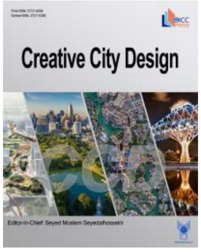

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Review Article

Meta-Synthesis of Urban Form Resilience in the Face of Natural and Environmental Hazards: A Conceptual Approach

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Abstract

Aims: This study seeks to develop a comprehensive conceptual understanding of urban resilience by examining it through the lens of urban form in relation to natural and environmental hazards. The objective is to clarify how the physical and spatial characteristics of urban form contribute to the capacities of absorption, adaptation, and recovery within urban systems exposed to environmental disturbances.

Methodology: A qualitative meta-synthesis was conducted following the seven-step framework proposed by Sandelowski and Barroso, which represents a rigorous form of qualitative systematic review. A total of 2,439 articles were retrieved from the Scopus database using a structured search strategy. After PRISMA-based screening of titles, abstracts, and full texts, 49 articles meeting the inclusion criteria were selected for the final synthesis. The extracted findings were coded, compared, and interpretively integrated to develop a unified conceptual framework of urban form resilience.

Finding: The synthesis identifies six core components that define the conceptual structure of urban form resilience: ecological sensitivity, indeterminacy, polycentricity (decentralization and modularity), connectivity (permeability), functionality (multi-capacity), and redundancy. These components collectively represent the multidimensional and dynamic nature of urban form, demonstrating how spatial configuration, functional diversity, and system flexibility shape resilience outcomes with respect to natural and environmental hazards.

Conclusion: The results indicate that the resilience of urban form emerges from the interaction between spatial structure, functional complexity, and the adaptive potential of urban systems when confronted with environmental risks. The conceptual framework proposed in this study provides a theoretically grounded model for understanding the resilience of urban form and offers a foundation for future empirical investigations and resilient urban planning strategies

Keywords: Resilience, Urban form, Natural hazards, Meta-synthesis

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1. Introduction

In recent years, resilient urban planning and environments have emerged as central themes in the prevention of urban disasters, offering novel perspectives on urban development. The concept of resilience was introduced into urban planning in the late 1990s and gained wide application in urban disaster prevention and mitigation during the early 21st century [1, 2]. Resilience is commonly defined as the ability of a system or community to resist, absorb, adapt to, and recover efficiently and effectively from hazards while maintaining or restoring essential structures and functions. Since then, academic research and planning practices related to urban resilience have continued to expand. Resilience has become a pivotal concept in the domains of disaster management, climate change, and sustainability. International organizations such as the United Nations, along with governments worldwide, have integrated resilient city strategies into urban planning and construction policies [3]. As cities continue to evolve, there is growing recognition that urban form and its transformation significantly influence the attainment of resilience and urban sustainability. Consequently, urban form resilience has become a focal point of research on resilient cities [4, 5, 6]. Urban form encompasses both the physical environment and the spatial configuration of urban elements. In a broader sense, it results from a complex and dynamic set of interactions among multiple entities, including physical, social, economic, technological, and cultural components [7, 8]. Most scholars argue that urban form resilience entails the capacity to withstand hazard-induced changes, minimize losses, facilitate rapid recovery, and support adaptation and transformation [8, 9]. Urban form resilience closely related to spatial patterns, physical structures, density, connectivity, and the configuration of urban elements reflects not only design and planning decisions but also plays a decisive role in shaping how cities respond to hazards [10]. From the perspective of urban planners, one of the strategies to achieve sustainable development and improve the quality of the urban environment is to balance the spatial distribution of land uses through a sustainable urban form [89]. The environment of cities is one of the places that influence this issue. This literature covers a wide range of possible elements for both physical and non-physical features, which represent urban form [90]. Studies have shown that the characteristics of urban form can either enhance or weaken the ability to absorb, adapt, and recover from environmental disruptions. Nevertheless, despite increasing attention to the subject, our understanding of how urban form interacts with resilience processes remains fundamentally limited. Most existing studies rely on qualitative analyses and general conceptual frameworks, with relatively few providing systematic reviews or in-depth conceptual models that capture the complexity and multidimensionality of urban form in relation to resilience. Moreover, the predominant emphasis of resilience research has been on social, economic, or managerial dimensions, while physical and spatial aspects critical to structural resistance and environmental adaptability have often been overlooked. In the context of natural hazards such as floods, droughts, or heatwaves, evaluations have primarily focused on socio-economic vulnerability, with limited systematic attention given to how spatial urban form contributes to or mitigates the intensity of such impacts. In other words, the existing literature frequently lacks an integrated framework capable of conceptually and endogenously analyzing the diverse facets of urban form in relation to environmental risks and their interplay with other factors. This gap, particularly in the face of a wide array of climate and environmental threats, may lead to uninformed or suboptimal spatial design and planning decisions. Accordingly, the present study adopts a conceptual approach to explore urban form resilience not as a static or purely physical attribute, but as a complex, context-dependent, and adaptive process in response to natural and environmental hazards.

2. Theoretical foundations

2.1. The concept of resilience and urban resilience

Resilience originally referred to the ability to return or recover to an initial state, a concept that was first introduced in engineering and psychology. Most scholars regard Holling's (1996) work as the starting point of modern resilience theory. Holling referred to the multiple stable states of ecosystems and was the first to apply the concept of resilience to the study of system-related problems. Subsequently, resilience research evolved from early studies on urban ecosystems to the broader framework of social–ecological systems, incorporating social dimensions into the analysis [11]. In this context, resilience is associated with a system's capacity for self-organization, learning, and adaptation.

Since then, resilience has been widely applied across various scientific fields. The concept has evolved through three primary stages: engineering resilience, ecological resilience, and evolutionary resilience [12].

- Engineering resilience assumes that a system exists in a single equilibrium state and focuses on the system's ability to resist shocks and recover rapidly to that equilibrium. It is commonly applied in the study of physical systems [13].
- Ecological resilience emphasizes that systems may have multiple equilibrium states and refers to their

ability to absorb disturbances before shifting to another structural and functional regime. This approach is mainly used in ecological studies [14].

- Evolutionary resilience is a long-term, dynamic process that emphasizes a system's capacity for continual adaptation by repeatedly restructuring its economic, social, and political dimensions in response to recurring disruptions.
- Its close connection to economic systems derives from the fact that economic structures are inherently cyclical, innovation-driven, and sensitive to external shocks; as such, they exemplify the adaptive cycles of growth, collapse, reorganization, and renewal that underpin evolutionary resilience. This perspective highlights how ongoing learning, experimentation, and transformation enable systems to accommodate change rather than merely return to a prior equilibrium, making evolutionary resilience a widely recognized theoretical foundation for contemporary resilience practice and application [16, 17].

As the scope of resilience research has expanded, scholars and policymakers have proposed broader definitions. For instance, Himes (2009) defines resilience as the capacity of a system to withstand significant damage within acceptable thresholds and to recover in a timely and cost-effective manner with reasonable risk.

The Intergovernmental Panel on Climate Change (IPCC) describes resilience as the ability of a system to anticipate, absorb, adapt to, or recover from the impact of a hazardous event. Sinner and Barnes (2019) argue that resilience typically refers to the ability to cope with social or environmental changes while maintaining core structural, functional, and identity elements.

Convertino and Valverde (2019) define resilience as a system's response to observed or anticipated risks. Bruce et al. (2020) characterize it as the ability of a system to persist, adapt, and transform when conditions demand change [11].

Although there is no consensus on a single definition of resilience, commonalities can be observed. These include core characteristics such as robustness, recoverability, redundancy, intelligence, and adaptability.

In recent years, resilience has become a prominent term and has been applied across a wide range of disciplines including agriculture [15, 16], environmental sciences [15], energy [16, 17], climate change [18, 19] and transportation [20, 21].

Some scholars view resilience as a process emerging from the dynamics of a system [22], while others define it as a state or outcome that reflects the system's capacity [23]. A growing body of research, however, conceptualizes resilience as an integration of both process and outcome, emphasizing that its full meaning is captured only when these dimensions are considered together [24, 25].

The operationalization of resilience varies across research fields. For instance:

- In infrastructure studies, it is often framed as resistance, coping ability, recovery, and adaptability [26].
- In the energy sector, it relates to availability, accessibility, affordability, and acceptability of energy production, transport, and distribution;
- In community-based research, it refers to the capacity to adapt to and absorb disruptions [27].

