Resiliency Efforts in Construction Supply Chain: A Systematic Literature Review

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Abstract
Resiliency holds tremendous significance in ensuring that infrastructures withstand adverse events, as natural hazards threaten large amounts of property and human lives every year in the United States. The collaborative effort by stakeholders of the construction supply chain (manufacturers, distributors and contractors) to incorporate resilient practices is essential for building resilience. The purpose of this research is to evaluate the current state of various resilience efforts implemented by stakeholders in the construction supply chain and to compare these stakeholders based on their integration of resilient practices. A systematic literature review was conducted to extract the different resiliency factors and the definitions from various literature sources. A total of 21 papers were considered for the systematic literature review, through which 28 different resiliency factors were extracted and categorized into three categories based on common themes. The comparison among stakeholders from the review revealed that manufacturers have adopted resilient practices more extensively than distributors and contractors. The study offers valuable guidelines for the stakeholders to examine and implement relevant factors in their respective areas, promoting resilient construction practices.

Keywords
Resiliency, Construction Industry, Manufacturer, Distributors, Contractors

1. Introduction
Buildings are regularly exposed to diverse weather conditions such as sunlight, rain, snow, hail, and wind. Beyond these everyday elements, they also encounter severe natural disasters, including earthquakes, floods, hurricanes, and tornadoes. These combined factors necessitate resilient construction practices to ensure durability and safety over time. Resilience is usually associated with the ability to deliver a certain service level even after the occurrence of an extreme event, such as an earthquake, and to recover the desired functionality as fast as possible (Bocchini, et al., 2014).

The United States spends billions of dollars annually helping communities recover from natural disasters caused by wildfires, hurricanes, floods, tornadoes, blizzards and other natural hazards (NAHB, 2023). To reduce the impacts associated with these natural hazard events, federal agencies, including HUD (U.S. Department of Housing and Urban Development), pursue initiatives to improve housing resilience, including developing technical guidance (NAHB, 2023). The United Nations Development Programme (UNDP) estimates that by 2050, the global population exposed to climate-related hazards will increase by 50%, highlighting the importance of incorporating resilient construction practices in new and existing buildings (CFBL Consulting, 2024). To accomplish this, the stakeholders within the construction supply chain need to collaborate.

The construction supply chain involves multiple stakeholders, including manufacturers/suppliers, distributors, and contractors/subcontractors. Integrating these stakeholders is crucial to the construction industry, which is susceptible to various disruptions, such as material shortages, labor issues, transportation delays, and natural disasters, which can significantly impact project timelines and costs (Singh et al., 2024).The stakeholders of the supply chain are an essential part of any business. They will have tremendous ramifications and repercussions that are difficult to manage if there is any disturbance to it, even more to the construction industry (Azmi et al., 2022).

This study, through a systematic literature review, aims to better understand the current resiliency efforts being implemented by the construction industry supply chain stakeholders, specifically manufacturers, distributors and contractors. The objectives of this study were to:

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i) Determine the current state of various resiliency efforts implemented throughout the supply chain by the various stakeholders.

ii) Identify the juxtaposition of these stakeholders regarding integrating resiliency practices.

This paper outlines a systematic literature review covering publications from the past decade. It emphasizes the qualitative analysis employed to extract definitions and factors related to resiliency from the reviewed literature. Furthermore, it presents the categorization of resilience factors, along with a discussion on how practices among stakeholders in the supply chain complement each other or diverge.

2. Methods

A systematic literature review with a quantitative content analysis was adopted to achieve the goals of this research. This includes thoroughly reviewing and analyzing articles on resiliency in the construction industry from peer-reviewed articles from various sources to help enhance the study's credibility and reliability. Compared to many traditional and less systematic approaches for carrying out literature reviews, a systematic literature review is generally considered to be superior in terms of transparency as other researchers can more easily verify the findings of the study by replicating the research setup (Aarseth et al., 2017).

This study's qualitative analysis commenced with a literature review to extract data (factors and definitions) related to resiliency. The qualitative analysis tool QDA Miner Lite was utilized to develop a comparison matrix from these extracted factors and definitions. This process was repeated to incorporate data from all selected articles in the study. The summary of the systematic literature review is demonstrated in Figure 1.

