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Review

Investigating the Built Environment's Resilience and Sustainability Paradox

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Abstract

This systematic literature review examines the growing relationship between resilience and sustainability within the built environment, specifically how climate change-induced hazards affect building and infrastructure performance requirements. To find conceptual similarities, differences, and complementarities between the two paradigms, the review integrates results from peer-reviewed research. The latest research indicates that even highly sustainable buildings may still be vulnerable to climate extremes, such as floods, heatwaves, earthquakes, and heavy rainfall, despite sustainability frameworks historically prioritizing reductions in environmental impacts, including carbon emissions, resource consumption, and waste. This review utilized the SPAR-4-SLR framework to analyze a total of 83 peer-reviewed publications. The findings suggest that resilience is concerned with a system's ability to absorb, adjust, and recover from disruptions, whereas sustainability is mainly linked with long-term environmental impacts. Significantly, the literature shows a growing trend toward integrated S+R models, in which resilience parameters like structural robustness, redundancy, flexibility, and adaptive capacity are added to sustainability strategies. The review indicates that integrating comprehensive frameworks that equally handle environmental performance and hazard resistance is necessary to achieve climate-proof built environments. The paper contributes by identifying and integrating these two concepts, which improves the long-term sustainability of buildings and infrastructure while also ensuring long-term reliability.

Keywords: built environment; climate change; building and infrastructure performance; resilience; sustainability

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1. Introduction

The construction industry is a major sector of any economy and has a significant impact on the environment. Buildings and construction account for 37% of global carbon emissions and 34% of energy use, highlighting the built environment as a significant driver of climate change [1].

Design decisions regarding material selection and climate strategies for urban use significantly impact environmental performance. At the same time, the built environment accounts for around 40% of energy consumption and acts as a major contributor to carbon emissions [2–4]. A study ref. [5] found that environmental impacts are created due to rapid urbanization, resource consumption, and construction practices.

Meanwhile, climate change is escalating hazards (heatwaves, droughts, storms, flooding) that threaten the built environment [5]. Natural disasters such as hurricanes, floods, earthquakes, and wildfires are occurring as a result of the faster progression of climate

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change due to the continuation of greenhouse gas emissions [4]. Frequent extreme events caused by climate change will lead to climate variations [6]. Climate change has had a great impact on the built environment, which makes resilience and sustainability act as the main concepts for achieving the Sustainable Development Goals (SDGs) ref. [7]. The authors [8] have stated that several studies have also highlighted that natural hazards and climate change are interconnected, as climate extreme events can result in disaster risk. The growth of carbon emissions and other greenhouse gases worsens the challenges of climate change and global warming [5,9].

Traditional hazard mitigation strategies support the built environment to become a part of the solution rather than increasing the risk. Such strategies include structurally retrofitting buildings and transportation networks against earthquakes, protecting roofs against volcanic ash falls, and proactively designing ground floors in flood-prone areas, along with climate change mitigation, and systems to adapt to extreme weather conditions like droughts and flash floods [10]. According to ref. [5], to eliminate the negative impact on both the climate and the natural environment, the concept of green buildings within the built environment was established throughout the design, construction, and operational stages. The author has mentioned that green buildings have effectively reduced energy consumption, CO_2 emissions, and water management while maintaining the life cycle of materials in several projects [5]. Green building strategies and urban sustainability solutions have been integrated to address the impacts of climate change, population growth, rapid urbanization, and economic development [11]. The author has explained that the development of carbon-neutral buildings has increased to address the climate change impacts, whereas utilizing low-carbon emission sources helps to reduce energy consumption. Publication ref. [12] highlighted that the connections between resilience and environmental, economic, and social sustainability factors make it possible to find the best solutions for constructed systems and balance various demands.

Both sustainability and resilience are considered essential features in building design [13]. Resilience in this context refers to a system's capacity to anticipate, absorb, accommodate, or recover from hazards while maintaining its essential functions. Sustainability typically refers to meeting present needs (economic, social, and environmental) without compromising the needs of future generations. Both concepts aim for durable, livable communities but originate from different perspectives. Understanding how they overlap and diverge is critical, as some researchers even describe their relationship in different ways [14]. The author ref. [15] has also emphasized that these two concepts can be integrated into the built environment. Moreover, some literature has treated resilience as a component of sustainability, while others have treated it the other way around, or as two separate concepts [16]. Furthermore, a combination of Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) is essential for sustainable development worldwide [10].

Resilience and sustainability have been discussed more and more together in research on the built environment, but the link between the two ideas is still not clear. Some research considers resilience to be a part of sustainability, while other research sees sustainability as a long-term result of resilience, and some see them as separate but related ideas. Moreover, a significant portion of the current literature examines sustainability tools and resilience strategies in isolation, with less integration of their overlapping, different, and potentially common components within a comprehensive framework for buildings and infrastructure. This lack of conceptual agreement makes the built environment less safe, as buildings that are considered safe for the environment may still be at risk from natural and climate-related hazards. This study identifies this conflict as the resilience–sustainability paradox in the built environment. Buildings may meet sustainability criteria such as energy efficiency, carbon reduction, and resource conservation, yet they might remain vulnerable to natural and climate-related hazards if resilience is not built into their design, operation, and assessment frameworks. Therefore, there is a need for a systematic review to clarify the definitions, frameworks, indicators, interactions, and practical applications of resilience and sustainability in the built environment.

Defining Research Questions

This research aims to provide insights into the concepts of sustainability and resilience in the context of the built environment. Research questions (RQ1–RQ4) in Table 1 below were formulated to explore the aspects, frameworks, indicators, and definitions of the two concepts.

Table 1. Research Questions.

Code	Research Question
RQ1	How are "resilience" and "sustainability" defined in the built environment literature?
RQ2	What theories or frameworks are used to implement sustainability and resilience in buildings and infrastructure?
RQ3	How have these concepts been applied in the real world?
RQ4	How do the concepts of sustainability and resilience interact or differ in the context of the built environment?

Aligning with Table 1, Sections 3.1 and 3.2 answer RQ1 by considering how the built environment literature defines resilience and sustainability. Sections 3.1.1 and 3.2.1 discuss RQ2 by exploring the main frameworks, metrics, and indicators that are employed to make buildings and infrastructure more resilient and sustainable. In Section 3.3, we explore how resilience and sustainability have been used in real life to fulfill RQ3. Section 3.4 addresses how the two concepts are similar or different, and how they interact together to answer RQ4. Lastly, Sections 4 and 5 bring the findings together using the suggested S+R conceptual transition model, providing separate recommendations for industry stakeholders.