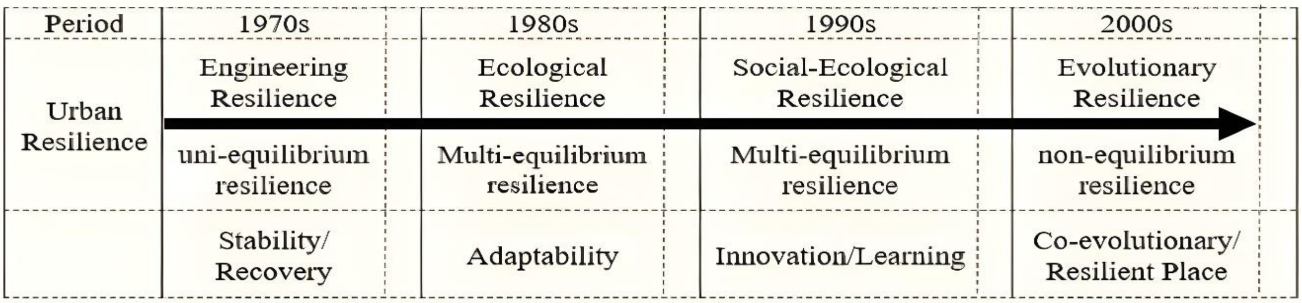
The rapid expansion of metropolitan areas and the rise of urban vulnerabilities have become pressing issues in contemporary societies.

In response to existential threats to urban sustainability, the notion of urban resilience has emerged. Compared to earlier studies that primarily focused on urban hazards, disasters, and vulnerability, urban resilience emphasizes a city's capacity to endure risk and recover effectively after a disaster.

It represents a comprehensive function aimed at enhancing risk resistance, reducing vulnerability, and minimizing urban losses.

In contrast to more reactive approaches, urban resilience is inherently strategic, forward-looking, and global in scope [28].

A review of the literature indicates that the evolution of urban resilience discourse mirrors the broader transformation of resilience paradigms over recent decades from engineering-based to more adaptive and evolutionary approaches. (see Figure 1).



Period	1970s	1980s	1990s	2000s
Urban Resilience	Engineering Resilience	Ecological Resilience	Social-Ecological Resilience	Evolutionary Resilience
	uni-equilibrium resilience	Multi-equilibrium resilience	Multi-equilibrium resilience	non-equilibrium resilience
	Stability/ Recovery	Adaptability	Innovation/Learning	Co-evolutionary/ Resilient Place

Figure 1. Timeline of the evolution of urban resilience discourse [29]

Urban systems consist of multiple interdependent and overlapping networks that encompass various physical and social elements.

Vulnerability in cities is omnipresent ranging from infrastructure and transportation to energy supply, resource access, and beyond. Godschalk (2003) proposed that resilient cities are composed of sustainable networks of physical systems and human communities that are capable of managing extreme events and must be able to persist and function during such conditions.

Urban resilience is inherently a comprehensive concept that includes both hard indicators (e.g., infrastructure, transportation, etc.) and soft indicators (e.g., economic, social, and institutional dimensions). In its earlier stages, the theory of urban resilience was primarily applied in physical and socio-economic contexts:

- Physical resilience generally refers to the robustness of infrastructure systems [7, 30].
- Economic resilience pertains to a stable and healthy level of economic development [31].
- Social resilience refers to the capacity of communities and individuals to recover from shocks and disruptions [32].

With the emergence of increasingly complex urban challenges, the central focus of urban resilience research has shifted toward enhancing the capacity of cities to withstand natural disasters and socio-economic hazards in the context of climate change, globalization, and rapid urbanization. These capabilities include the ability to act before, during, and after disruptive events in order to mitigate negative impacts [18], as well as the capacity to maintain or restore essential urban functions in response to disturbance across spatial and temporal dimensions [33]. In general, urban resilience is now widely regarded as a robust and integrated response to escalating risks in urban areas. The concept has evolved from its origins in technological sciences [34], environmental sciences, and life sciences [35], and has since expanded significantly in scope and application [36].

3. Methodology

In this study, the PRISMA checklist was used to guide the systematic review of current research related to the topic under investigation. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is widely applied across academic disciplines to enhance the methodological rigor and reporting quality of systematic reviews. It provides a structured, evidence-based framework for documenting the identification, screening, eligibility assessment, and inclusion of studies. PRISMA offers a standardized flow diagram that systematizes these stages, ensuring transparency, comprehensiveness, and traceability throughout the review process. Additionally, it supports the organized retrieval and evaluation of relevant studies for data extraction and synthesis, promoting objectivity and verifiability in qualitative research (see Figure 2).

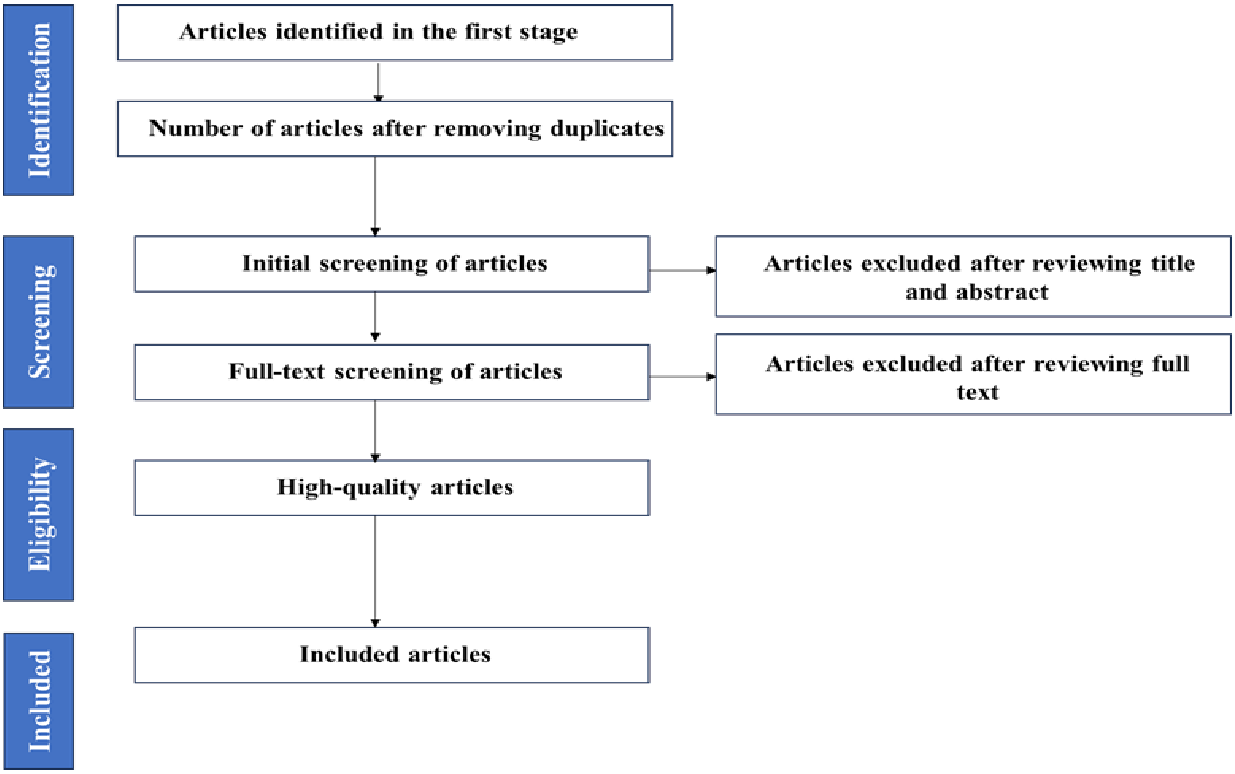


Figure 2. illustrates the specific stages undertaken in the implementation of the PRISMA checklist

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In addition to the PRISMA framework, this study employed a qualitative interpretive meta-synthesis following the seven-step approach proposed by Sandelowski and Barroso, a widely recognized methodology for generating higher-order conceptual interpretations from qualitative evidence. This approach was selected because it enables the systematic comparison, translation, and integration of conceptual findings across studies, thereby supporting the development of a new conceptual framework for urban form resilience, rather than merely summarizing existing literature.

