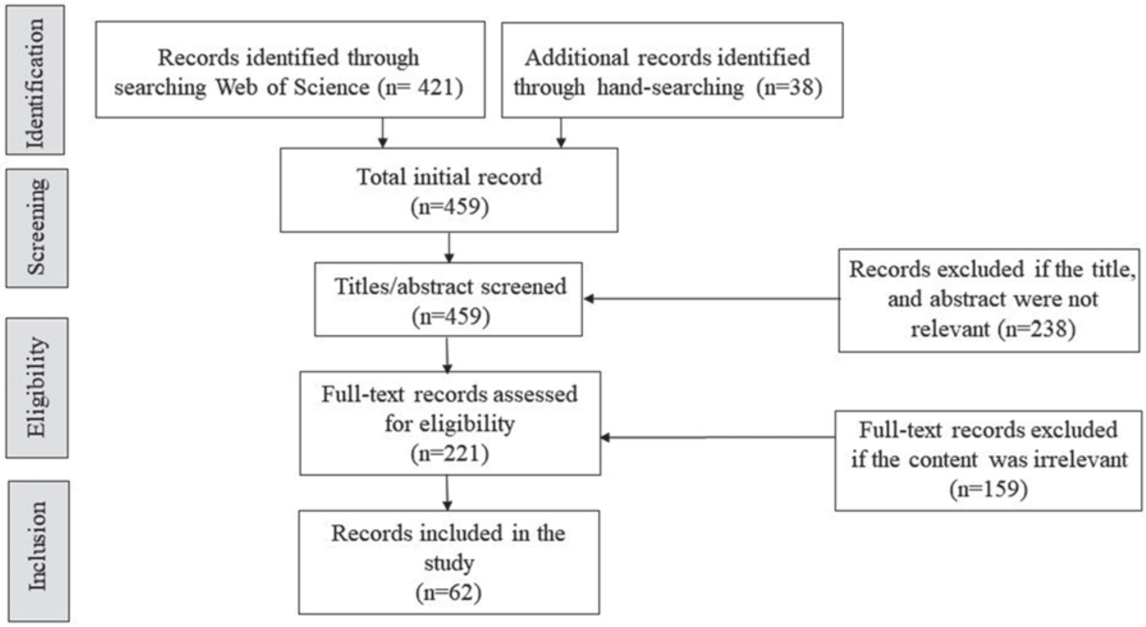
To find an inclusive list of globally used green building assessment frameworks a search was conducted in the Web of Science database. To control the quality and uniformity of data, the document type was limited to articles, books, and book chapters, and the language was set to English. As the first environmental assessment tool, BREEAM was established in 1990 the search timespan was set from 1990 to 2020. This search yielded 421 results.

Once the data search was completed, 38 records identified through hand-searching were added. Additional data was directly acquired from the official technical manuals for the rating schemes and the official homepages of the certification organization. This resulted in a total of 459 records eligible for the screening process.

TABLE 3. Search inputs and results.

Database	Web of Science
Topic	(green building OR sustainable building) AND rating systems) AND sustainability)
Document Type	Article, Book, Book Chapter
Time Span	1990–2020
Language	English
Results	421

FIGURE 2. Literature review search strategy. Based on (Liberati et al., 2009).



2.2 Screening analysis of rating systems to limit the review to most applicable systems

Titles and abstracts of the records were then screened and irrelevant results were excluded. 221 full-text records were selected for the eligibility check. After reading the full texts records, a total of 62 papers were included in this study (Figure 2). After selecting the final records to be included in the study, they were fully assessed to create a list of whole building assessment systems. As this study focuses on whole building assessment frameworks, the benchmarking or evaluation tools and software programs were excluded for not meeting the criteria. Different variations of the same systems were not considered and therefore excluded from the study.

2.3 Eligibility Evaluation

The selected frameworks were then assessed for their coverage of resilience in areas including Risk Avoidance, Passive Survivability, Durability & Longevity, Redundant Systems, Response & Recovery.

2.4 Final Evaluation

Among all the rating systems available worldwide, only four had a significant portion dedicated to resilience and therefore, met the criteria for a more detailed review. These four rating systems were thoroughly analyzed to explore similarities and differences in their coverage of resilience indicators and, eventually, identify implications for the design of comprehensive assessment frameworks that cover both sustainable and resilient design indicators. In order to calculate the percentage coverage of resilience for the final four systems we counted the points or credits allocated to resilience in each sustainability assessment framework and divided them by the total number of points or credits offered by each system.

3. RESULTS

TABLE 4. Initial Screening of SAFs for Resilience Coverage.