2. Methodology

The study follows the SPAR-4-SLR to assemble, arrange, and assess the relevant research articles. Thorough examinations of the literature using the SPAR-4-SLR technique to compile, organize, and evaluate literature should be able to provide (1) innovative perspectives and (2) stimulating agendas to further knowledge in the review area [11].

Using a database search, Scopus, a search strategy was created to investigate these questions thoroughly. Considering its broad coverage and credibility, the Scopus database was chosen [17]. Researchers frequently use Scopus, which is acknowledged as a reliable academic resource [18].

Table 2 below illustrates the three stages in SPAR-4-SLR with respect to the study.

Keyword co-occurrence analysis was carried out to examine the relationships between the three major study areas, '*Resilience*', '*Sustainability*', *and* '*Green buildings*'. Network maps generated through bibliometric analysis are shown in Figures 1–3. Nodes represent keywords, and links show how frequently they occur in the same publications. As shown in the Figures below, "sustainable development" was the most common and central term in all three networks, indicating that it served as an interconnected link between the three themes. Figure 1 highlights resilience connections, emphasizing the adaptability and long-term performance aspects of sustainability through strong relationships with infrastructure resilience, climate adaptation, and disaster risk reduction. The sustainability network shown in Figure 2 illustrates a broader relationship between urbanization, climate adaptation, and the circular economy, highlighting the interconnected nature of sustainability research. The technical and environmental focus of this field is reflected in Figure 3, where the keyword network for green buildings shows strong connections to terms such as energy efficiency, life-cycle assessment, and green materials. The three Figures show how research on resilience, sustainability, and green buildings relates to one another, with sustainable development as the key idea that connects all three fields.

Table 2. SPAR-4-SLR Framework.

Assembling	Relevant publications with respect to sustainability and resilience in the built environment were gathered through reputable academic databases such as Scopus and ScienceDirect. Scopus was the main database used to find the literature, as it covers a broader area and overlaps with Web of Science [19]. As noted by [19], 99.11% of Web of Science titles are also indexed in Scopus. ScienceDirect was used to access the relevant full-text studies. Search string combines the terms like "*built environment*," "*construction industry*," *and* "*green buildings*" *and* "*indicators*," "*index*," "*framework*," "*parameters*," also includes terms for resilience (*resilient building*, *resilience*) and sustainability (*sustainable building*, *sustainable development*). The study limited the search primarily to English-language, peer-reviewed sources (journal articles) and focused on the period between 2015 and 2025 to ensure the review contains the most recent studies, frameworks, and indicators.
Arranging	The gathered literature was arranged and screened in an organized way. In addition to excluding duplicate entries and non-English publications, titles and abstracts were examined in relation to inclusion criteria that matched the study's research questions. Thematic groups (theory, frameworks/metrics, comparative analyses) were used to group relevant sources. After screening, a total of 83 peer-reviewed publications were categorized as sources that focused primarily on resilience, sustainability, or both to ensure comprehensive reporting. As advised by SPAR-4-SLR, this step is connected to ensuring the review encompasses both the breadth and depth of all important themes relevant to the study [11].
Assessing	Selected literature was analyzed qualitatively and contextually. From each source, definitions, conceptual frameworks, and findings were extracted, and the respective approaches of resilience and sustainability were compared and contrasted. The analysis was designed to answer the research questions by integrating definitions, compiling key frameworks and indicators, and identifying real-world applications, while highlighting similarities and differences. The study identified gaps in the literature and assessed the occurrence of particular themes across studies to ensure accuracy. In line with the SPAR-4-SLR's multiple objectives of producing an up-to-date summary and insights for furthering the field, the results are presented as a comprehensive review of current knowledge and a compelling plan for future research.

Limitations

This review is subject to several limitations. The search was limited to English-language peer-reviewed journal articles and mainly utilized Scopus and ScienceDirect, possibly excluding relevant articles from alternative databases and grey literature. Also, current evidence regarding fully integrated S+R implementation varies across different scales and contexts. The relative focus on resilience and sustainability may differ by region based on climate risk, urbanization impact, regulatory maturity, economic capacity, and local hazard profiles.

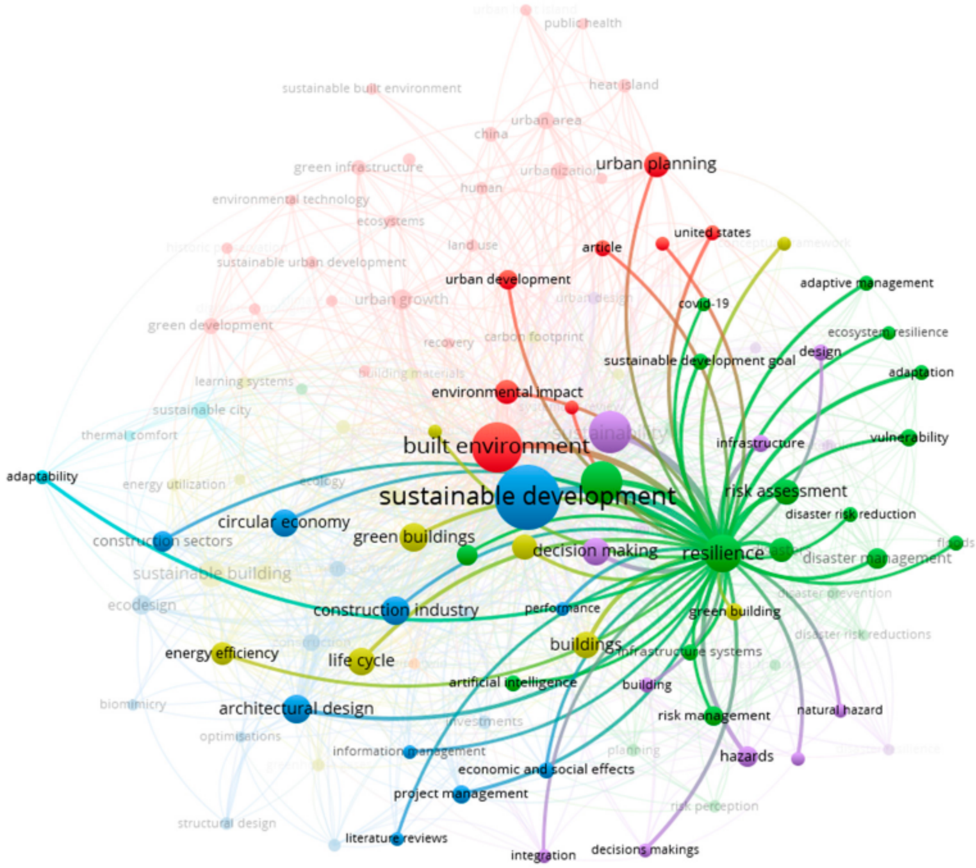

Figure 1. Keyword co-occurrence network for resilience.