Meta-synthesis, in this interpretive tradition, involves moving beyond aggregation to the construction of third-order interpretations by examining relationships among first-order (participants') and second-order (authors') interpretations. Operationalization of this method in the present study included:

(1) identifying conceptually relevant qualitative studies;
(2) extracting interpretive statements;
(3) comparing and classifying conceptual categories;
(4) translating categories across studies; and
(5) synthesizing these translations into higher-level constructs.

Employing a qualitative meta-synthesis a rigorous type of systematic review the present study moves beyond descriptive summarization toward explicit interpretive translation and conceptual integration. This approach differs fundamentally from a narrative review, which typically provides a less systematic and more descriptive account of the literature. Through the meta-synthesis procedure, fragmented insights regarding the spatial and morphological dimensions of urban form resilience were consolidated into coherent thematic patterns, enabling the construction of a unified conceptual model. As Thorne (2022) notes, interpretive meta-synthesis is particularly effective in fields characterized by conceptual divergence, as it systematically transforms disparate qualitative findings into cumulative, theoretically grounded knowledge. A defining characteristic of this method as with all systematic reviews is the reliance on predefined protocols for searching, screening, evaluating, selecting, and synthesizing studies, thereby ensuring transparency, replicability, and analytical rigor.

A qualitative meta-synthesis was selected because the aim of the study was to generate a higher-order conceptual framework for urban form resilience by synthesizing interpretive insights across multiple qualitative studies. Alternative review methods such as bibliometric analysis or scoping reviews were considered but deemed insufficient for this objective. While bibliometric analysis can identify publication patterns and research networks, it does not enable the deep interpretive integration required to construct new conceptual constructs. Similarly, scoping reviews map the breadth of a field but do not provide the analytical depth needed for conceptual synthesis. Meta-synthesis, by contrast, offers a robust interpretive approach that allows for the translation, comparison, and integration of diverse qualitative findings into coherent, higher-level theoretical insights.

In this study, the meta-synthesis process was guided by the seven-step framework proposed by Sandelowski and Barroso (2006). Beyond listing the procedural steps, the study operationalized each stage as follows. After defining the research question and search strategy, inclusion and exclusion criteria were applied to identify conceptually relevant studies. During the extraction phase, all definitions, conceptual statements, and descriptions related to urban form resilience were manually coded and compiled into an analytical matrix.

3.1. Formulation of the research question

To address the existing research gap, this study is guided by the following core question:

What constitutes the concept of resilient urban form, and what are its key elements and characteristics?

This central question serves as the foundation for the systematic review and meta-synthesis process, directing the selection, screening, and interpretation of relevant literature.

3.2. Development of the search strategy

The literature search was conducted using English-language journal articles indexed in the Scopus database, covering the period from 2001 to 2025. The strategy was designed to identify scholarly contributions that specifically address the conceptualization, components, and frameworks associated with resilient urban form. Key features of the search strategy included:

- Database selection: Scopus was selected as the primary database due to its extensive disciplinary coverage, strong indexing of urban studies and environmental research, and suitability for structured systematic searches. Although best practices in systematic reviews often recommend searching multiple databases to minimize indexing bias, Scopus was selected as the sole database for two reasons. First, it provides extensive interdisciplinary coverage of urban studies, environmental planning, geography, and sustainability science, with substantial overlap with Web of Science and other major indexing platforms. Second, preliminary cross-checking indicated that key conceptual works on urban form resilience were already captured within Scopus. However, relying on a single database may still introduce the possibility of missing relevant studies indexed elsewhere; therefore, this choice is acknowledged as a methodological limitation and is addressed in the limitations section of the manuscript.

- Keyword identification: Seven primary keywords related to urban form resilience were used across titles, abstracts, and author keywords to ensure comprehensive retrieval of relevant sources.
- Exclusion criteria: Certain Scopus subject areas such as psychology, medicine, chemistry, and materials engineering were excluded because their disciplinary focus does not conceptually engage with the spatial, morphological, or structural dimensions of urban form.

  In addition, subject areas such as Engineering (ENGI), Earth and Planetary Sciences (EART), and Energy (ENER) were excluded based on the specific conceptual scope of this study. While these fields are central to analyzing infrastructure performance, geophysical hazards, and energy system resilience, preliminary scoping revealed that their contributions tend to emphasize technical, mechanical, or hazard-specific modeling rather than the morphological, spatial, and configurational dimensions of urban form, which constitute the conceptual focus of this meta-synthesis.

  Including these domains would have shifted the review toward engineering-based structural resilience or hazard science, potentially diluting the conceptual boundaries of urban form resilience as a morphological construct.

  Therefore, the exclusion of these subject areas was a deliberate conceptual decision intended to maintain a focused synthesis on urban morphology, spatial configuration, and built-form characteristics, rather than infrastructural engineering or geophysical processes.

  However, it is acknowledged that this choice may limit the integration of insights from engineering and earth sciences, and such exclusion is recognized as a methodological limitation in the discussion section.
- Documentation of search strings: Detailed search strings and filtering parameters used in Scopus are presented in Table 1, demonstrating the combinations of keywords, inclusion filters, and exclusion settings applied during the search process.

Table 1. Search algorithm used in the database query

Database	Search Query / Strategy
Scopus	TITLE-ABS-KEY (resilience OR resilient AND urban OR city AND form OR principles OR attributes) AND PUBYEAR > 2001 AND PUBYEAR < 2025 AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (SUBJAREA , "ENGI") OR EXCLUDE (SUBJAREA , "COMP") OR EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "ENER") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "BUSI") OR EXCLUDE (SUBJAREA , "MATH") OR EXCLUDE (SUBJAREA , "ECON") OR EXCLUDE (SUBJAREA , "PSYC") OR EXCLUDE (SUBJAREA , "MATE") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "NURS") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "IMMU") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "VETE") OR EXCLUDE (SUBJAREA , "DENT"))

Table 2. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
• Articles in which search terms appear in the title, abstract, or author keywords • Document type limited to peer-reviewed journal articles in English • Publications released between 2001 and 2024 • Title explicitly related to resilient urban form • Abstract includes reference to the definition of urban resilience • Full text discusses indicators of resilient urban form or provides indirect conceptualizations	• Duplicate articles • Grey literature (conference papers, theses, dissertations, reports, etc.) • Irrelevant subject matter • Full text not accessible • Absence of explicit or implicit reference to resilient urban form

3.3. Defining inclusion and exclusion criteria

The retrieved documents were screened using an operationalized protocol designed to ensure objectivity, consistency, and replicability in the selection process. Articles were included if they met at least one of the following clearly defined criteria:

- Provided an explicit definition of urban form resilience, or
- Addressed urban form resilience by analyzing at least two spatial–physical characteristics of urban form (e.g., street network configuration, density, land-use mix, connectivity, block size, morphological patterns, or spatial distribution of functions) explicitly in the context of enhancing resilience to natural or environmental hazards.

This operational definition replaced the initial subjective categories of “relevance” and “indirect definition,” ensuring that only studies engaging with identifiable and codable elements of urban form were included. Screening was conducted through a three-stage evaluation of titles, abstracts, and full texts based on these objective criteria, as summarized in Table 2.

3.4. Selection of sources

Following the implementation of the search strategies across the selected databases, the retrieved documents were imported into Zotero reference management software. Duplicate entries were identified and removed. The selection process was conducted in four distinct stages, based on the PRISMA checklist, to ensure methodological rigor.

- Stage 1: Initial Filtering by Keyword Use
  This phase limited the dataset to journal articles that explicitly employed the identified keywords. A total of seven topic-specific searches were conducted in the Scopus database, each combining one of the seven selected terms with the phrase "urban resilience". Keywords were applied to article titles, abstracts, and author keywords. This initial query resulted in 2,439 articles.
- Stage 2: Title and Abstract Screening
  Articles were screened for relevance based on their titles, abstracts, and keywords. The abstracts and introductions were carefully reviewed, and the structural layout of each article was considered. Articles most closely aligned with the study’s objectives were selected.
  This step yielded a refined sample of 130 journal articles.
- Stage 3: Full-Text Review
  The full texts of the selected articles were subjected to a structured content analysis to extract definitions, conceptual statements, and morphological indicators associated with urban form resilience. During this stage, each article was examined to identify the specific physical, spatial, or functional characteristics it proposed as contributing to resilience. The extracted elements were then compared across all studies to identify recurring patterns, points of divergence, and thematic clusters relevant to the conceptualization of resilient urban form. A total of 49 articles met these criteria and were included in the final synthesis.
- Stage 4: Temporal Analysis of Selected Articles
  The final set of 49 articles spans the period from 2001 to 2025. As shown in Figure 3, a pronounced surge in publications occurred between 2021 and 2024, highlighting the growing academic interest in this topic in recent years.