Launch Year	Name	Country	Different Categories	Resilience Coverage Yes/NO	Points Allocated to Resilience	Coverage Ratio
1990	Building Research Establishment Environmental Assessment Method **(BREEAM)**	UK	1. Management 2. Health and wellbeing 3. Energy 4. Transport 5. Water 6. Materials 7. Land use and ecology 8. Pollution (BREEAM, 2018; Kamsu-Foguem et al., 2019; Sijakovis et al., 2020)	Yes	1/148	0.7%
1993	Building Environmental Performance Assessment Criteria **(BEPAC)**	Canada	1. Ozone Layer Protection 2. Environmental Impacts of Energy Use 3. Indoor Environmental Quality 4. Resource Conservation 5. Site and Transportation (Cole, 1994)	No	0	0
1996	Hong Kong Building Environmental Assessment Method **(BEAM Plus)**	Hong Kong	1. Site Aspects (SA) 2. Materials Aspects (MA) 3. Energy Use (EU) 4. Water Use (WU) 5. Indoor Environmental Quality (IEQ) 6. Innovation (HKGBC, 2010)	No	0	0
1997	Haute Qualité Environnementale **(HQE)**	France	1. eco-construction 2. eco-management 3. comfort 4. health (Kryvomaz et al., 2018)	No	0	0

TABLE 4. (Continued)

Launch Year	Name	Country	Different Categories	Resilience Coverage Yes/NO	Points Allocated to Resilience	Coverage Ratio
1998	Leadership in Energy and Environmental Design **(LEED)**	USA	1. Integrative Process 2. Location & Transportation 3. Sustainable Sites 4. Water Efficiency 5. Energy and Atmosphere 6. Material and Resources 7. Indoor Environmental Quality 8. Innovation 9. Regional Priority (USGBC, 2020)	Yes	17/110	15%
	Sustainable Building Tool **SB-Tool (former GBTool)**	Multi-National	1. Urban form 2. Land use and infrastructure 3. Ecology and biodiversity 4. Energy 5. Water 6. Materials and wastes 7. Comfort of outdoor areas 8. Safety 9. Amenities 10. Mobility 11. Local and cultural identity 12. Employment promotion and investment (Castanheira & Bragança, 2014)	No	0	0
1999	Ecology, Energy Saving, Waste Reduction and Health **(EEWH)**	Taiwan	1. Ecology 2. Energy Saving 3. Waste Reduction 4. Health (Lin, 2005)	No	0	0
2000	**Green Globes**	Canada/ US	1. Project Management 2. Site 3. Energy 4. Water Efficiency 5. Materials 6. Indoor Environment (Kibert, 2016)	Yes	26/1000	2.6%

TABLE 4. (Continued)

Launch Year	Name	Country	Different Categories	Resilience Coverage Yes/NO	Points Allocated to Resilience	Coverage Ratio
2001	**ESCALE**	France	1. Energy resources 2. Other resources 3. Waste 4. Large scale pollution 5. Local pollution 6. Contectual fit 7. Comfort 8. Health 9. Environmental management 10. Maintenance 11. Adaptability (Nibel et al., n.d.)	N0	0	0
2002	Comprehensive Assessment System for Built Environment Efficiency **(CASBEE)**	Japan	1. Indoor Environmental 2. Quality of Service 3. Outdoor Environment (On-site) 4. Energy 5. Resources & Materials 6. Off-site Environment (CASBEE, 2014)	Yes	234/849	27.5%
	Green Building Certification System **(GBCS)**	South Korea	1. Energy efficiency and load on the environment 2. Indoor environmental quality 3. Land use, transportation and ecology (Portalatin et al., 2015)	No	0	0
	Green Star	Australia	1. Management 2. Indoor environmental quality 3. Energy 4. Transport 5. Water 6. Materials 7. Land use and ecology 8. Emissions 9. Innovation	No	0	0

TABLE 4. (Continued)

Launch Year	Name	Country	Different Categories	Resilience Coverage Yes/NO	Points Allocated to Resilience	Coverage Ratio
2002			10. Governance 11. Design 12. Livability 13. Economic prosperity 14. Environment (Portalatin et al., 2015)			
	Comprehensive Environmental Performance Assessment Scheme **(CEPAS)**	Hong Kong	1. Indoor Environmental Quality 2. Building Amenities 3. Resources Use 4. Loadings 5. Site Amenities 6. Neighbourhood Amenities 7. Site Impacts 8. Neighbourhood Impacts (Wu & Yau, 2005)	No	0	0
	Sustainable Building Assessment Tool **(SBAT)**	African Countries	1. Environmental 2. Economc 3. Social (Bernardi et al., 2017)	No	0	0
2003	**Protocollo Itaca**	Italy	1. Outdoor Environmental Quality 2. Resource Consumption 3. Loadings 4. Indoor Environmental Quality 5. Quality of Service 6. Management Quality 7. Transport (Moro et al., 2005)	No	0	0
2004	Økoprofil **(Eco Profile)**	Norway	1. External environment, 2. Resources 3. Indoor climate (Bernardi et al., 2017)	No	0	0

TABLE 4. (Continued)

Launch Year	Name	Country	Different Categories	Resilience Coverage Yes/NO	Points Allocated to Resilience	Coverage Ratio
2005	**Green Mark**	Singapore	1. Climate Responsive Design 2. Building Energy Performance 3. Resource Stewardship 4. Smart and Healthy Building 5. Advance Green Efforts (BCA, 2015)	No	0	0
	Green Building Standard SI-5281	Israel	1. Energy 2. Site 3. Water 4. Materials 5. Health and Wellbeing 6. Waste 7. Transport 8. Environmental Management 9. Innovation (Pushkar & Engineering, n.d.)	No	0	0
	Liderar por el ambiente para la Construcción Sostenible **(LiderA)**	Portugal	1. Site and Integration 2. Resources 3. Environmental Loadings 4. Environmental Comfort 5. Socio-economic Experience 6. Sustainable Use (LiderA, 2011)	No	0	0
	National Australian Built Environment Rating System **(NABRES)**	Australia	1. Energy 2. Water 3. Waste 4. Indoor Environment 5. Green House Gas Emission (Bannister & Action, 2016)	No	0	0
			1. Land savings and Outdoor Environment 2. Energy Savings 3. Water Savings			