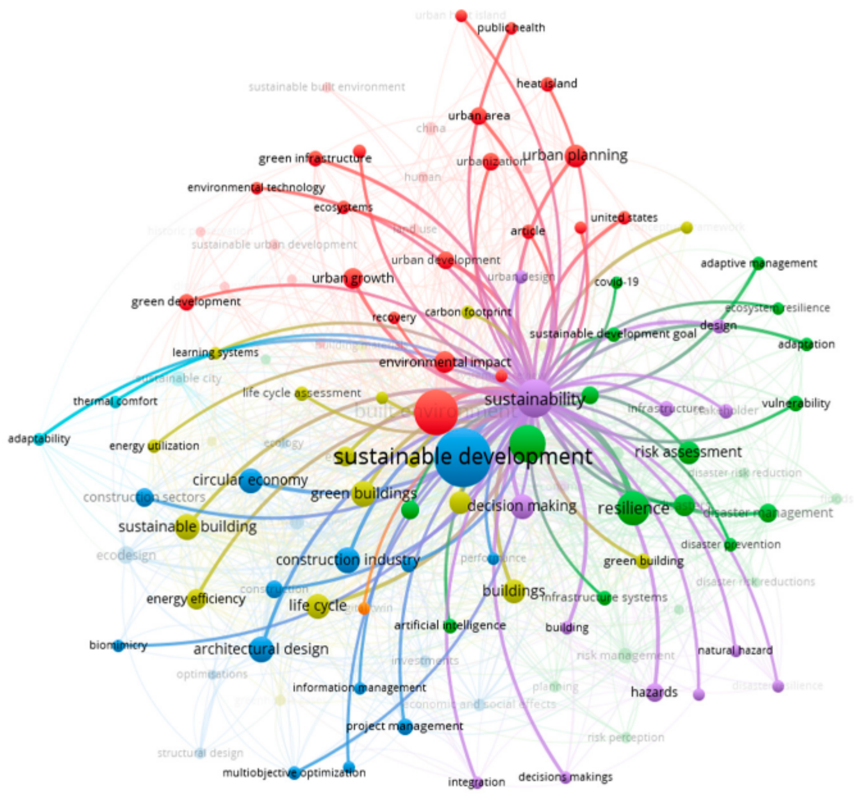

Figure 2. Keyword co-occurrence network for sustainability.

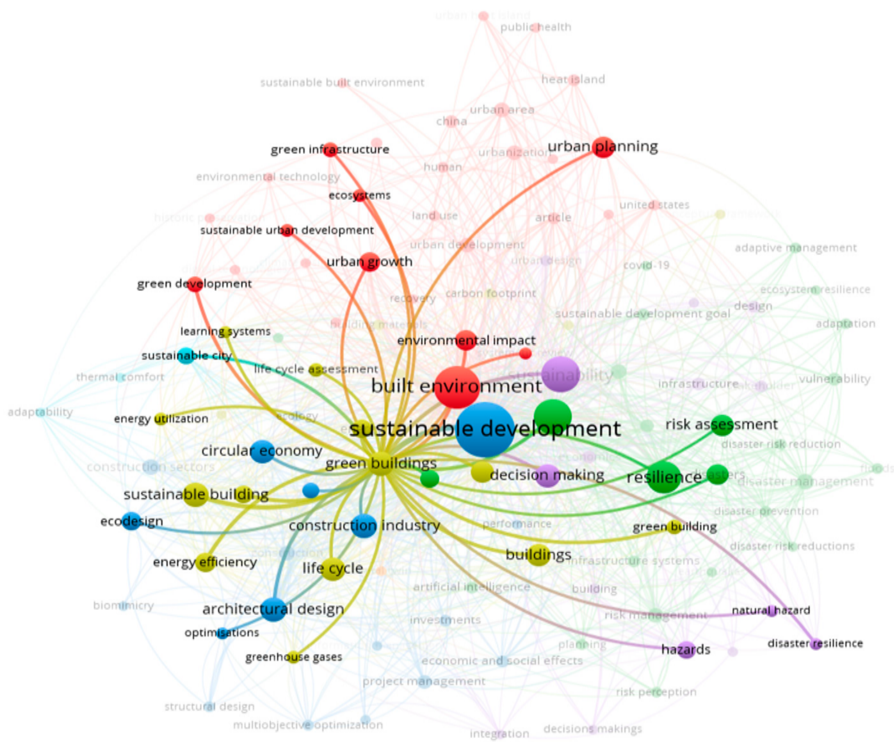

Figure 3. Keyword co-occurrence network for green buildings.

3. Literature Review

3.1. Resilience in the Built Environment

3.1.1. Principle-Based Definitions

Thomas Tredgold brought up the term "resilient" to describe a kind of timber that would bend but not break under abrupt and heavy loads. The ability of a material to return to its original state after being affected by an external force is known as resilience [13]. The author has moreover mentioned that resilience is "an ecosystem's capacity to absorb change generated by an event and retain its original status, function, shape, and relationship to other systems in the context of adaptive management of ecosystems. Researchers have defined resilience as a system's capacity to adapt to extreme and unforeseen changes without transforming into an entirely novel system framework [20]. In disciplines such as ecology and systems theory, the concept of "resilience" initially defined the ability of a system to withstand shocks and return to equilibrium [21].

3.1.2. Functional and Adaptive Resilience in the Built Environment

Simultaneously, numerous definitions of resilience have been offered by earlier research in various academic domains; in ref. [22] resilience refers to the ability of a buildings and the systems that support their functions, such as the architectural, structural, mechanical, electrical, plumbing, security, communication, and information technology systems, as well as the connections to external infrastructure and services, to withstand disturbance. Publication ref. [23] defined it as a conceptual framework and a tool to achieve a sustainable built environment. At the same time, it can respond, recover, resist, repair, transform, preserve, balance, absorb, adapt, and maintain the urban built environment. The author ref. [24] believes that adaptability contributes to resilient built environments by enabling structures to respond to shocks and changing needs throughout their lifecycles. The concept of resilience has been applied to architectural and urban environments in recent decades to meet the demand for structures and urban areas that are resilient to a range of environmental and socioeconomic shocks [25,26]. In addition to structural stability, it is stated that architectural resilience now includes resource efficiency, adaptability, and sociocultural continuity. The concept of resilience has been addressed in different fields, including engineering, information technology, environmental science, social science, and disaster science, and is defined as the ability of a system to withstand and absorb internal and external disruptions, as well as the capacity for restructuring that facilitates quicker recovery after disasters [12]. The study ref. [27,28] described that resilience as the adaptive capacity of the premises to prepare, absorb, and recover. Similarly, ref. [21] has mentioned that resilience is broadly defined as the system's ability to recover, absorb, and adapt to disturbances.