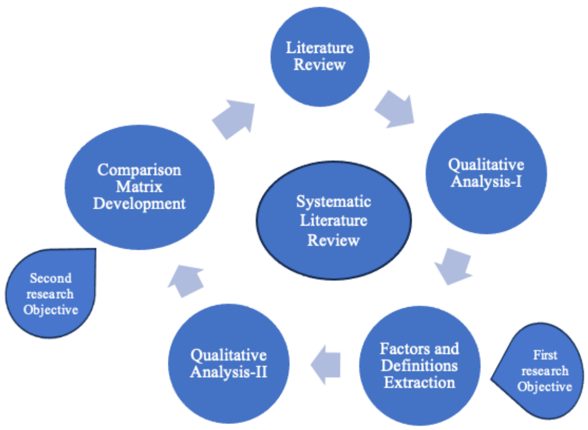

Figure 1- Summary of systematic literature review process

The methodology of this study comprised two phases: phase one included the systematic literature review to identify pertinent studies on resilience, and phase two included the qualitative analysis of the literature to identify recurring factors and definitions. The sequential process of how the literature was broken down to identify the 28 resiliency factors is shown in Figure 2.

Figure 2- Systematic Literature Review Breakdown

Various keyword combinations relevant to resilient practices in the US construction industry were utilized for this research. These combinations included terms like "United States," "manufacturing," "distributor," "contractor," and "building construction." Boolean logic, utilizing operators such as 'AND' and 'OR' along with

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parentheses for grouping, was employed to refine these combinations depending on the database. Additionally, truncation was applied to key terms like "resilien*" to capture variations such as "resilience" and "resilient," ensuring comprehensive retrieval of relevant data from the database.

To initially identify relevant publications, keyword combinations with Boolean logic were searched across eight different databases focusing on construction-related fields: EBSCOhost, Engineering Village, ASCE Library, IEEE Xplore, Technology Collection (ProQuest), BuildingGreen Suite, JSTOR, and Web of Science Core Collection (including ScienceDirect). BuildingGreen Suite did not yield any articles relevant to the context of resilience in this research. The keyword combinations and their corresponding number of articles retrieved are detailed in Table 1. Initially, all articles returned by the search were considered, totaling the number of articles retrieved without specific inclusion criteria. These criteria were then applied to refine the search, limiting articles to those published between 2013 and 2023 and only including peer-reviewed journals with full text available in English. Following the application of these criteria, 485 peer-reviewed journals were identified. These articles were cataloged in an Excel spreadsheet and sorted by title and author to eliminate duplicates. After reviewing abstracts and paper topics, any remaining duplicates were further removed. Subsequently, 21 articles were selected for in-depth analysis.

Table 1: Keyword Combination List

No.	Keywords	No. of Articles	No. of relevant articles	No. of selected articles
1	(resilien*) AND (building construction) AND (United States)	44,228	92	4
2	(resilien*) AND (manufacturing) AND (building construction)	17,682	47	3
3	(resilien*) AND (building construction) AND (supply chain)	12,706	30	3
4	(resilien*) AND (architectural design) AND (building)	16,371	58	2
5	(resilien*) AND (built environment) AND (building construction)	37,398	79	3
6	(resilien*) AND (adaptive design)	47,197	95	1
7	(resilien*) AND (distributor) AND (building construction)	9,150	22	0
8	(resilien*) AND (contractor) AND (building construction)	7,838	27	3
9	(resilien*) AND (building construction) AND (stakeholder)	12,910	35	2

A breakdown of which databases returned the relevant articles is displayed in Table 2.

Table 2: Databases and inclusion criteria

<table>
<tr><th>Electronic Databases</th><th>Inclusion Criteria</th><th>No. of Relevant Articles</th></tr>
<tr><td>EBSCOhost (Academic Seach Complete, Applied Science and Technology, Avery Index to Architectural Periodicals, GreenFILE)</td><td rowspan="7">• Publication Date: 2013-2023
• Publication type: Only Peer-Reviewed Articles
• Location: United States
• Language: English
• Full text</td><td>56</td></tr>
<tr><td>Engineering Village (Compendex, GeoRef, INSPEC & Knovel)</td><td>85</td></tr>
<tr><td>ASCE Library</td><td>97</td></tr>
<tr><td>IEEE Xplore</td><td>15</td></tr>
<tr><td>Technology Collection (ProQuest)</td><td>48</td></tr>
<tr><td>JSTOR</td><td>109</td></tr>
<tr><td>Web of Science Core Collection (includes ScienceDirect)</td><td>75</td></tr>
</table>