TABLE 4. (Continued)

Launch Year	Name	Country	Different Categories	Resilience Coverage Yes/NO	Points Allocated to Resilience	Coverage Ratio
2006	**3-Star**	China	4. Materials Savings 5. Indoor Environmental Quality 6. Operations and Management (Khanna et al., 2015)	No	0	0
	EccoEffect	Sweden	1. Materials Use, 2. Energy Use, 3. Indoor Environment, 4. Outdoor Environment 5. Lifecycle Costs (Myhr & Johansson, 2008)	No	0	0
	The Finnish Environmental Assessment and Classification System **(PromisE)**	Finland	1. Human Health 2. Use of Natural Resource 3. Ecological Consequences 4. Environmental Risk Management (Building et al., 1800)	No	0	0
2007	Green Rating for Integrated Habitat Assessment	India	1. Sustainable Site Planning 2. Construction Management 3. Energy Optimization 4. Ocupant Comfort 5. Water Management 6. Solid Waste Management 7. Sustainable Building Material 8. Life Cycle Costing 9. Socio-Economic Strategies 10. Performanve Metering and Monitoring(TERI & GRIHA, 2019)	No	0	0

TABLE 4. (Continued)

Launch Year	Name	Country	Different Categories	Resilience Coverage Yes/NO	Points Allocated to Resilience	Coverage Ratio
2007	**LOTUS**	Vietnam	1. Energy 2. Water 3. Material & Resource 4. Health & Comfort 5. Site & Environment 6. Management 7. Exceptional Performance (VGBC, 2019)	No	0	0
2008	**AQUA process**	Brazil	1. Building Relationship with Its Surroundings 2. Integrated Products, Systems and Construction Processes Choice 3. Building Site with Low Environmental Impact (Aparecida et al., 2010)	No	0	0
	LEnSE	Belgium	1. Climate Change 2. Biodiversity 3. Resource Use 4. Environmental and Geophysical Risk 5. Occupant Wellbeing 6. Security 7. Social and Cultural Value 8. Accessibility 9. Financing and Management 10. Whole Life Value 11. Externalities (Bernardi et al., 2017)	No	0	0
	The Swiss standard for energy-efficient construction **(Minergie)**	Switzerland	1. Light 2. Embodied Energy 3. Air Tightness 4. Solar Protection 5. Ventilation 6. Auxiliary Energy 7. Household Appliances (Mennel et al., 2007)	No	0	0

TABLE 4. (Continued)

Launch Year	Name	Country	Different Categories	Resilience Coverage Yes/NO	Points Allocated to Resilience	Coverage Ratio
2009	Deutsche Gesellschaft für Nachhaltiges Bauen **(DGNB)**	Germany	1. Environmental Quality 2. Economic Quality 3. Sociocultural and Functional Quality 4. Technical Quality 5. Process Quality 6. Site Quality (DGNB, 2018)	Yes	—	1.1%
	Green Building Index **(GBI Malaysia)**	Malaysia	1. Energy Efficiency 2. Indoor Environment Quality 3. Sustainable Site Planning and Management, 4. Materials and Resources 5. Water Efficiency 6. Innovation (PAM & ACEM, 2009)	No	0	0
	Building for Ecologically Responsive Design Excellence **(BERDE)**	Philippines	1. Energy Efficiency and Conservation 2. Water Efficiency and Conservation 3. Waste Management 4. Management 5. Use of Land and Ecology 6. Green Materials 7. Transportation 8. Indoor Environment and Quality 9. Emissions (PGBC, 2018)	No	0	0
2010	**Pearl/ Estidama**	United Arab Emirates	1. Integrated Development Process 2. Natural Systems 3. Livable Communities/ Buildings/ Villas 4. Precious Water 5. Resourceful Energy 6. Stewarding Materials 7. Innovating Practice (Akerlof et al., 2014)	No	0	0

TABLE 4. (Continued)

Launch Year	Name	Country	Different Categories	Resilience Coverage Yes/NO	Points Allocated to Resilience	Coverage Ratio
2010	**GSAS**	Qatar	1. Site 2. Energy 3. Water 4. Materials 5. Outdoor/ Indoor Environment 6. Cultural Economic Value 7. Mnagament & Operations 8. Urban Connectivity (SmrtE, 2019b)	No	0	0
2016	**Al Safat**	United Arab Emirates	1. Ecology & Planning 2. Building Vitality 3. Resource Effectiveness—Energy 4. Resource Effectiveness—Water 5. Resource Effectiveness—Materials & Waste (SmrtE, 2019a)	No	0	0

The 34 green building rating systems listed in Table 4 were reviewed for their coverage of resilience under the five assessment themes of Risk Avoidance, Passive Survivability, Durability & Longevity, Redundant Systems, Response & Recovery. It should be noted that these five themes are not specifically mentioned in the sustainability assessment frameworks. Therefore, the authors checked the description of each category in different frameworks' guidebooks and decided what assessment theme each category may fall under. After a thorough analysis and review of the 34 frameworks, only five were identified to have at least partial coverage of resilience (Table 4). The BREEAM framework was excluded as its emphasis on resilience is negligible (0.7% of points available pertaining to resilience). CASBEE showed the highest coverage at 27.5% followed by 15% for LEED, 2.6% for Green Globe, and 1% for DGNB. These four frameworks and their approach to covering resilience are further explained as follows:

DGBN System:

DGNB System is a certification system developed by the German Sustainable Building Council in 2007 and introduced to the market in 2009. DGNB offers both national and international environmental assessments for buildings (New construction, Renovation, and Existing buildings, Buildings in Use, and Deconstruction of Buildings), interiors, and urban districts.