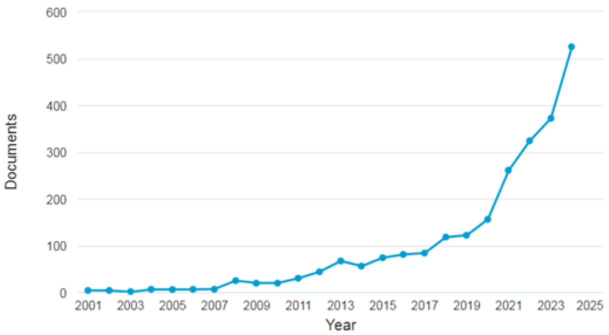

Figure 3. Publication Timeline of Articles on Urban Resilience

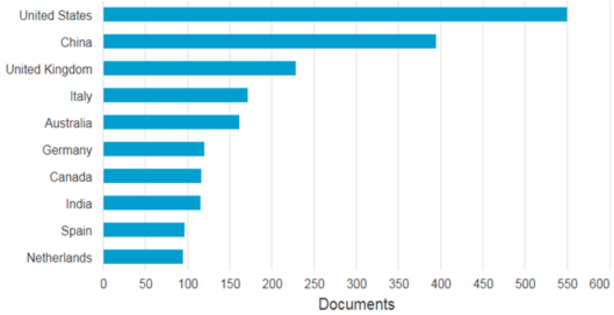

Figure 4. Top 10 Countries in Publications on Resilient Urban Form

Based on the results of the database search conducted in Scopus, the top ten countries (As shown in Figure 4) with the highest number of publications on resilient urban form are as follows: the United States, China, the United Kingdom, Italy, Australia, Germany, Canada, India, Spain, and New Zealand. Figure 5 illustrates the distribution of publications related to urban resilience from 2001 to 2025 across scientific journals within the following subject areas: urban studies, green and sustainable science and technology, environmental studies, regional and urban planning, and geography.

Figure 5. Subject-Area Distribution of Publications on Urban Resilience (2001–2025)

3.5. Extraction of indicators from the selected studies

The next stage of the analysis involved not only extracting relevant information from the selected studies but also synthesizing these data to identify the conceptual patterns that informed the final framework. To ensure systematic and transparent extraction, a structured data extraction form was developed. This form included key fields such as: author and year of publication; study context; the definition or interpretation of resilience used; the physical or spatial characteristics of urban form examined; the type of environmental hazard addressed; the spatial scale of analysis; and the specific indicators proposed or implied in relation to resilient urban form. Extraction was conducted manually, with each article reviewed in full and its conceptual content coded into the fields of the extraction form. However, the process did not end with extraction. The coded material was subjected to an iterative interpretive synthesis using a constant comparative approach. This involved comparing indicators across studies, clustering similar concepts, distinguishing overlapping terms, and identifying recurring conceptual logics. Through repeated cycles of comparison and refinement, preliminary categories were consolidated into higher-order thematic constructs. These analytical steps enabled the transformation of fragmented definitions and dispersed indicators into a coherent set of conceptual dimensions. Ultimately, this synthesis led to the identification of six core components of resilient urban form, which represent the higher-level conceptual patterns emerging from the 49 articles included in the meta-synthesis.

To enhance transparency and replicability, the primary categories of the data extraction form are provided as a supplementary appendix in this manuscript. These categories include:

- bibliographic information (author, year, journal),
- study context and geographic scale,
- definition or interpretation of resilience adopted,
- physical and spatial characteristics of urban form examined,
- type of environmental hazard addressed,
- spatial scale of the analysis (macro, meso, micro), and
- proposed or implied indicators related to resilient urban form.

Presenting these categories allows readers to clearly understand what data were extracted from each study and ensures that the analytical process adheres to standards of methodological transparency expected in qualitative systematic reviews.

To enhance methodological transparency, the extraction process combined both inductive and deductive strategies. The data extraction form was initially developed deductively based on foundational literature on urban form and resilience (e.g., Sharifi, 2016; Feliciotti et al., 2016; Masnavi et al., 2019), which informed the predefined categories such as: definition of resilience, morphological elements, spatial scale, hazard type, and proposed indicators. During full-text review, an inductive coding procedure was incorporated to capture emergent concepts that were not included in the predefined categories. As new themes appeared particularly those related to socio-ecological interactions, spatial dynamics, and adaptive processes the extraction form was iteratively refined to integrate these additional categories. This combined deductive inductive approach ensured both conceptual grounding in existing theory and openness to novel insights, thereby strengthening the analytical depth and flexibility of the synthesis. This iterative deductive–inductive development process strengthened the content validity of the extraction form by ensuring that it both reflected established theoretical constructs and captured emergent conceptual dimensions specific to urban form resilience.

3.6. Analysis of findings

A thematic content analysis was conducted on the final set of 49 articles. The analysis followed an interpretive constant comparative approach consistent with Sandelowski and Barroso. First, an initial open-coding phase was undertaken, during which extracted definitions and characteristics were coded line-by-line to identify discrete conceptual units related to urban form resilience. In the second stage, similar codes were iteratively compared across studies and consolidated into broader thematic categories through repeated refinement. This process enabled the organization of the data in a systematic and replicable manner while remaining aligned with the interpretive objectives of the meta-synthesis. Once thematic categories were established, the frequency of each coded characteristic was tabulated to determine its prevalence in the literature and to differentiate widely shared, emerging core concepts from more isolated or context-specific proposals. Because meta-synthesis is an interpretive method, its conceptual outputs do not inherently produce spatial indicators. Therefore, a methodological translation step was required to map qualitative concepts onto quantitative morphological measures. This step is not part of the meta-synthesis itself but forms the analytical bridge for design-oriented application.

3.7. Quality control

To enhance the rigor and credibility of the qualitative systematic analysis, several strategies were implemented to mitigate potential researcher bias and strengthen the reliability of the data collection tool. The primary instrument for data collection in this study was document analysis, a method particularly suited to qualitative meta-synthesis. However, recognizing that document-based coding can be sensitive to subjective interpretation, additional steps were taken to ensure analytic consistency. Although the screening, extraction, and initial coding were conducted by a single researcher, a two-step coding procedure was employed. The researcher conducted a second full coding pass after a two-week interval to reassess the coding decisions and evaluate the stability of initial interpretations. This temporal separation served as an internal reliability check, helping to reduce the influence of coder fatigue and immediate recall bias. In addition, the coding framework and a subset of coded articles were peer-reviewed by an external colleague with expertise in urban resilience. This peer-debriefing process functioned as an informal inter-rater reliability mechanism by allowing discrepancies, ambiguous categories, and coding inconsistencies to be identified and resolved. The external reviewer provided independent feedback on the clarity of the coding scheme and the alignment between codes and the underlying conceptual constructs. While these steps enhanced transparency and dependability, it is important to note that a formal inter-rater reliability (IRR) test was not conducted, and the data extraction form was not pilot-tested prior to full implementation. This constitutes a methodological limitation and is explicitly acknowledged in the limitations section. Future research would benefit from employing multiple coders and calculating formal IRR statistics to further improve methodological robustness. Despite the absence of formal IRR, the combination of repeated coding, peer debriefing, and the use of a structured extraction form contributed to a transparent, replicable, and credible analytical process.

4. Findings and discussion

The results indicate that the theory of resilience has been proposed in response to the uncertain risks of disasters in urban areas, suggesting a correlation between urban form and the occurrence of disasters. In this context, disasters serve as the linking factor that connects the concepts of resilience and urban form. According to Kevin Lynch, urban form refers to the spatial pattern of large, static, and permanent physical objects in the city, as well as land use characterized by mixed-use features. These definitions underscore the significant role of morphological elements in shaping the spatial structure of urban environments. During urbanization processes, form influences climate change, disaster mitigation and response, and energy consumption in both buildings and transportation through land use arrangements. In other words, the elements of urban form, through their interaction with the surrounding environment and disaster risks, form complex spatial and functional structures (see Table 3).