Factor and Definition Identification

The selected references were further analyzed to identify resiliency factors and their definitions. Each article was reviewed in detail to identify and highlight factors related to resiliency within the context of the built environment and material supply chain discussed in the paper. The title of the articles, their corresponding authors and web link were listed in rows of the first three columns of an Excel spreadsheet, followed by different resiliency factors and the

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stakeholders that they discussed. The framework for this data organization is shown in Table 3, with an 'X' indicating an intersection of the field mentioned in the reference and the factor identified in the column. Similarly, manufacturers are labeled as 'M', distributors as 'D' and contractors as 'C'. For instance, Article 1 discusses resiliency factor F2 within the context of the manufacturer. This process was completed for selected articles.

Table 3: Matrix for data collection

			Resiliency factors			Stakeholder		
Title	Ref	Link	F1	F2	F3	M	D	C
Article 1				X		X		
Article 2			X				X	X
Article 3					X	X	X	X

A dedicated table was created for each resilience factor to record individual definitions and the specific contexts in which references discussed these factors. These definitions were then subjected to qualitative analysis using QDA Miner Lite, enabling the assignment of codes to identify similarities across different definitions. As the analysis progressed and more articles were reviewed, the codes and classifications evolved, allowing for the linking of similar discussions. Factors sharing comparable definitions were coded under the same designation and subsequently consolidated. Additionally, a factor's definition could encompass multiple interpretations, suggesting a hierarchical relationship with sub-factors.

There is no common or formal framework for the categorization of resiliency factors, so they were grouped based on common themes identified and placed in three different categories. The categories are:

i. Structural and Environmental Resilience
ii. Functional and Operational
iii. Preparedness and response

3. Results

The factors and definitions extracted from the systematic literature review fulfill the first research objective. The factors that have been implemented and discussed within the context of stakeholders of the construction supply chain are demonstrated in different categories. Moreover, the second objective has been met, where the stakeholders have been compared based on the integration of each resiliency factors. The factors discussed in the studies from the perspective of different supply chains are labeled with 'Y', while those not discussed are labeled with 'N'. The results are presented in three categories.

Category 1: Structural and environmental resilience

This category includes all the factors related to maintaining the physical integrity of the buildings and infrastructures, also including the built environment. Structural resiliency describes the ability to rapidly resume the use of buildings and structures following a shock incident or event (Structural Healthcare, 2024). For example, factors like ductility, durability, functionality, and longevity are all the essential abilities of building that keep the building safe even after disruptive events. Similarly, environmental resiliency is about the ability to withstand, respond and recover from environmental perturbations and shocks (Stavros et al., 2023). The factors related to both structural and environmental resilience are included in this category. The factors are listed in Table 4.

Table 4: Factors- Structural and environmental resilience

Factors	**M**	**D**	**C**
Absorptive capacity	N	N	N
Disaster resistant	Y	N	N
Ductility	N	N	N
Durability	N	N	N
Functionality	Y	N	N
Longevity	N	N	N
Material effectiveness	Y	N	N
Restructurability	N	N	N
Robustness	N	N	N
Tolerance	N	N	N

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Total ‘Y’	**3**	**0**	**0**

In this category, among the ten factors, three factors have been linked to only one stakeholder, the manufacturer of the supply chain.

Category 2: Functional and operational resilience

All the factors that are related to the proper functioning of a building and its overall operation are included in this category. For instance, back-up energy system and on-site renewable energy lessen the likelihood of long-duration electrical outage (Felicioni et al., 2023). It helps to keep the building in operation even during and after a disruption. This category includes all the factors related to ensuring the essential services remain available such as power and water. It also includes building redundancy into critical systems and allowing for flexible responses to the changing condition of the environment. The factors that fall under this category are listed in Table 5.