3.1.3. Resilience to Hazards, Climate, and Social-Technical Factors

However, resilience has emerged to address the challenges posed by climate change, urbanization, and socioeconomic instability [28,29]. In the literature, resilience is often addressed as structural stability by considering the conventional practices such as modular construction and reinforced composite systems that allow for the replacement of damaged parts rather than the demolishing the building [30]. In contrast, ref. [31] states that resilience covers multiple dimensions, including community well-being, ecosystem balance, and the capacity of the building to adapt and respond to environmental stresses.

Economic resilience could be achieved by life-cycle cost optimization and long-term industrial building performance by means of risk elimination and cost-cutting measures [32]. On the other hand, ref. [33] stated that with technological improvements, Artificial Intelligence (tracking, forecasting) enables supply chain resilience (adaptability, consistency), which is conceptualized through the Resource-Based View (RBV) and Complex Adaptive Systems (CAS). Study [34] stated that through user-building interactions and behaviors that improve adaptability and continuous operations in buildings, resilience is based on human and organizational factors. Furthermore, ref. [6] expressed that ecological systems initially defined the concept of resilience to explain the "persistence of the ecosystem against fluctuations"; nevertheless, in recent years, building retrofit, comfort, and health, microgrid power systems, and power grids, and many fields have broadly applied the concept. The author has mentioned that "energy resilience" in the built environment, consisting of buildings, infrastructure, and urban energy systems, is the unique and adaptive ability to predict, absorb, recover from, and react adaptively to changes in energy supply and demand while maintaining long-term functionality, efficiency, and equity. Several common themes, such as adaptive reuse and sustainability, climate adaptation, socio-ecological systems, and urban resilience, address a comprehensive approach to resilience in building design that takes into account both current structural requirements and broader social and environmental impacts [21].

To enable buildings and urban areas to withstand extreme weather events and promote a resilient community, resilience involves climate-adaptive design elements such as flood-resistant structures, thermal regulation, and natural disaster preparedness [35,36]. The author has explained that transportation networks, green infrastructure, and mixed-use zoning highlight interconnectivity within cities by illustrating urban resilience. According to ref. [7,37] a resilient built environment is a collection of structures that have gone through a variety of pre- and post-event measures to ensure that they can withstand and recover from a shock. Similarly, resilience in performance-based terms is a combination of hazard analysis, structural response, damage analysis, and loss analysis to convert conditions into functionality and repair requirements for buildings and infrastructure [28,37]. Furthermore, ref. [10] assessed that, given the significant expenses associated with restoring things to normal after a disaster, resilience-based planning and design initiatives that protect the built environment, and ensure the safety of people and economies have proven to be cost-effective methods. According to ref. [38], resilience, the ability of systems to deal with a hazardous event, trend, or disruption, could be addressed by incorporating more proactive design features, while adaptation involves actions that are taken after an incident. An "adaptable facility" can be easily adapted to meet those challenges, whereas a "resilient facility" is built for sustainability in the face of expected hazards [38]. The need for short-term adaptation should be minimized by mitigating the effects of climate-related hazards. Particularly, resilient built environments may assist in minimizing the losses after natural disasters, according to [7], a resilient built environment is a collection of buildings that have undergone a variety of pre- and post-event measures to ensure their ability to withstand and recover from a shock. Resilience in the context of the built environment describes the ability of a system to rapidly return to its original state of working in an undamaged layout [4]. Thereby, the author has connected resilience to structural resilience, stating that it is the ability of a system to "minimize the chances of a shock, to absorb such a shock when it occurs, and to recover promptly after the shock". The author ref. [15] expressed that resilience indicators reflect necessity of coping with climate change or hazard events, and making sure that the infrastructure functions in an emergency.

Considering the overall reviewed literature, resilience is mainly aligned with the ability to absorb, adapt, recover, and maintain operations during disruptions. Robustness, redundancy, adaptability, recovery, and continuity are considered common terms that indicate that resilience extends beyond structural strength to system-level performance.

3.1.4. Resilience-Aligned Frameworks, Metrics, Indicators

The resilience-related frameworks, metrics, and indicators identified in the literature are summarized in Table 3.

Table 3. Resilience Frameworks, Metrics, Indicators.

Category	Framework/Metric/Indicator	The Main Focus	References
Qualitative Framework	Case-based framework for the industrial buildings.	Explores the way to improve the long-term functionality and cost–benefit performance of industrial buildings.	[33]
Global and International Policy Framework	Sendai Framework for DRR Paris Agreement United Nations SDGs	Supports the planning process for resilience to reduce disaster risk, adapt to climate change, and make cities more sustainable. Promotes strategies for resilience that are linked to adapting to and reducing climate change. Encourages resilience by managing resources, taking action on climate change, and making long-term plans for cities to adapt.	[25,39]
Resilience framework and Multi-scale resilience model	Flexible resilience-oriented architectural frameworks. Rotterdam resilience strategy.	Transfers design away from fixed rules and toward adaptability and long-term benefit. Applies resilience on three levels: micro (building design and materials), meso (district and city systems), and macro (national and international policy).	[25,40]
Strategic approach	"Adaptive mitigation" and "build back better."	Promotes proactive resilience design and developing policies. Provides recovery after a disaster to create stronger and more resilient buildings and structures.	[10]