Several studies have highlighted the critical role of urban form elements in enhancing resilience against environmental hazards. Gill et al. (2007) designed a classification of 29 urban form types based on the UK Land Use Database, including agricultural land, mining sites, residential, commercial, industrial, and energy-related areas, to analyze the urban heat island effect in Greater Manchester. They later summarized nine land cover types that confirmed the positive role of urban form in mitigating climate change [37]. Sharifi et al. (2021) employed specific indicators to assess the resilience of urban form elements against hazards such as heatwaves and flooding.

Table 3. Correlation Between Urban Form Elements and Disaster Risks

Spatial Scale	Urban Form Element	Heatwaves	Flooding
Micro	Windows	Quantity and design style, glass-to-wall ratio, orientation	-
	Building Facade	Materials, surface reflectivity, shading, vegetation coverage	Building scale (mass, form)
	Roof	Materials, vegetation, green roofs	Vegetation coverage, green roofs (runoff reduction)
	Building	Depends on facade and roof	Site elevation
Meso & Macro	Parcels	Type and amount of vegetation cover, type and extent of paving	Impervious and semi-impervious surfaces, vegetation cover
	Streets	Materials, shading, skyline profile, ventilation corridors	Flood prevention
	Open Spaces	Scale, materials, vegetation, water, sky-view factors	Impervious/semi-impervious surfaces, vegetation cover
	District	Distribution of open spaces, distance to large blue-green spaces and ventilation paths	Location and number of developments outside floodplain, river greening, small-scale control measures
	City	Emergency response infrastructure (electricity, medical aid, artificial precipitation, etc.)	Large-scale flooding, dams, overflow infrastructure, emergency response facilities

Additional studies have shown that temperature patterns and wind flow [38], as well as relative humidity and solar radiation [39], are significantly influenced by combinations of urban form elements, which in turn shape a city's capacity to respond to disaster risks. Thus, urban form elements are increasingly regarded as key instruments for enhancing resilience. In the field of urban studies, resilience is often conceptualized as a principle of planning and design to address socio-economic and environmental changes. Particularly at the urban design scale, growing attention is given to the following questions:

- What types of hazards should be addressed in resilience planning?
- Which urban form elements are utilized to confront these hazards?
- At what stages do these elements interact with hazard processes?
- And finally, what resilience objectives are achieved through such interactions?

These questions are logically interconnected and provide a structured framework for analyzing urban form resilience (see Figure 6).

Urban form, as a key domain in urban studies, is composed of multiple interrelated and interdependent elements and can be analyzed across three spatial scales: macro, meso, and micro [40].

Consequently, the spatial configuration, patterns, and interactions of urban form elements at each scale are understood to influence the frequency and intensity of various disaster risks. This relationship forms the foundation of scientific inquiry into the link between morphology and resilience, which is typically assessed using specific indicators [41]. Masnavi et al. (2019) further affirmed this perspective by introducing an urban resilience index designed to analyze how a sustainable, integrated design of urban form elements across different spatial scales can affect exposure to disaster risks. Their findings offer valuable insights into the study of resilient urban form and have encouraged scholars to further explore its conceptualization and defining characteristics [42].

4.1. Empirical pattern analysis of extracted characteristics

The systematic review revealed a diverse yet uneven conceptual landscape surrounding the relationship between urban form and resilience. Across the 49 articles included in the meta-synthesis, an average of eight distinct characteristics of resilient urban form were identified per study, although many articles focused on only one or two dimensions. The distribution of concepts illustrates the current state of theoretical development in the field. Approximately 40% of the characteristics were mentioned by only a single author, reflecting a fragmented and still exploratory body of knowledge in which scholars propose context-specific or discipline-specific indicators. In contrast, 54% appeared in more than two studies, signaling an emerging convergence around several recurring ideas. Notably, diversity and redundancy two characteristics referenced in at least half of the reviewed publications stood out as central morphological attributes linked to resilience across a range of urban contexts. Together, these patterns highlight both the conceptual breadth of prior research and the need for a more integrated interpretive framework (Figure 7).

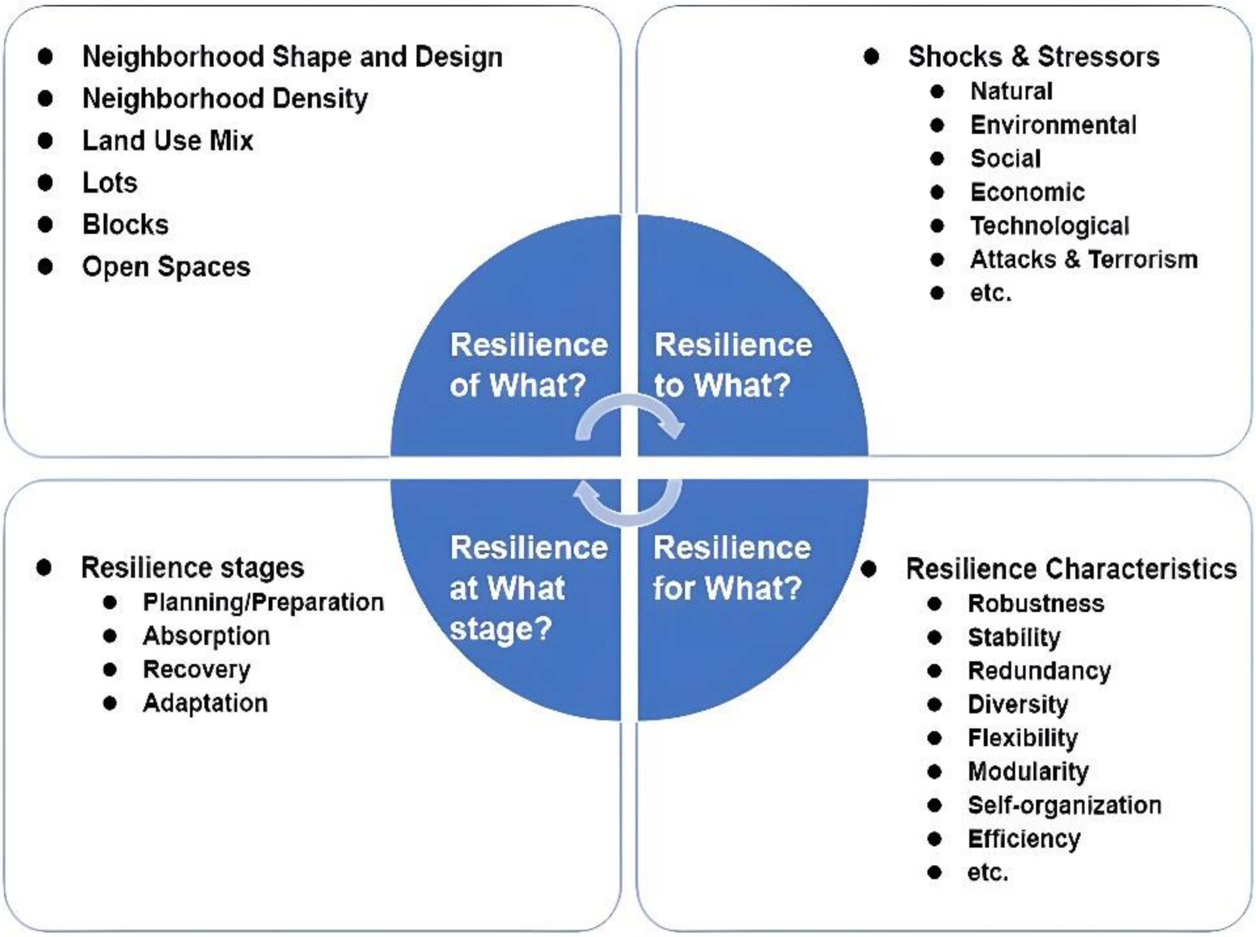

Figure 6. Key Issues and Internal Correlation Analysis in Urban Form Resilience Research [5]