Table 5: Factors- Functional and operational resilience

Factors	**M**	**D**	**C**
Back-up energy system and on-site renewable energy	Y	N	N
Flexibility	N	N	N
Habitability	N	N	N
Indoor comfort conditions	N	N	N
Passive lighting and ventilation	Y	N	N
Passive survivability	Y	N	N
Redundancy	N	N	N
Resourcefulness	N	N	N
Sensible cooling	N	N	N
System control strategies	N	N	N
Transportation system protection	Y	N	N
Water management	Y	N	N
Total ‘Y’	**5**	**0**	**0**

In this category, among the twelve factors, five factors have been linked to manufacturers and none to the distributors and contractors.

Category 3: Preparedness and response resilience

This category includes all the factors that involve strategies and plans to respond and recover from disruptive events. For instance, the factor ‘adaptive’ explains the ability of physical assets to adapt to changing conditions such as extreme weather conditions and shocks (Aghabegloo et al., 2023). Similarly, other factors such as rapidity, recovery, restoration capacity and stress are also included in this category as they are all related to the speed with which a structure recovers, copes with the disruptive event and restores to the original state. The factors and their definitions for this category are listed in Table 6.

Table 6: Factors- Preparedness and response resilience

Factors	**M**	**D**	**C**
Adaptive	Y	N	N
Preparedness	N	N	N
Rapidity	N	N	N
Recovery	Y	N	N
Restoration Capacity	N	N	N
Stress	N	N	N
Total ‘Y’	**2**	**0**	**0**

Among the six factors, only two resilient factors in this category have been discussed from the perspective of manufacturers of the supply chain.

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4. Discussion

The integration of resilient practices by the stakeholders of the construction supply chain is critical in a construction project as it ensures that the project can withstand unexpected events and continue to provide long-term benefits for the communities. Identifying 28 resilient factors from peer-reviewed journals over the past decade is valuable for stakeholders, allowing them to integrate these factors into their fields and benefit from their application. Moreover, definitions of the factors have also been explored from the studies which will help to understand the gist.

Among the factors included in the category 'structural and environmental resilience,' three have been discussed from the manufacturers' perspectives. Felicioni et al. (2023) defined 'disaster resistant' as reducing disaster risk and 'material effectiveness' as enhancing the ecological and economic life cycle of project materials through increased recycling and reuse, local extraction, and harvesting. Similarly, the studies by Kurth et al. (2019) and Zhao et al. (2015) described 'functionality' as a system's ability to consistently deliver and maintain critical functions.

Conversely, the studies also addressed a significant number of factors related to the overall construction industry without considering supply chains. Aghabegloo et al. (2023) and Zhao et al. (2015) defined 'absorptive capacity' as the ability of the physical asset to absorb the disruptive event or external stresses. Amini et al. (2018) described 'ductility' as providing good seismic resistance with well-predicted behavior, thus reducing uncertainty in seismic resilience. Similarly, Dabija (2021) linked 'durability' to resilience, explaining it as the capacity to last longer with minimal environmental impact, thereby making buildings more resilient to various stresses. Alexandrou (2023) explained 'longevity' as the ability to endure over time through continuous use or adaptive reuse. Reddy (2020) described 'restructurability' as a system's flexibility under partial failure, allowing it to restructure itself to maintain as much functionality as possible. Bocchini, et al. (2014) and Reddy (2020) defined 'robustness' as the ability to withstand extreme events such as external shocks and still deliver essential services without interruption, often measured by the residual functionality level after the event. Razzaghmanesh et al. (2014) explained 'tolerance' as the ability to tolerate climatic and environmental changes such as heat and moisture stresses.

Likewise, the 'functional and operational resilience' has five factors linked to the manufacturers. Felicioni et al. (2023) defined 'back-up energy system and on-site renewable energy' as resilient power systems that reduce the likelihood of prolonged electrical outages through battery energy storage and on-site generators. They also described 'passive lighting and ventilation' as systems that ensure indoor comfort, allowing the buildings to remain operational during disruptive events. Additionally, Felicioni et al. (2023) and Baniassadi et al., (2018) defined 'passive survivability' as the ability of buildings to maintain and moderate indoor thermal comfort during regular operation and temporary loss of mechanical cooling, grid power, fuel outages, heat waves, and other emergencies. Felicioni et al. (2023) emphasized the importance of 'transportation system protection' by increasing accessibility and diversifying transportation options during a crisis. Furthermore, they also explained 'water management' as the improved integration of human development with the natural hydrological cycle, maintaining a balance with surface water, rain events, and water use.