The evaluation is based on 37 criteria, subdivided into six categories of Environmental Quality, Economic Quality, Sociocultural and Functional Quality, Technical Quality, Process

Quality, and Site Quality. The total performance index of a building is calculated using these six topics, taking their individual weighting into account. The first three categories, known as the "three pillars" of sustainability are weighted equally in the assessment criteria (22.5% each), making DGNB the only system to place equal emphasis on both economic and ecological aspects of sustainability (DGNB, 2018). The other three categories weigh 15%, 12.5%, and 5% respectively. The DGNB system offers four levels of certification based on the total performance index of buildings as follow:

- Bronze: Total performance indices of 35% and higher.
- Silver: Total performance indices of 50% and higher.
- Gold: Total performance indices of 65% and higher.
- Platinum: Total performance indices of 80% and higher.

DGBN's Resilience Coverage

DGNB System's coverage of resilience is concentrated under the Site Quality category and more specifically under the Local Environment section. The Local Environment acknowledges the fact that the geography of the building's site has its own set of natural hazards which cannot be changed and are hard to predict. Therefore, the objective of this subcategory is to protect the building and its users from the impact of negative environmental influences and extreme events and to improve the resilience of buildings to any influences that might be present in the local environment (DGNB, 2018). Resilient design measures included in DGNB are mainly focused on Durability & Longevity and Response & Recovery. Durability & Longevity requires carrying out site-specific risk analysis and implementing structural measures to protect against those risks. Response & Recovery is implemented by providing safety measures to protect the occupants.

TABLE 5. DGNB category description and weighting.

Category	Description	Weighting
Environmental Quality	Focuses on the effects of buildings on the global and local environment as well as the impact on resources and the generation of waste	22.5%
Economic Quality	Addresses the long-term economic viability (life cycle costs) and economic development	22.5%
Sociocultural and Functional Quality	Assess buildings with regard to health, comfort, and user satisfaction as well as the essential aspects of functionality	22.5%
Technical Quality	Provide a scale for evaluating the technical quality in view of relevant sustainability aspects	15%
Process Quality	Increases the planning quality and the construction quality assurance	12.5%
Site Quality	Assess the impact of the project on its environment and vice versa	5%

The natural disasters and the environmental risks covered under the Local Environment criterion are as follows:

- Earthquake
- Volcanic Eruption
- Avalanches
- Storm
- Floods
- Heavy Rain
- Hail
- Landslides/Subsidence
- Storm Surge/ Tsunami
- Extreme Climates
- Forest Fires

Since the Site Quality itself accounts for 5% of the total performance index, and the Local Environment as one of the four subcategories accounts for 1.1% of the total points.

CASBEE:

CASBEE is the Japanese rating system that assesses the environmental performance of buildings. The first CASBEE assessment tool was completed in 2002 for offices. It was followed by CASBEE for New Construction in July 2003, CASBEE for Existing Buildings in July 2004, and CASBEE for Renovation in July 2005. CASBEE offers certification on different scales including, housing, building, urban and city scale. On the building scale, it offers assessments for New Construction, Existing Buildings and Renovation. CASBEE evaluates features such as interior comfort and scenic aesthetics, in consideration of environmental practices which include using materials and equipment that save energy or achieve smaller environmental loads.

CASBEE has 20 criteria divided under two main umbrellas of Environmental Quality (Q) and Environmental Load Reduction (LR). The Environmental Quality category is itself divided into three subcategories of Indoor Environmental, Quality of Service, and Outdoor Environment (On-site). The Environmental Load Reduction also has three subcategories as Energy, Resources & Materials, Off-site Environment. To assess buildings performance,

TABLE 6. CASBEE category description and weighting.

Category	Description	Weighting
Environmental Quality Q1. Indoor Environmental Q2. Quality of Service Q3. Outdoor Environment (On-site)	The quality related to improving everyday amenity for users	50%
The Environmental Load Reduction LR1. Energy LR2. Resources & Materials LR3. Off-site Environment	Focuses on energy consumption, resource consumption and diverse impact on the off-site environment such as pollution	50%

CASBEE uses a metric called the Built Environment Efficiency (BEE) which takes into account both the Environmental Quality of Building and the Environmental Load of building using the following formula:

$$\text{BEE} = \frac{Q = \text{Environmental Quality of Building}}{L = \text{Environmental Load of Building}} = \frac{25(SQ-1)}{25(5-SLR)},$$

where SQ = total score for the Q categories
SLR = total score for LR categories

CASBEE offers five levels of certification based on the BEE value and the Q score as follow:

- Excellent (S): BEE score of 3.0 or more, and Q value of 50 or more.
- Very Good (A): BEE score of 1.5 to 3.0; or BEE score of 3.0 or more and Q value of less than 50.
- Good (B+): BEE score of 1.0 to 1.5.
- Fairly Poor (B–): BEE score of 0.5 to 1.0.
- Poor (C): BEE score of less than 0.5.