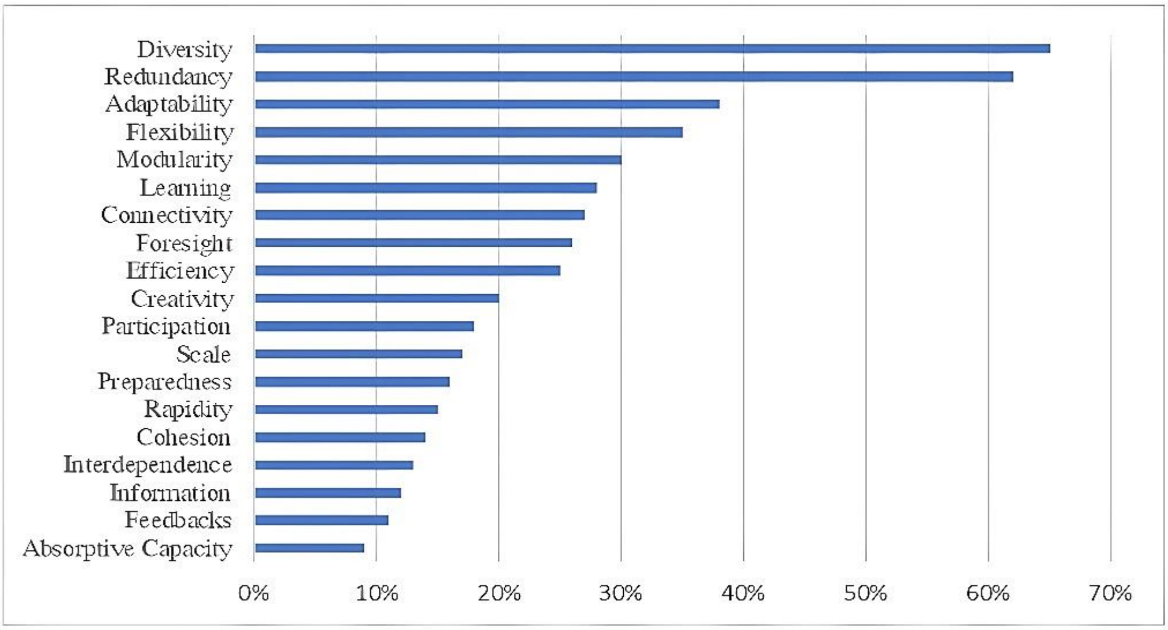

Figure 7. Frequency distribution of urban resilience characteristics

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Following the completion of the coding and categorization process, the analytical focus shifted from identifying individual characteristics to synthesizing them into a coherent set of higher-order concepts. This stage constituted the core interpretive contribution of the meta-synthesis and required moving beyond frequency counts toward conceptual integration. To ensure transparency, the synthesis followed three explicit procedures. First, semantic clustering was performed by grouping characteristics with overlapping meanings or shared theoretical roots. For example, land-use diversity, functional mix, and activity heterogeneity although labeled differently across studies were consistently linked to enabling multiple pathways of use under disturbance. Second, functional consolidation was undertaken by examining the role that each characteristic played in system behavior. During this stage, repeatedly occurring features such as diversity, spare capacity, functional substitution, and multiple pathways were found to contribute to the same mechanism: the presence of alternative spatial or functional options that allow a system to continue operating under disruption. Consequently, diversity was subsumed under the broader system-level concept of redundancy, which captures both multiplicity (diversity) and substitutability (functional alternatives) as complementary dimensions of the same resilience function. Third, hierarchical integration was applied by comparing preliminary thematic groups across studies to identify the most stable higher-order patterns. Through iterative refinement, the numerous characteristics were consolidated into six core concepts ecological sensitivity, indeterminacy, polycentricity and modularity, connectivity, multifunctionality, and redundancy each representing a cluster of lower-level characteristics that consistently co-occurred in the literature.

4.2. Concept of resilient urban form

The concept of resilience entered the field of urban planning in the 1990s, and since then, researchers have undertaken various studies in the domain of resilient urban planning and development. Around 2010, the significance of urban form in enhancing resilience began to gain recognition, drawing scholarly attention to the concept of resilient urban form. Dibble argued that the spatial composition of morphological elements influences the frequency and intensity of disaster risks, thereby directly affecting urban resilience. He emphasized that a resilient urban form is one that can optimize resources and promote sustainable development [7]. Sharifi, who has extensively contributed to this area, defines resilient urban form as a spatial network system interlinked with socio-ecological dynamics, capable of maintaining its cohesion, resilience, and adaptability under changing socio-economic and environmental conditions [43]. According to him, it is a sustainable configuration of morphological components that can absorb shocks, facilitate rapid recovery after disasters, and enhance urban adaptability [44]. Currently, there is no universally accepted definition of resilient urban form, and scholarly debate on its conceptual boundaries continues. However, a shared understanding has emerged around its core function: enabling urban systems to anticipate, absorb, and recover quickly from hazardous events while continuing to operate in a changing environment.

A holistic analysis suggests that the morphological and physical resilience capacities of urban form are shaped by the interactions among its constituent elements across different spatial scales, as well as by the broader socio-economic context of the urban system. From a spatio-temporal perspective, and drawing on Sharifi's framework, this study conceives resilient urban form as a spatial pattern configuration emerging from the nested integration of morphological components at multiple levels. Such a configuration possesses sufficient spatial and functional resilience to reorganize and reshape itself dynamically in response to evolving economic and societal demands. In essence, the capacity of urban form to maintain the structural integrity and functional continuity of urban systems, adapt to changing spatial and temporal conditions, optimize resource distribution, and support long-term sustainability constitutes the foundation of what is referred to in this study as a resilient urban form.

4.3. Characteristics of a resilient urban form

Urban form plays a critical role in reducing risks and enhancing resilience. This role is manifested through key characteristics such as connectivity, redundancy, modularity, and adaptability.

- Connectivity
  Connectivity is a prerequisite for morphological resilience, facilitating the bidirectional flow of information, assets, and resources, and enabling the timely provision of evacuation channels [45]. However, some scholars argue that excessive connectivity can introduce new vulnerabilities, potentially undermining the overall resilience of the system [46].
- Modularity
  Modularity explains how morphological elements are spatially organized in relation to the whole system, how they interact across scales, and the extent to which higher-level wholes can be disaggregated or re-integrated while maintaining resilient internal linkages independent of the larger system. This characteristic

enables localized failures without causing systemic collapse.

- Redundancy

  Redundancy refers to the capacity of morphological elements to perform similar or backup functions and to be interconnected in ways that reduce the likelihood of common failure points. It ensures that not all components with similar functions are equally exposed to hazards, thereby enhancing systemic robustness.
- Adaptability

  Adaptability reflects the ability of morphological elements to respond to evolving hazards at any point in time and to reduce exposure to climate-related risks. This characteristic is closely linked to vulnerability, as it reveals the sensitivity of urban form components to environmental shocks.

These defining features highlight the potential for morphological components not only to mitigate uncertain disaster risks but also to proactively enhance long-term sustainable urban development [47].

4.4. The relationship between resilient urban form and urban ecology

Based on the conducted analyses, it can be concluded that urban form influences disaster risks primarily through land-use practices, and that scientific and rational land-use strategies can significantly enhance urban resilience. The core focus of urban ecology is to investigate the interaction between cities and the natural environment, and to promote sustainable urban development by examining variables such as urban climate, hydrology, soil, biology, and the ecological and environmental impacts resulting from intensive land use. In particular, land-use changes have a profound influence on the structure and ecological functionality of urban systems [48]. Therefore, it can be inferred that there is a positive relationship between resilient urban form and urban ecology, primarily mediated through land-use patterns.

4.5. Spatial scale categorization of urban form elements

The city is a dynamic hierarchical network composed of nested elements with varying spatial and temporal scalesfactors that are critical to urban resilience [49]. In academic research, multiple approaches exist for classifying components of urban form. Among these, hierarchical classification is considered particularly effective in reflecting urban form and facilitating a better understanding of the complexity inherent in urban systems (see Table 4).

Following a hierarchical approach, the elements of resilient urban form can be categorized across macro, meso, and micro scales, enabling access to lower-scale morphological components (Table 5).

Table 4. Methods for classifying urban form elements

Approach	Elements	Theorist
Perceptual	Path, edge, district, node, landmark	Lynch, 1960
Dualistic	Built environment, transport network	Siva, 2017
Attribute-based	Density, diversity, connectivity, accessibility	Bourdic, 2012
Tripartite (Conzenian School)	Streets, plots, buildings	Conzen, 1960
Hierarchical (Caniggian School)	Structure, system, organism	Caniggia, 2001

Table 5. Classification of urban form elements by spatial scale

Scale	Morphological Elements	Resilience Function
Macro	Urban structure & landscape	City size Hierarchical scale Development model Functional aggregation Landscape connectivity
Meso	Neighborhood	Neighborhood modularity Neighborhood density
	Streets, blocks, open spaces	Land-use mix Plot and block shape and size Size, type, and layout of open spaces Street network model Street width, edges, and orientation
Micro	Buildings and sites: layout, type, roof, etc.	Energy efficiency, environmental responsiveness
	Site design and scale	Adaptability to hazards, spatial optimization

This classification aids in understanding the nested structure, spatial positioning, and interactions among morphological elements, while emphasizing the physical characteristics and spatial configuration of elements across scales to enhance urban resilience potential and promote sustainable development.