On the contrary, various studies have addressed factors that, although not linked to specific supply chains, have significantly impacted resilient construction. Fouda and ElKhazendar (2023) defined 'flexibility' as the willingness to use alternative strategies to facilitate rapid recovery. Rehman and Hasan, (2023) described 'habitability' as the building's ability to remain in habitable thermal conditions after power loss through reduced heat transfer, natural ventilation, and natural light. Heracleous et al. (2021) referred to 'indoor comfort conditions' as having better indoor environments. Bocchini, et al. (2014) described 'redundancy' as the extent to which elements and components of the system are substitutable and 'resourcefulness' as the capacity to allocate the necessary budget, identify problems, establish priorities, and mobilize resources after an extreme event. Lassandro and Cosola (2018) defined 'sensible cooling' as strategies like increasing green roofs, phase change material (PCM) options, and albedo to reduce the heat rate rejected by cooling device condensers in the urban environment. Similarly, Wu and Wang (2019) explained 'system control strategies' as enhancing the failure restoration capability of the system.

Regarding 'preparedness and response resilience,' two factors, 'adaptive' and 'recovery', have been discussed from manufacturers' perspectives in the studies. Aghabegloo et al. (2023) and Felicioni et al. (2023) defined 'adaptive' as the ability of physical assets to avoid discontinuity after disruption by adapting to changing conditions and major disruptions caused by extreme weather, resisting shocks while preserving the essential functions and restoring all system features to a pre-disaster level. Similarly, Kurth et al. (2019) and Sun et al. (2020) described 'recovery' as anticipating how a building will perform under hazard conditions, which informs the recovery starting point, showcasing the ability of a building to recover rapidly from major disruptions, including those caused by extreme weather conditions such as thermal or heat resilience. Like the other categories, there are factors in this category that are not linked to any of the supply chains. Sun et al. (2020) defined preparedness as the ability of a building to prepare for major disruptions due to extreme weather conditions, such as thermal or heat resilience.

Bocchini, et al. (2014) defined ‘rapidity’ as the speed with which a structure recovers from such events to reach a high functionality level. Aghabegloo et al. (2023) and Reddy (2020) defined ‘restoration capacity’ as the capability of a physical asset to be repaired or restored to its pre-degraded state or the original state after partial or total failure within acceptable time periods and penalties (monetary, human hardship, etc.) during post-disaster recovery. Tsai et al. (2022) explained ‘stress’ as the ability to cope without changing the community’s structure while enhancing its ability to withstand future disaster impacts.

The juxtaposition of three stakeholders of the construction supply chains regarding the integration of resilient practices has been identified through this research. Most of the studies were limited to manufacturers of the supply chains (6 out of 21 papers), and none of the studies have been linked with distributors and contractors, thus not representing their perspectives. It is clear from the study that the resilient factors were not discussed enough from the perspective of three supply chains in most of the research articles selected. This gap indicates a significant oversight in understanding the full impact of these factors on the entire supply chain and the construction industry.

Consideration of sustainability factors is equally important to resiliency in the construction industry. Establishing clear sustainability and resiliency goals by considering several important factors, integrated planning among the supply chains, and coordinated efforts helps to achieve maximum benefits moving forward in the construction industry.

5. Conclusions

The study evaluated various studies of the past decade regarding integrating resilient practices through the perspectives of stakeholders of the construction supply chain. While this study provides a comprehensive analysis of resilient factors, it is important to note that the findings are limited to the scope of literature reviewed from the past decade. The time limitation may not fully capture all the advancements and trends related to resiliency. Additionally, the study is restricted to examining only three key stakeholders within the supply chains. This limitation may overlook the perspectives and contributions of other crucial stakeholders. The analysis concluded that the resilient factors were primarily investigated within the context of manufacturers, with less consideration given to distributors and contractors, highlighting the need for future studies to focus on these stakeholders to maintain the resilience of construction projects. Furthermore, the stakeholders of the supply chains can develop comprehensive strategies that not only reduce environmental harm but also enhance the capacity of systems and structures to adapt to and recover from adverse events. The insights from this study can guide the selection and use of materials, the design of backup energy systems, and the development of adaptive and recovery mechanisms. The focus on resilience in the study can lead to more durable and adaptable buildings, which can result in cost savings, reduced environmental impact, and improved safety and comfort for building occupants.

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