CASBEE's Resilience Coverage:

When it comes to resilience coverage, CASBEE addresses the concept more comprehensively. Resilience-related checkpoints in CASBEE are spread out under multiple categories. In CASBEE, resilience has been introduced within the tool as an improvement of the Quality of Service but then extended to involve Load on Local Infrastructure and assurance that even structural and non-structural component material must have a proportion of recycled material (Achour et al., 2015). CASBEE translates resilience to Quality of Services and focuses on Durability & Reliability during extreme events such as earthquakes, strong winds, and major accidents. The Durability and Reliability category has three subcategories as follows:

- Earthquake resistance evaluates the building's performance in terms of its seismic capacity and occupant comfort in windy conditions.
- Service life refers to the expected period of life which ends when material or equipment breaks down or loses its required physical function.
- Reliability is the ability of the building to maintain its functions in the event of a natural hazard or major accident. The main systems included in this category are the HVAC system, water supply and drainage, electrical equipment, support method of machines and ducts, communications and IT equipment. (CASBEE Technical Manual, 2014).

Other checkpoints such as Floor Load Margin and Adaptability of Facilities address resilience based on buildings' potential for future adaptations and changes of the building type under Flexibility & Adaptability. The third category of Environmental Load Reduction of the Building, Off-site Environment, also takes into account resilience with checkpoints such as Consideration of Global Warming and Wind/Sand Damage & Sunlight Obstruction. Global warming consideration addresses the lifecycle CO2 emission during the construction, operation, and demolition phase. Restriction of Wind Damage under Wind/Sand Damage & Sunlight

Obstruction focuses on measures taken to avoid or reduce wind-related hazards (CASBEE Technical Manual, 2014).

Resilient design measures covered in CASBEE fall under the Durability & Longevity assessment theme. Durability & Reliability measures are associated with structural robustness and withstanding external shocks and disturbances. Flexibility & Adaptability focus on flexibility of use that provides the buildings with the capacity to serve for a long time. Other measures such as Consideration of Global Warming and Wind/Sand Damage & Sunlight Obstruction also focus on preparing for future hazards associated with global warming as well as wind and sand damage and therefore contribute to the Durability & Longevity of buildings.

Green Globes:

Green Globes is based on ANSI Standard GB-01-2019, which defines a system for evaluating commercial and institutional buildings relative to the tenets of integrated design and current best practices for high-performance green buildings. The system was developed by The Green Building Initiative (GBI) in 2000, Canada, and in its present version is mainly used in the US. This rating system applies to an extensive range of building types such as multi-family, offices, schools, health care, universities, industrial, labs, retail, etc., though it does not refer to single-family and two-family homes and townhouses with three stories or less.

The evaluation is based on six assessment areas including project management, Site, Energy, Water Efficiency, Materials, and Indoor Environment. The first category, known as Project Management, is weighted 10% of total points, the other three categories such as Site, Materials, and Indoor Environment are each weighted 15% of the total. Water Efficiency has 19% of all, and the major category with 26% of the total is Energy. The green Globes system offers four levels of achievement based on the percentage of Points Achieved Out of Applicable Points as follow:

- Level 4: 85–100% of points achieved
- Level 3: 70–84% of points achieved
- Level 2: 55–69% of points achieved
- Level 1: 35–54% of points achieved

To gain compliance in each Level, buildings must, first, achieve a minimum of 35% of applicable points out of the 1000 possible points available, and then, achieve a minimum percentage of 20% in each environmental assessment (ANSI, 2019; Kibert, 2016).

Green Globes Resilience Coverage:

Green Globes system's coverage of resilience is concentrated under the Project Management and Site categories. In the Project Management category, there is a subdivision, known as Site and Building Resilience which includes Building Risk Assessment and Building Operational Continuity or Recovery Assessment. The assessment distinguishes hazards and evaluates the severity and probability of the occurrence of them. These hazards include, but are not limited to:

- weather
- flooding
- seismic
- volcanic events

TABLE 7. Green Globes category description and weighting.

Category	Description	Weighting
Project Management	Focuses on Team & Owner Planning, Environmental Management During Construction, Life Cycle Cost Analysis or Building Service Life Planning, Moisture Control Analysis, Commissioning or Systems Manual & Training	10%
Site	Addresses Development Area, Transportation, Construction Impacts, Stormwater Management, Landscaping, Exterior Light Pollution.	15%
Energy	Assess building's performance based on ANSI/ASHRAE/IES Standard 90.1-2016 or Building Carbon Dioxide Equivalent (CO_2e) or Building Envelope and Form, Lighting, HVAC Systems and Controls	26%
Water Efficiency	Provide a scale for evaluating Indoor Domestic Plumbing, Cooling Towers, Boilers and Hot Water Systems, Water Intensive Applications, Water Treatment, Alternate Water Sources, Irrigation, metering	19%
Materials	Focuses on Whole Building Life Cycle Assessment, Product Life Cycle, Product Risk Assessment, Sustainable Materials Attributes, Reuse of Existing Structures and Materials, Waste	15%
Indoor Environment	Assess Air Ventilation and Quality, Source Control and Measurement of Indoor Pollutants, Lighting Design and Systems, Thermal Comfort, Acoustic Comfort	15%

- drought
- wildfire
- soil stability
- terrorism

This category also focuses on the requirement of rapid or continuous recovery of different building functions during and after an advanced event has been conducted.