In practice, there are no strict boundaries between these three spatial scales.

Therefore, understanding the relational context of each scale both in relation to one another and to the broader urban system is essential for uncovering the mechanisms of resilience embedded in urban form elements.

The elements listed in Table 5 play a significant role in enhancing urban resilience and have been validated by various empirical studies. However, further research is required to address existing gaps in understanding the impact of morphological elements on urban resilience. Cities, as complex systems, require the integration of these elements to form a coherent whole that functions effectively and sustainably [50]. In this context, the regional composition of different urban form elements serves as an analytical approach to examining their influence on urban resilience across different spatial scales and in response to various hazards.

4.6. Resilient urban form elements at the macro scale

Urban form elements at the macro scale are reflected in the overall structure of the city and region. Resilience at this level is often expressed through factors such as city size, hierarchical structure, development models, and functional aggregation patterns:

- City Size

While larger cities are often considered more vulnerable to catastrophic events, this vulnerability can be counterbalanced by factors such as economies of scale, superior resource accessibility, and greater systemic redundancy, which collectively may enhance their overall resilience [51]. In this sense, the extent to which city size contributes to resilience ultimately depends on the underlying urban growth model and the presence of strategies capable of leveraging these advantages while mitigating the social and environmental risks associated with large-scale urbanization [52].

- Hierarchical Scale

Systems characterized by a hierarchical spatial structure tend to exhibit higher levels of resilience. Such systems form nested subsystems that enable gradual change, self-organization, and adaptive transformations across time and space. They also support the emergence of new configurations when needed, thereby reducing urban vulnerability and enhancing morphological resilience [53]. Empirical evidence shows that hierarchical spatial organization integrates smaller-scale elements into higher-level systems, forming network structures with fractal properties. These structures improve a city's ability to withstand disaster risks and contribute to urban design strategies that support transport-friendly layouts and improved spatial permeability [2].

- Development Model

Debates on development models in resilience research primarily focus on the impacts of compact versus decentralized urban forms. From an environmental perspective, urban compactness reduces energy demands for buildings and transportation by encouraging mixed land use, proximity between housing and employment, and convenient travel patterns [54], particularly evident in densely developed areas [55]. Moreover, well-designed streets and open public spaces can create disaster-resilient environments, improving cities' ability to respond to hazards [5]. Conversely, decentralized or sprawling models may provide opportunities for large-scale green infrastructure and open spaces, but also tend to increase impervious surfaces, leading to higher environmental risks [56]. Overexploitation of land resources, encroachment on ecologically sensitive areas, loss of biodiversity, and degradation of ecosystem functions disrupt the natural energy flows between urban and natural systems, exacerbating the frequency and severity of floods and heat-related disasters [57]. In terms of economic resilience, compact urban form can reduce infrastructure costs, improve efficiency of public service delivery, and lower household transport expenses [58]. A walkable and compact environment attracts foreign investment, boosts productivity, and reinforces economic stability [59]. Socially, compactness promotes diverse urban interactions, enhances opportunities for community engagement, reduces isolation and social exclusion, and strengthens social resilience [44]. Nevertheless, some studies point out the downsides of compactness, including limitations in absorptive and adaptive capacity of morphological elements, environmental stress, restricted green space, and potential harm to public health and social equity [58]. In emergency situations, limited open space for evacuation and shelter in dense areas may compromise urban resilience [60]. Therefore, compactness alone is insufficient to ensure resilience; it must be strategically combined with other principles, such as land-use diversity and improved access to amenities. While both density and decentralization offer distinct advantages, the key lies in optimizing their integration to minimize negative impacts and maximize resilience benefits [61].

- Functional Aggregation Model

Urban functional aggregation is generally categorized into monocentric and polycentric configurations. Polycentric models enhance urban resilience by increasing modularity across the system, facilitating decentralized allocation of services and facilities at multiple spatial scales [62]. They also support mixed-use development, promote public transport connectivity, balance residential and employment locations, and strengthen the distribution of resilience-supporting infrastructures. In contrast, monocentric structures tend to concentrate population and infrastructure in central areas, which can lead to higher energy consumption and increase vulnerability to the impacts of extreme events due to systemic dependence on a single core. However, some studies have also indicated that polycentricity, despite its benefits, can result in greater land consumption and reduced ecosystem services, thereby amplifying negative environmental effects [63]. Therefore, selecting an appropriate functional aggregation model should be based on a comprehensive assessment of multiple factors such as urban size, regional characteristics, economic capacity, and ecological sensitivity. A balanced approach that aligns spatial structure with resilience goals is essential for enhancing the adaptive and absorptive capacities of urban systems.

- Landscape Connectivity

Landscape connectivity refers to the increasing diversity and redundancy of linkages between urban areas and surrounding ecosystems, both within and beyond urban boundaries. This enhanced connectivity fosters balance between urban systems and natural environments, supports the provision of ecosystem services, mitigates urban heat island effects and flood risks, and enables cities to absorb shocks and reorganize adaptively [59]. Furthermore, scientifically designed connectivity can prevent landscape fragmentation, improve the uninterrupted flow of energy and resources, and support the ecological integrity of urban environments [46]. However, excessive connectivity may also accelerate the spread of disastrous events, such as fires or disease outbreaks, across urban systems. The concept of optimal connectivity aligns with the principle of morphological modularity in resilience theory. This involves many strong, short-range connections combined with a few weak, long-range ones, which together provide robust, flexible links that reduce systemic risk while enhancing overall urban resilience [62]. In summary, elements such as urban size, hierarchical spatial scales, compactness versus decentralization, monocentric versus polycentric forms, and connectivity patterns all contribute to the city's capacity to withstand and adapt to various hazards. However, the relationships between specific morphological configurations and particular types of disaster risk remain underexplored, indicating a critical area for future research (see Table 6).

4.7. Resilient urban form elements at the meso (Intermediate) scale

Resilient urban form at the meso scale is reflected in the configuration and design of neighborhoods, blocks, parcels, open spaces, and street networks. This scale plays a critical role in shaping the local morphological layout and directly influences the system’s ability to absorb, respond to, and recover from disturbances.

- Neighborhood Modularization

Neighborhood modularization enables elements to be integrated within the broader urban structure to achieve self-organization and adaptability. It enhances neighborhood self-sufficiency and the ability to maintain essential functions when other parts of the city are disrupted, while facilitating controlled exchange between modules [44]. In this way, when certain modules are affected by disasters, support from other modules becomes possible. Moreover, designing a pedestrian- and bus-oriented environment helps reduce dependence on private vehicles and enhances both social and environmental resilience [62].

Table 6. Relationship between resilience functions of macro-scale urban form elements and environmental & natural hazards

Hazard Type		Hierarchical Scale	City Size	Compact	Sprawl	Polycentric	Monocentric	Connectivity
Natural	Earthquake	-	-	✔	✔	✔	✔	-
	Flood	-	-	✔	✔	✔	-	✔
	Wildfire	-	-	✔	✔	✔	✔	-
	Storm	-	-	-	-	✔	✔	-
	Other natural hazards	-	-	✔	✔	-	-	-
Environmental	Climate change	✔	✔	✔	✔	✔	✔	-
	Extreme weather events	✔	-	✔	-	-	-	✔
	Resource scarcity	✔	-	✔	✔	✔	-	✔

- Neighborhood density

Appropriate neighborhood density provides access to various service facilities and convenient public transportation, thereby reducing energy consumption, improving residents' health, minimizing adverse environmental impacts, enhancing neighborhood resilience to disasters, and creating multiple opportunities for residents. It also promotes the formation of local social networks, thereby strengthening social resilience [64].

- Land use mix

Land use mix contributes to the creation of diverse urban environments and enhances the redundancy of urban systems. It encourages non-motorized transportation, reduces energy consumption, benefits residents' psychological well-being and health, and supports the development of pedestrian-friendly communities. Moreover, by fostering increased social interactions, it contributes to enhancing social resilience [49].