Table 3. *Cont.*

Category	Framework/Metric/Indicator	The Main Focus	References
Urban resilience framework	Urban resilience strategic framework	Rooftop farming, stormwater reuse, nutrient cycling, and renewable energy assist in maintaining functioning building services. Addresses the issues of resilience arising from urbanization, land use change, and climate change.	[30,36,41]
Quantitative metrics	Occupant metrics Grid metrics Infrastructure metrics Economic metrics Hybrid metric	Examines the safety and comfort of residents during an event of disruption like extreme heat. Assesses the vulnerabilities and performance of energy systems during disruption. Evaluates the status of the energy infrastructure, backup capacity, and the ability to maintain service during disruption. Investigates the way energy disruptions affect the economy and assesses the overall effectiveness of the resilience resources by contributing to a resilient built environment.	[6,42,43]
Assessment tools	Vulnerability and resilience assessment tools	Supports decision-making, action planning, and resource allocation to minimize hazards.	[44–46]
Resilience indicators	Robustness, Redundancy, Resourcefulness, Rapidity	Measures structural ability, the ability to sustain loads when damage occurs, assembling resources, and speed of recovery.	[12,45]
Resilience parameter	ResilientCity, BuildingGreen, Resilient Design Institute, Resilience-based Earthquake Design Initiative	Defines resilience through risk avoidance, passive survivability, durability, longevity, redundant systems, and response and recovery.	[13,47]
Adaptation measures	Urban zoning, groundwater recharge systems, disaster risk analysis, and wetland management	Practical measures taken to make the built environment more resilient.	[48]
Implementation framework	Five-step building resilience framework	Guides resilience planning through stakeholder identification, resilience levels, disruption types, current status evaluations, and improvement measures.	[6]

3.2. Sustainability in the Built Environment

3.2.1. Definitions Based on Preservation and Future Generations

The author [32] expressed that the concept of sustainability has over a hundred definitions as it has evolved over a hundred years. The author mentioned that sustainability is a comprehensive philosophical analysis of adaptive ecosystem management for an indefinite future. Publication [49] has defined “preserving something over time” and “multi-century preservation” as sustainability, whereas the concept has also been framed within the UN’s SDGs. According to the World Commission on Environment and Development (WCED), sustainability is “meeting the needs of the present generation without compromising the ability of future generations to fulfill their own needs” [13,21,33,47]. The author [29] similarly explained that sustainability primarily ensures meeting the needs of the current generation while also protecting natural resources and the built environment for future generations. Moreover, the author has defined sustainability as “protecting and maintaining natural and cultural resources for the future and mitigating change” [21].

3.2.2. Environmental, Social, and Economic Dimensions

Furthermore, the author has also emphasized that sustainability aims to enhance the quality of life and the condition of nature by creating a multidimensional system [27]. Simultaneously, ref. [50] stated that focusing on the economic, environmental, and social factors is a triple bottom line approach to sustainable built environment design. The author has emphasized that sustainability is a complex concept that has transformed into one of the major challenges facing the construction sector. The concept of sustainability involves enhancing people's quality of life so that they can live in a healthy environment with better social, economic, and environmental circumstances [50]. Sustainability transformation in the construction sector worldwide has become a key requirement for providing a better built environment, which reduces environmental impact, preserves economic gains, and supports the community social needs [35]. The author emphasized that integrating key tenets of economy, environment, functionality, durability, health, and well-being into both new and existing buildings will improve the quality of life and also sustainability performance in buildings. Moreover, ref. [35] expressed that healthy lifestyles, resilient communities, and environmentally friendly consumption patterns are supportive of the multidimensional socio-technical aspect embraced by the concept of sustainable development. In the construction industry, sustainability means minimizing environmental effects, managing resources effectively, and fostering social equity and economic growth [3]. Study ref. [21] has explicitly stated that interpretations for the concept of sustainability are most commonly given in the environmental domain, where the describe it as "anything that ensures the well-being of societies and the environment" or else "an ethical concept that things should be better in the future than they are at present".

3.2.3. Resource Efficiency and Life-Cycle Perspectives

In response to increasing demands and challenges caused by global issues, sustainability has changed and become recognized in various ways. Some researchers have also defined sustainability through six principles: (i) minimizing resource consumption, (ii) maximizing reuse, (iii) promoting renewable and recyclable resources, (iv) protecting the environment, (v) creating a healthy and non-toxic environment, and (vi) pursuing quality [33]. Design for Adaptability (DfA) strategies, such as management, economic, policy, design, technology, and social factors, are used to operationalize the sustainability and circularity goals [24]. The idea of sustainability provides a balance among nature, long-term lifestyles, and organizational practices, and also ensures the integration of innovative practices to support the built environment's productivity, reduce GHG emissions, preserve biodiversity, and increase the quality of life for all [38]. Furthermore, a reduction in carbon, air, and waste pollution, which are considered environmental concerns, reflects exactly what is meant by sustainability [15].

In summary, long-term environmental responsibility, resource efficiency, life-cycle thinking, and social and economic well-being are linked to sustainability. Environmental protection, circularity, quality of life, and intergenerational responsibility are the main terms reflecting that sustainability is more focused on long-term goals.

3.2.4. Sustainability Aligned Frameworks, Metrics, Indicators

The literature identifies sustainability-related frameworks, metrics, and indicators that can be categorized into assessment tools, life-cycle frameworks, performance metrics, and strategy-oriented indicator areas. Table 4 below summarizes their main focus and application in buildings and infrastructure.

Table 4. Sustainability frameworks, metrics, and indicators.

Category	Framework/Metric/Indicator	The Main Focus	References
Decision support framework	Sustainability approach at the micro level	Encourages individuals to make smart choices that will reduce the impacts of buildings on human health and the environment.	[51]
Green Building Rating System (GBRS)	Building Research Establishment Environmental Assessment Method (BREEAM), Building for Environmental and Economic Sustainability (BEES), Leadership in Energy and Environmental Design (LEED), Comprehensive Assessment System for Building (CASBEE)	Sets standards to minimize the environmental impact of buildings. Assesses the environmental and economic sustainability of building materials and systems. Utilizes green building standards to evaluate and encourage sustainability in construction. Aims to establish buildings that are more environmentally friendly, and also considers how effectively they work and how significantly they affect the environment. Indoor and outdoor environmental quality, offsite environment, materials, and resources are used in green tools to measure the sustainability of buildings and infrastructure.	[5,13,51,52]
Life-cycle framework	Sustainable industrial building life-cycle framework	Through energy efficiency, waste reduction, and green certification, it ensures that individuals use sustainable practices throughout the life cycle.	[33,45,53]
Sustainability metrics	Environment, water, and carbon footprints	Measures the sustainability benefits achieved through green retrofits and life-cycle assessment.	[7,11]
Strategies	Circular economy practices	Encourages the efficient use of resources and the reuse of resources during the design phase of a project	[3,54]

3.3. Practical Application of the Concepts of Sustainability and Resilience

Considering the literature discussed above, Table 5 shows how both sustainability and resilience concepts have been applied together in the built environment.

Table 5. Practical application of the concepts.