In the Site category, there is a subcategory, called Development Area considers the project which is not placed on or nearby to sensitive natural sites or on land that was a sensitive natural site for at least three years earlier to the time of investment or from the start of the project. The other important part that should be considered in evaluating is Floodplains. To attain points for this part, the buildings in the floodplain should elevate a minimum of 3 ft. (.9 m) above the 100-year floodplain or build in a way to allow water to flow through or under the lowest floor. Resilience-related measures in Green Globes under Project Management belong to different assessment themes. Building Risk Assessment falls under Durability & Longevity as it identifies the potential risk that the building withstands. Building Operational Continuity calls for incorporating measures such as redundant systems that help buildings remain functional when facing disturbances. The Recovery Assessment, as the name suggests, belongs to the Response & Recovery assessment theme. Strategies under the Site category mainly belong to the Risk

Avoidance theme as they focus on avoiding construction on sensitive natural sites or buildings in floodplains.

The Project Management category accounts for 100 points of the total performance index and consists of 11 points for the risk and recovery issues. The Site itself accounts for 150 points of the total and includes 15 points for resilience. Overall, 26 points of total 1000 points (2.6%) of the Green Globes accounts for resiliency.

LEED:

LEED was first launched by the US Green Building Council (USGBC) in 1998. It offers five rating systems including LEED for Building Design and Construction (BD+C), LEED for Interior Design and Construction (ID+C), LEED for Building Operations and Maintenance (O+M), LEED for Homes, and LEED for Neighborhood Development (ND). LEED assesses buildings based on 54 criteria distributed under nine categories as Integrative Process, Location & Transportation, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation.

The LEED scoring system has a maximum score of 110 points that counts towards four levels of certification as follows:

Certified: Total points of 40 to 49.

Silver: Total points of 50 to 59.

Gold: Total points of 60 to 79.

Platinum: Total points of 80 to 110 (USGBC, 2020).

LEED's Resilience Coverage:

LEED offers three pilot credits on resilient design under the Integrative Process category. The first credit, Assessment and Planning for Resilience is worth one point and requires project teams to identify potential vulnerabilities at the project location and to plan for the potential impact of natural disasters and climate change before the design phase. Sea level rise and storm surge, flooding, hurricane and high-wind areas, tornado, earthquake, tsunami, wildfire, drought, landslides and unstable soils, extreme heat, and winter storms are the hazards included in this credit (USGBC, 2015a).

The second credit is Designing for Enhanced Resilience which accounts for two possible points and focuses on designing and constructing buildings that can resist, with minimal damage, reasonably expected natural disasters and weather events. Once the project is assessed and the risk-related information is collected, the project team needs to address either one or two of the top hazards, with one point available for each (USGBC, 2015b).

The third credit, Passive Survivability and Back-Up Power During Disruptions, accounts for two points. This credit asks project teams to ensure that buildings will maintain safe thermal conditions in the event of an extended power outage or loss of heating fuel. Additionally, it requires the teams to provide backup power to satisfy critical loads (Blackwelder, 2019).

Apart from these three pilot credits, indirect traces of resilience could be found under other LEED criteria. For example, the second option of Sensitive Land Protection credit encourages avoiding the location of the projects on floodplains or flood hazard areas (one point). Optimize Energy Performance credit also offers up to four points under its third option for system optimization employing daylight control measures and for providing building envelope

TABLE 8. LEED category description and weighting.

Category	Description	Weighting
Integrative Process (IP)	To support high-performance, cost-effective project outcomes through an early analysis of the interrelationships among systems.	1/110 = 0.9%
Location & Transportation (LT)	To avoid development on inappropriate sites. To reduce vehicle distance traveled. To enhance livability and improve human health by encouraging daily physical activity.	16/110 = 14.5%
Sustainable Sites (SS)	To ensure that a project's natural environment would be valued and respected throughout every step of the building process, from planning to construction to management.	10/110 = 9%
Water Efficiency (WE)	To maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.	11/110 = 10%
Energy and Atmosphere (EA)	To promote energy performance and controllability and the use of renewable sources.	33/110 = 30%
Materials and Resources (MR)	Focuses on material selection, material use reduction and minimizing the embodied energy associated with material extraction and transport, and disposal of building materials.	13/110 = 12%
Indoor Environmental Quality (EQ)	Addresses design strategies and environmental factors including air quality, lighting quality, acoustic design and control over one's surroundings to promote occupants' comfort, well-being, and productivity.	16/110 = 14.5%
Innovation (IN)	To encourage projects to achieve exceptional or innovative performance.	6/110= 5.5%
Regional Priority (RP)	To encourage addressing geographically specific environmental, social equity, and public health priorities.	4/110 = 3.6%

thermal mass. Renewable Energy also offers up to five points for producing renewable energy on-site and carbon offsetting. Building Product Disclosure and Optimization—Environmental Product Declarations also offers up to two points for use of products sourced (extracted, manufactured, purchased) within 100 miles (160 km) of the project site (USGBC, 2020). Two pilot credits dedicated to resilience in LEED, Assessment and Planning for Resilience, Designing for Enhanced Resilience fall under the Durability & Longevity assessment theme. These pilot credits encourage project teams to identify risks associated with the project site and implement design strategies that strengthen the building against them. The third category Passive Survivability and Back-Up Power During Disruptions, belongs to the Passive Survivability theme and focuses on maintaining livable conditions for occupants if essential services such as power are lost for an extended period. Other credits provide resilient measures under different themes. Sensitive Land

TABLE 9. SAFs and Their Resilience Coverage.