Areas	Discussion	References
People and Process-centered Implementation	Stakeholder participation, community involvement, and collaboration among the stakeholders are commonly mentioned as ways to integrate adaptability into long-term asset management and project delivery. Preparedness and effective resource use are maintained through training, practices, and behavioral incentives during the operation and maintenance stages. Most of these process-focused approaches ensure that resilience is not limited to the design stage but also continuously implemented through management practices and the workforce. Life-cycle sustainability practices during the design and operational stages result in lowering maintenance cost by 13% compared to conventional buildings. Roof insulation using solar control glazing, integrating solar power and battery systems, modifying operating strategies, innovative construction strategies, and regulations that improve resilience. Integrating renewable energy sources, such as solar or wind power, into building projects ensures overall sustainability.	[3,6,24,29,33,34,50,55,56]

Table 5. *Cont.*

Areas	Discussion	References
Urban and Infrastructure Systems	The built environment, which integrates both sustainability and resilience at the urban scale. Risk-based planning optimizes accessibility paths, network resilience, and spatial layouts to sustain essential facilities in the event of disruptions. Water-sensitive urban design (WSUD), low-impact development, and network redundancy planning are employed to improve ecological and social resilience and decrease vulnerability. Redundancy in infrastructure, which ensures flexibility in the face of disruptions that practically apply while integrating nature and social systems into the urban resilience frameworks. Additionally, technology integration will bring innovative solutions to forecast, model, and improve the built environment's resilience to a range of issues, including urbanization, climate change, and natural disasters.	[23,25,30,41,44,49,55,57,58]
Digital Practices	Digital twins, BIM-integrated sustainability practices, and GIS-based mapping tools guided data-driven decision-making to predict the behavior of the infrastructure systems. Artificial Intelligence (AI) and Machine Learning (ML) are used to facilitate maintenance selection, energy optimization, and the forecasting of material performance in a building and infrastructure towards sustainable development.	[22,33,34,59–61]
Circular Economy and Material Reuse	Adaptive reuse promotes sustainability by minimizing the need for new construction, using less material, and extending the life of buildings- Energy-efficient design, waste reduction, and green certification are applied to enhance long-term operability and cost resilience. Integrating sustainable design practices and reuse strategies in the evolution of resilience, aiming to extend the life cycle of buildings by repurposing them for new uses, thereby supporting environmental sustainability and resource consumption. Circularity-focused studies define sustainability and resilience through resource loops, adaptive design, and the utilization of refurbished or recycled materials. Modular construction and component life-cycle monitoring are some of the strategies used to minimize waste and embodied energy while maintaining the functional durability of the buildings and infrastructure.	[3,24,25,33,54,62–65]
Rating tools, Credit, and Policies	Resilience and sustainability are formalized through structured frameworks such as LEED, GREENSL, and BREEAM. Disaster risk reduction, emergency access, climate adaptation, and LCA-based criteria are all incorporated into building evaluation processes through modified credit categories. The integration of resilience into measurable methods encourages consistency and accountability in project assessment. Connecting both resilience and sustainability to procurement, design validation, contractual obligations, regulatory frameworks, and public procurement policies strengthens these concepts and increase their adoption in the supply chain.	[4,23,24,46,56,62,66–71]
Retrofit and Post Disaster Recovery	The integration of resilience and sustainability concepts into building retrofits, reconstruction, and disaster recovery is the focus of a smaller but solid collection of work. Sustainable methods incorporate long-term resilience goals into short-term recovery procedures, including seismic retrofitting, the adaptive reuse of current resources, and energy-efficient reconstruction.	[6,11,32,50,72]

Resilience and sustainability principles are becoming more useful in practice, yet challenges remain in applying them, as shown in the literature. High initial costs can make people less likely to invest in resilient retrofits, digital monitoring systems, and advanced material solutions, even though they are aware of the payoff in the long run. Furthermore, technical problems include not obtaining enough data, not being able to use digital tools together, and not being able to measure resilience in practical terms. Lastly, organizational barriers, such as unclear roles for stakeholders, a lack of professional expertise, and a focus on short-term investments, make it harder for the construction industry to adopt integrated sustainability and resilience approaches.

3.4. Interactions, Differences and Overlaps

The following Table 6 explains the intersections and differences between the two concepts.

Table 6. Intersection and Differences in Resilience and Sustainability.

	Focused Area	Key Insights	References
Interactions	Adaptive design and innovation	Highlights adaptable design strategies for managing environmental uncertainty. Promotes climate-responsive and adaptable design.	[4,39,40]
	Resilience and sustainability relation	Investigates the relationship between resilience strategies and sustainability outcomes. Demonstrates the similar relationships between construction and urban systems.	[11,22,42]
	Human and Nature linking	Examines the connections between natural ecosystems and human systems through green or sustainable infrastructure. Focuses on resource efficiency, sustainable design, and ecosystem services.	[38,43,47,48]
	Stakeholder collaboration	Explores how communities, professionals, and policymakers interact to implement sustainability goals. Draws attention to the role of partnerships in preparing for resilience.	[49,51,52]
	Policy and governance integration	Studies the ways that institutional frameworks affect the adoption of resilient and sustainable practices.	[55,57,58]
Differences	Concept difference	Resilience (short-term adaptability) is distinguished from sustainability (long-term objectives).	[15,22,28,59,60]
	Time focus	Resilience concentrates on recovery and change, whereas sustainability emphasizes persistence and mitigation.	[7,61]
	Indicators and frameworks	Various frameworks for evaluating sustainability (efficiency, equity) and resilience (robustness, redundancy).	[4,40,42,62]
	Various perspectives	Resilience is based on risk management and the concept of systems, while sustainability is based on the study of the environment.	[50,63,66]
	Implementation approach	Resilience strategies are quick and adaptive, while sustainability strategies are frequently proactive and preventive.	[13,32,57,63,67]

Table 7 below. Illustrates the overlaps between the concept of sustainability (S) and resilience (R) as per the searched research articles. S + R refers to sustainability-led research, which integrates resilience to improve the long-term robustness, performance, and adaptability of sustainable materials, systems, or designs. R + S, on the other hand, represents a resilience-led strategy that incorporates sustainability principles to ensure both resilient systems and infrastructures maintain social, economic, and environmental stability. Both viewpoints demonstrate that the two concepts are becoming increasingly overlapping, emphasizing that resilient systems must incorporate sustainability to survive in the long term, while sustainable solutions require resilience to withstand future stresses.

Table 7. Overlaps in both concepts.

Notation	Overlaps	References
S+R	Studies have explicitly expressed that the main objective of "Sustainability" is focusing on the long-term goals, while resilience provides defense against stresses or unexpected events. The majority of these studies have considered sustainability as the main concept and incorporated resilience through green materials, sustainable designs, life-cycle thinking, green buildings, circular economy, and net-zero carbon emission.	[1,4,7,13,32,33,37,38,43,50,57,68–77]
R+S	Studies considered "Resilience" as the main focus area and incorporated sustainability as a reinforcing goal to ensure that resilient structures are environmentally and socially reliable. Urban infrastructure, robustness, adaptability, supply chain, construction practices, and climate change are some of the focus areas of resilience.	[6,8,12,13,15,20,21,23,27,32–34,40,42,49,51,60,61,63,67,68,75,78–82]

4. Discussion

Considering the definitions, indicators, and frameworks of both sustainability and resilience, many researchers have noted overlaps and similarities between them. A resilience–sustainability paradox arises when environmental efficiency is achieved without sufficient consideration of hazard resistance, adaptability, and recovery following disruptions.

Researchers have raised concerns about whether sustainability alone is a sufficient response in light of the current rate of climate change and frequent natural hazards. Publications [13,67] emphasized that green buildings should not only reduce their environmental impact but also be resilient to potential external stresses throughout their lifetimes. Therefore, researchers have also emphasized that integrating the parameters of these two concepts is essential for mitigating risks, adapting to shocks, and maintaining functionality. Study [49] stated that while addressing current sustainability and diversity issues will also increase resilience within societies, integrating the SDGs, DRR, and CCA measures into community-level initiatives seems both reasonable and essential. Publications [4,13,20] as examples of the integrated S+R approach in the literature have applied the DEMATEL-based integration of resilience indicators into sustainability assessment frameworks, alterations to green rating tools to include disaster resilience, and decision-support frameworks that connect sustainable and fire-resilient building design.

This discussion synthesizes the findings in relation to RQ1 to RQ4. The following Figure 4 illustrates that the built environment's resilience is becoming increasingly important, necessitating a change in its design and construction.

Figure 4 conceptually demonstrates how resilience principles blend with sustainability to transform a Sustainable Green Building (SGB) into a Sustainable and Resilient (S+R) building. S1, S2, and S3 indicate the overall state of the building, while F1, F2, and F3 represent the functionality conditions before a disruption, during degradation, and after recovery. The legend explains the meaning of the labels used for the figure.

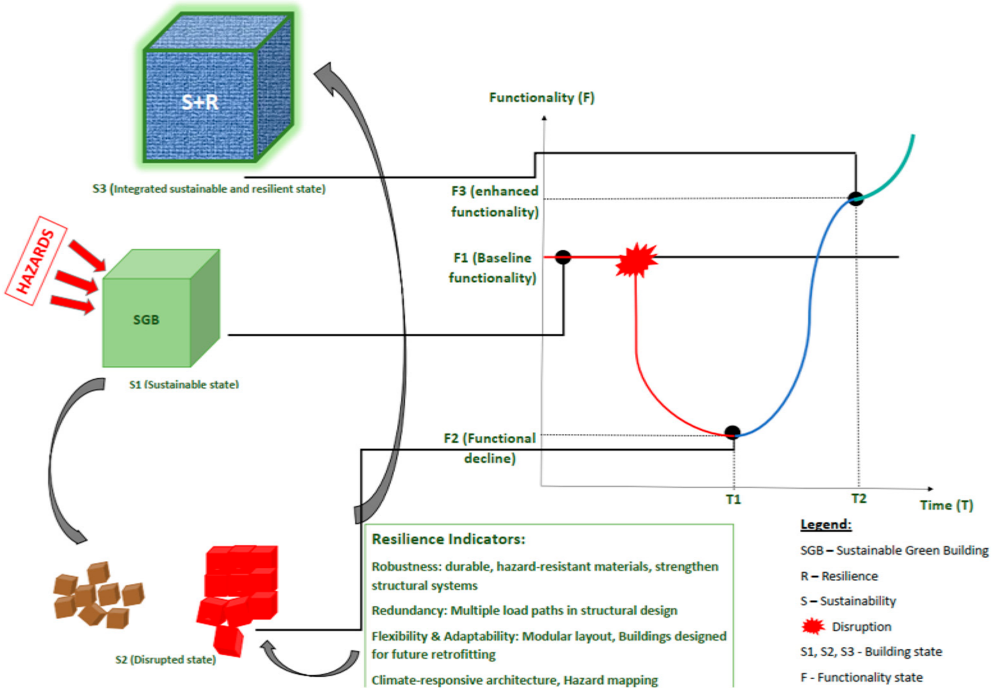

Figure 4. Conceptual transition of an SGB to a sustainable and resilient building (S+R), which illustrates how building states and functionality conditions are related during times of disruption and recovery.

The building acts as an SGB at the first state (S1), with a focus on the environmental and energy performance of that respective building while keeping its functionality (FI). However, its functionality may significantly deteriorate (F2) in response to climate-induced and natural hazards like heatwaves, heavy rainfall, flooding, cyclones, wildfires, earthquakes, and landslides, resulting in an impact that puts the SGB into a failure state (S2). Over time, this disruption appears as a significant decrease in functionality, indicating the building's vulnerability in the absence of resilience measures. The building may recover more quickly and efficiently by incorporating resilience strategies, such as redundancy through multiple structural load paths, flexibility and adaptability through modular and retrofit-ready designs, and robustness through long-lasting and hazard-resistant materials. As a result of these actions, the building eventually achieves an improved functionality state (F3) and becomes a fully integrated Sustainable and Resilient (S+R) building (S3), regaining and possibly improving its performance beyond pre-disruption levels. This figure highlights that resilience is a dynamic, time-dependent process that enhances sustainability by enabling buildings to minimize performance loss, absorb shocks, and adapt to potential hazards. This ensures long-term functionality and sustainability throughout the building life cycle. In practical terms, disruptions caused by climate and hazards can be evaluated based on building performance indicators like structural integrity, thermal comfort, indoor environmental quality, repair time, and operational downtime. For instance, floods can damage building parts and make it difficult to maintain operations, while earthquakes may cause buildings to be less stable and take longer to recover.

This study proposes the following individual definitions for resilience and sustainability based on the combined findings from the reviewed literature.

Sustainability in the built environment can be defined as "*The ability of structures and infrastructure systems to provide long-term environmental, social, and economic value by minimizing resource consumption, lowering environmental impacts, and promoting human wellbeing throughout their life cycle without compromising the needs of future generations*". Whereas the Resilience in the built environment can be defined as "*The ability of buildings and infrastructure systems to foresee, absorb, adapt to, and recover from internal and external disruptions such as climate induced or natural hazards while preserving critical functions, safety, and efficiency over the years*".