Name	Developer	Criteria and Weighting Structure	Weighting Coefficient: Non-factory	Weighting Coefficient: Factory	Rating Levels	Resilience Coverage and Weight
CASBEE	Japan Sustainable Building Consortium (JSBC)	**Q Environmental Quality**			BEE (Built Environment Efficiency) SQ = total score for the Q categories SLR = total score for LR categories $\text{BEE} = \frac{Q = \text{Environmental Quality of Building}}{L = \text{Environmental Load of Building}} = \frac{25(SQ-1)}{25(5-SLR)}$ S: Excellent, BEE ≥ 3.0, Q ≥ 50 ☆☆☆☆☆ A: Very Good, BEE = 1.5–3.0 or BEE ≥ 3.0, Q ≤ 50 ☆☆☆☆ B^+: Good, BEE = 1.0–1.5 ☆☆☆ B^-: Fairly Poor, BEE = 0.5–1.0 ☆☆ C: Poor, BEE ≤ 0.5 ☆	≈27.5%
		Q1. Indoor Environmental	0.40	0.30		
		Q2. Quality of Service	0.30	0.30		
		Q3. Outdoor Environment On-site	0.30	0.40		
		LR Environmental Load Reduction of the Building				
		LR1. Energy	0.40			
		LR2. Resources & Materials	0.30			
		LR3. Off-site Environment	0.30			

DGNB	German Sustainable Building Council (DGNB)		**Overall Weight**	TPI = Total Performance Index Bronze: TPI ≤ 35% Silver: 35% ≤ TPI ≤ 50% Gold: 50% ≤ TPI ≤ 65% Platinum: 65% ≤ TPI ≤ 80%	1.1%
		Environmental Quality (ENV)	22.5%		
		Effects on The Global and Local Environment			
		Resource Consumption and Waste Generation			
		Economic Quality (ECO)	22.5%		
		Life Cycle Costs			
		Economic Development			
		Sociocultural and Functional Quality (SOC)	22.5%		
		Health, Comfort and User Satisfaction			
		Functionality			
		Technical Quality (TEC)	15%		
		Process Quality (PRO)	12.5%		
		Planning Quality			
		Construction Quality Assurance			
		Site Quality (SITE)	5%		

TABLE 9. (Continued)

Name	Developer	Criteria and Weighting Structure		Rating Levels	Resilience Coverage and Weight
Green Globe			**Allocated Points**	Percentage of Points Achieved 4 GLOBES: 85% ≤ PPA ≤ 100% 3 GLOBES: 70% ≤ PPA ≤ 84% 2 GLOBES: 55% ≤ PPA ≤ 69% 1 GLOBES: 35% ≤ PPA ≤ 54%	2.6%
		Project Management	100		
		Site	150		
		Energy	260		
		Water Efficiency	190		
		Materials	150		
		Indoor Environment	150		
LEED	United States Green Building Council (USGBC)		**Allocated Points**	TP = Total Point Total Possible Points =110 Certified: 40 ≤ TP ≤ 49 Silver: 50 ≤ TP ≤ 59 Gold: 60 ≤ TP ≤ 79 Platinum: 80 ≤ TP ≤ 110	15%
		Integrative Process (IP)	1		
		Location & Transportation (LT)	16		
		Sustainable Sites (SS)	10		
		Water Efficiency (WE)	11		
		Energy and Atmosphere (EA)	33		
		Material and Resources (MR)	13		
		Indoor Environmental Quality (EQ)	16		
		Innovation (IN)	6		
		Regional Priority (RP)	4		

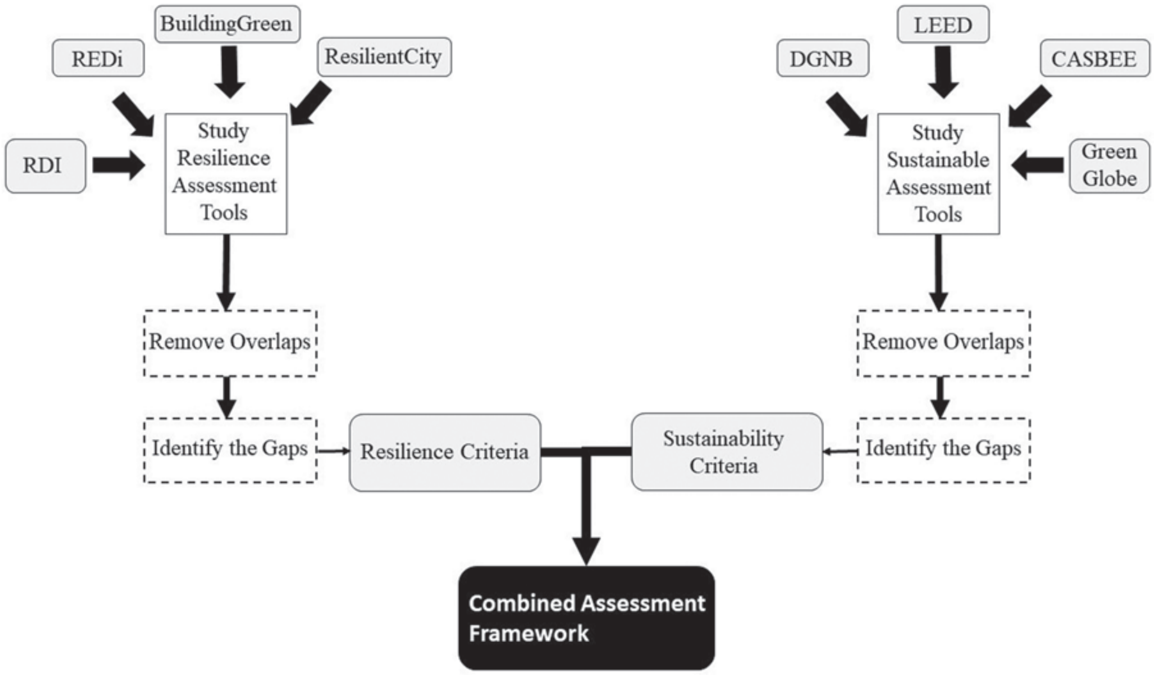
Protection, for example, belongs to the Risk Avoidance theme, while Renewable Energy falls under the Redundant Systems assessment category. Additionally, Building Product Disclosure and Optimization that encourages the use of products sourced within 100 miles of the project site, falls under the Response & Recovery theme. Because using locally available products and skillsets enables the project to respond and recover from disturbances faster.