S+R is an integrated approach to the built environment that combines "*resilience features and sustainability principles to make buildings and infrastructure not only environmentally efficient but also able to withstand, adapt to, and recover from disruptions caused by hazards and climate change*".

Table 8 below clarifies how the integrated S+R definition is interpreted in different built environment contexts.

Table 8. Interpretation of the S+R definition in different built environment contexts.

Context	Interpretation of S+R
Building context	Energy efficiency, indoor environmental quality, durability, service continuity, and recoverability
Infrastructure context	Reliability, robustness, network continuity, adaptive capacity, post-disruption recovery
Urban context	Interconnected systems, spatial redundancy, green infrastructure, community resilience

Based on the definition above, five guiding principles may assist in performing S+R successfully in the built environment.

- First, both hazard and climate risks should be built into the design from the beginning.
- Second, the performance of a building must prioritize functionality as much as environmental efficiency.
- Modular systems, backup capacity, and retrofit-friendly design should make systems more adaptable, redundant, and recoverable.
- Consider how long the material will last, how easy it is to fix, and how resistant it is to hazards when selecting materials, rather than just embodied carbon and efficiency.
- Policies, procurement systems, and building assessment frameworks should utilize the same sustainability and resilience standards to make it easier for the construction industry to adopt them.

Simultaneously, Figure 5 illustrates the practical implementation of the integrated S+R approach. The flow chart outlines risk identification, selection of relevant indicators, decision-making, and continuous performance monitoring.

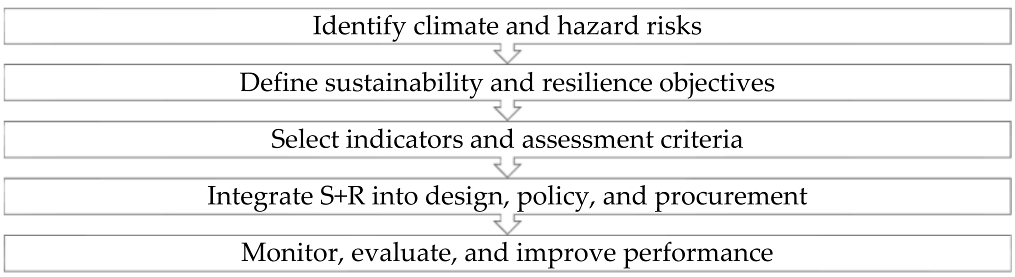

Figure 5. Practical Implementation of the S+R approach.

While responding to RQ1, the above discussion denotes that resilience and sustainability are interconnected but separate concepts. Resilience is mostly about being able to handle, adjust to, and bounce back from issues, while sustainability is mainly about generating long-term value for the environment, society, and the economy. In response to RQ2, the literature defines a broad range of frameworks, metrics, and indicators employed to operationalize resilience and sustainability in buildings and infrastructure. The review shows that resilience and sustainability are utilized extensively together in real life by individuals through process-centered implementation, urban and infrastructure systems, digital practices, circular economy strategies, policy tools, and retrofit or post-disaster recovery measures in response to the RQ3. The results indicate that sustainability and resilience intersect in many areas; however, they remain conceptually unique. Sustainability is more about eliminating difficulties and planning for the long term, while resilience is more about being able to adapt, keep going, and recover during disruption, providing an answer to RQ4.

5. Conclusions

The review reveals that the actual integration of resilience (R) and sustainability (S) within the built environment remains inconsistent, despite being frequently discussed as complementary concepts. Sustainable buildings are not naturally resistant to the growing effects of climate change, even though they comply with environmental performance standards. The literature highlights that a significant gap exists in current practices that sustainability alone cannot ensure functionality, reliability, and durability under extreme events. Resilience parameters such as robustness, adaptability, redundancy, and rapid recoverability are introduced to maintain system performance both during and after disruptions. Resilience ensures short- and medium-term functionality during times of uncertainty, while sustainability promotes long-term aspects and responsibility for the environment. Buildings and infrastructure that are environmentally friendly, resilient to shocks, and future-proof can be achieved by combining the two paradigms (S+R). Therefore, the built environment presents a paradox: sustainability alone does not always guarantee resilience, even though the majority considers that both of these concepts ensure that buildings remain more durable.

The review found that in response to RQ1, resilience and sustainability are closely related yet separate concepts. Resilience focuses on adaptation and recovery, while sustainability focuses on long-term environmental, social, and economic benefits. In response to RQ2, the literature defined various frameworks, metrics, and indicators employed to implement these concepts within buildings and infrastructure. In response to RQ3, the study identified the development of practical integration in areas including design, governance, digital tools, circularity, and retrofit or recovery practices. In response to RQ4, the review defined that resilience and sustainability significantly overlap, but differ in time focus, implementation, and performance prioritization.

The review concludes that integrating resilience principles into the sustainability standards, policies, frameworks, construction practices, and material selection is essential to address the climate risks and ensure that the built environment remains safe and reliable throughout its life cycle. Existing building codes and sustainability rating systems usually address environmental performance and hazard resilience through different methods. This separation may make it difficult to reach decisions that take all factors into account, since energy, carbon, and resource indicators often receive priority over criteria related to resilience parameters. To achieve a more integrated S+R approach, sustainability assessment tools, resilience guidelines, and regulatory standards need to be more closely connected.

The results have also provided practical implications for the main stakeholders in construction, including governments and regulators, who should shift building codes, construction norms, and sustainability rating systems to include specific resilience standards along with environmental performance goals. While making investment decisions, developers should consider more than just short-term economic viability; they should also think about long-term functionality, recoverability, and risk exposure. Furthermore, designers should include resilience parameters in sustainable design plans from the very beginning. Facility managers and operators should ensure that sustainable buildings remain productive during times of disruption through post-occupancy monitoring.

Future research should focus on the development of standardized integrated metrics, the validation of S+R frameworks across building, infrastructure, and urban scales, and the assessment of the practical performance of S+R approaches through case-based studies. Similarly, sensitivity analysis could enhance future S+R research by identifying the resilience parameters that significantly influence sustainability outcomes, resulting in enhanced prioritization, framework improvement, and decision-making.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
BEES	Building for Environmental and Economic Sustainability
BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
CAS	Complex Adaptive System
CCA	Climate Change Adaptation
DRR	Disaster Risk Reduction
DfA	Design for Adaptability
GBRS	Green Building Rating System
GHG	Green House Gas
LEED	Leadership in Energy and Environmental Design
LCA	Life-cycle Assessment
RBV	Resource-based View
SDGs	Sustainable Development Goals
USGBC	U.S Green Building Council
WCED	World Commission on Environment and Development

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