Overall, LEED offers a total of 17 points that directly or indirectly cover resilience which equals 0.15% of the total points offered.

4. DISCUSSION AND CONCLUSION

The results of the study indicate that resilience indicators are not significantly accounted for in the green building rating systems. Out of 34 assessment tools analyzed only five had partial coverage of resilience and four were selected for further analysis, with BREEAM excluded due to <1% coverage of resilience indicators. Among them, CASBEE has the largest amount coverage at 27.5%. This relatively high coverage of resilience is due to the fact that Japan is one of the most earthquake-prone countries, and therefore resilience to disasters such as earthquakes is of the utmost priority. Due to its coverage of resilience, as well as the thorough engagement of technical, strategic, social, and political stakeholders, CASBEE has been recommended to be used as a model for incorporating sustainability and resilience (Achour et al., 2015). Although this is true to some extent, CASBEE does not provide comprehensive coverage of resilience as it includes a limited range of hazards including earthquakes, flooding, fire, mudslide or landslide, explosion, cyberattack, and subsidence. For CASBEE to be used as a model for incorporating resilience, it must be tailored and customized to fit the buildings based upon the location, climate, and type of natural hazards specific to the region. Also, the resilience coverage of 27.5% although considerably higher than the other rating systems, does not do resilience justice as it shows that the rating system still puts more emphasis on sustainability indicators. The resilience coverage of DGNB is 1% and despite considering a wide range of hazards as explained earlier, is very low. This could be explained by the fact that resilience to natural hazards in Germany is covered by the building code rather than voluntary programs such as DGNB. The resilience coverage of LEED and Green Globes are 15% and 2.6% respectively, and both of these systems are widely used in the United States. This is considered low coverage, especially because apart from passive survivability measures the hazard avoidance and durability, and longevity measures have only recently been added to these systems. At present, no assessment framework fully captures the two concepts. This is due to the unique geography of the United States, its expansive size and governmental structure. Each region has its own set of natural hazards, and although different assessment tools for sustainability and resilience exist, they work in isolation and focus on single concepts of sustainability or resilience but not on their combined application. Resilience-Based Earthquake Design Initiative (REDi), for example, focuses solely on earthquakes; Envision covers resilience on the infrastructure level and not buildings, and FORTIFIED provides certifications for residential and commercial buildings against hazards such as high winds and hurricanes. RELi, which is adopted by the USGBC to work synergistically with LEED, is a separate assessment tool. This study confirms that the current sustainability rating systems analyzed are not primarily concerned with resilience or withstanding the impacts of climate change and disturbing events. One of the major challenges of using separate tools is the problem of having to deal with more than one assessment framework. Each of those rating systems requires separate registration, application, and certification process and the

FIGURE 3. The conceptual framework to combine buildings' sustainability and resilience.



associated paperwork and fees. These additional costs in terms of time and effort can easily be avoided by using a combined sustainability and resilience assessment framework. Therefore, for sustainability assessment frameworks to fully integrate resilience indicators, the development of new systems or a thorough refinement of current systems seems inevitable (Roostaie et al., 2019b). Future directions for this work will include such integration. Through deeper analysis of existing sustainability and resilience assessment tools, a combined, coherent framework can be developed. (see Figure 3). The sustainability strategies to be included in future work from this group are drawn from these four frameworks analyzed in this study, namely CASBEE, DGNB, Green Globes, and LEED. The resilience indicators that will be integrated into these sustainability strategies will be acquired from the Resilient Design Institute (RDI), Resilience-based Earthquake Design Initiative (REDi), BuildingGreen Resilient Design Checklist, and ResilientCity Building Design Principles resilient design frameworks. Investigating these four resilient design frameworks will result in a set of resilient design indicators that can be incorporated into sustainability assessment frameworks. Finally, after removing the overlaps and addressing any potential gap in the coverage of each concept in their associated assessment frameworks, the final sustainability and resilience criteria will be proposed to form the combined sustainability and resilience assessment framework.

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