- Plot Size

By accommodating a diverse range of activities and building types, smaller plots can enhance urban resilience by increasing functional redundancy and systemic adaptability [65]. They also increase the number of connections to streets and open spaces that provide ecological services. Moreover, smaller plots facilitate a more balanced spatial distribution, promote diversity and accessibility, support redundancy in urban spaces, and improve the city's emergency response capacities [66].

- Urban blocks

In terms of scale, small to medium-sized blocks, when laid out in an orderly manner, are better able to adapt gradually to changing environments. They offer multiple access points that connect public spaces and enhance the permeability of the built environment, which is particularly beneficial for disaster response. These blocks can also facilitate both pedestrian and vehicular circulation. In contrast, large blocks create long, impermeable street edges, reducing diversity, accessibility, walkability, and the vibrancy of the built environment, thereby weakening socio-economic resilience [67].

- Open spaces

Open spaces with less complex shapes offer effective cooling benefits [68], and their varied scales and types help cities cope with different disruptions by improving walkability in heterogeneous environments, thereby facilitating rapid post-disaster recovery [69]. A uniform distribution of open spaces of various sizes and types enhances morphological modularity, accelerates disaster recovery and reconstruction, and improves airflow and wind circulation patterns to mitigate urban heat waves. However, large green spaces may negatively impact regional accessibility and street connectivity. In this context, well-connected small-scale green spaces can be located in urban cores, while larger ones may be placed at the periphery to limit urban sprawl and reduce urban heat island effects [60].

- Street network model

The most commonly discussed street network patterns are grid and tree-like structures. The grid pattern, characterized by short streets and frequent intersections, integrates resilience and redundancy into the road network, allowing it to adapt effectively to adverse events [62]. This type of network provides strong connectivity; disruptions in one street do not significantly affect the overall system, thereby ensuring high resilience. In contrast, tree-like networks, resembling a branching structure, reduce the system's modularity and eliminate low-scale resilience and self-organizing capabilities [21]. A failure in one section can lead to a loss of function in other parts, encouraging urban sprawl and dispersing urban activities in an undesirable way. To address these issues, urban design techniques advocate for a hierarchical network model with many small-scale connections, fewer medium-scale links, and even fewer large-scale arteries. This approach enhances the connectivity, robustness, and redundancy of the street network, thereby strengthening urban resilience [70].

- Street design

Optimal street width for enhancing urban resilience varies depending on the context, street canyon geometry, and land use intensity. Research shows that wider streets facilitate effective evacuation and adaptability to changing conditions, while also accommodating pedestrian pathways and green infrastructure [71]. From a hierarchical scale perspective, regardless of density, the presence of narrow streets within a structured hierarchy contributes to the creation of human-scaled environments, promotes internal and external connectivity, and enhances social resilience. Proper edge design of streets helps maintain built environment permeability, improves the interface between interior and exterior spaces, and thus strengthens social cohesion and resilience [72]. Additionally, street orientation affects urban microclimates through its influence on wind flow distribution and solar radiation received by the street canyon and adjacent buildings. Aligning deep street canyons parallel to prevailing wind directions can enhance wind speed via the wind tunnel effect, improve thermal comfort at street level during summer, and thereby increase climate resilience [73].

4.8. Resilient urban form elements at the micro scale

Micro-scale morphological elements are manifested in granular components such as buildings and plots, with their resilience expressed through layout, type, scale, form, and related characteristics. The layout of buildings influences solar access and natural ventilation, directly affecting energy consumption [43]. Different building typologies demonstrate varying levels of energy use and, when combined with other morphological parameters (e.g., density), can create synergistic effects that enhance local building resilience, energy efficiency, and thermal comfort due to better environmental adaptation. Roof type also affects heating demand and the solar potential of buildings. Furthermore, the design, scale, and shape of plots, which are influenced by block subdivision, enable the adaptability of service facilities and contribute to improved morphological resilience.

4.9. Conceptual framework of urban form resilience

The extent to which a city, as a complex system, can absorb, recover, adapt, or transform depends on the nature of changes and the magnitude of shocks it encounters. In fact, a city may be more or less likely to exhibit a certain response based on its inherent structural characteristics. These qualities are present in all complex systems and are not necessarily associated with a specific disturbance, yet they significantly influence the overall behavior of the system. Accordingly, the presence or absence of a particular feature may increase or decrease the likelihood of certain outcomes, or affect the system’s effectiveness in coping with stresses or shocks. Drawing on the reviewed literature, six key concepts have been identified as fundamental to urban form resilience: ecological sensitivity, indeterminecy, polycentrism and modularity, connectivity (permeability), multifunctionality, and redundancy. The concept of ecological sensitivity first emerged in Ian McHarg’s Design with Nature and later in the theory of ecological urbanism [74]. Parallel to urban resilience theory and consistent with biophilic cities [75] and social-ecological resilience [76], ecological sensitivity prioritizes either enhancing or avoiding the loss of a system’s natural ability to withstand disturbances particularly when responding to temporal disruptions, transformations, adaptations, and ecological succession. Similarly, Smithsons' "mat urbanism" promoted the productive revision of urban form to integrate natural and human systems, treating the landscape as infrastructure [77]. This concept also emphasizes the connectivity between local ecosystems (e.g., networks of connected patches) and resilience-oriented planning (e.g., overlapping clusters and time-evolving functions) [65]. More recently, landscape ecological urbanism operationalizes this concept at the urban scale by considering ecological landscape components as the building blocks of urban development, rather than relying solely on land-use or design elements like streets and blocks. Morphological configurations that integrate ecological sensitivity and resilience foster urban developments that are not only “environmentally healthy” but also “ecologically sustainable” [78]. The second concept, indeterminacy, refers to the inherent ability of urban form to accommodate an unpredictable future and respond to emerging needs. This concept gained prominence partly as a reaction to the perceived rigidity of modernist mass housing layouts developed after WWII, which highlighted the limitations of fixed, inflexible spatial structures. Habraken’s Open Building approach also embraces uncertainty by distinguishing between permanent and variable components of the built environment, which can be adapted over time as needed [79]. Uncertainty is thus achieved through resilience and adaptability, signifying a better fit between urban form and function. The third concept, polycentrism, promotes decentralized and distributed modular systems that diffuse risk. A polycentric system can interrupt cascading failures, preventing damage from propagating through the entire system. Widely used in landscape architecture, this approach when applied to urban design ensures a "fail-safe" approach that strengthens the resilience of urban form [45]. Specifically, modularity enables independent functionality across different parts of a polycentric urban form in response to various climate hazards [43, 80]. Empirical studies show that efficiency increases in mobility services (e.g., commuting and evacuation) and ecosystem services (e.g., thermal comfort), especially when polycentrism is combined with ecological sensitivity [81, 82]. Additionally, decentralized infrastructure systems (e.g., energy, water, and wastewater microgrids) tend to be more climate-resilient than centralized systems, although potentially more expensive. The fourth concept is connectivity, which enhances permeability—the ability to move between different places—through well-connected street networks. Fine-grained street grids maintain strong connectivity and permeability, allowing for easier, faster movement between smaller urban blocks [63]. For instance, Azhdari et al. (2018) found that smaller urban plots in Shiraz contributed to lower surface temperatures compared to newer, large-block developments. Such configurations also enhance multimodal transportation (e.g., walking, cycling, public transit), which becomes crucial during emergency evacuations to reduce risks to human lives. Street networks with rigid hierarchies, linear curves, or cul-de-sacs hinder evacuation and are difficult to retrofit. Evidence from historic Latin American neighborhoods [83] and Glasgow shows that fine-grained connectivity improves permeability and access to essential resources (e.g., shelter, food, health services), thereby increasing climate resilience [42]. The fifth concept is multifunctionality, which enables urban form components (e.g., streets, open spaces) to accommodate diverse functions based on evolving needs [84]. Multifunctionality aligns with Jabareen's City of Risk (2015), Hakim's productive urbanism (2007), and Vale's concept of progressive resilience (2020). For example, Modon (n.d.) shows that irregular intersections in San Francisco create unexpected urban pockets that offer recreational "breathing spaces" for communities. A city blocks capable of repurposing its use according to emerging demands enhances climate hazard resilience. The final concept, redundancy, refers to the presence of multiple alternatives to support the same function, thereby improving system performance during emergencies [85]. In line with Quigley et al.'s social-ecological resilience (2018), redundancy is often seen in ecological literature as a backup or non-essential repetition [80]. In urban design, however, it implies spatial and functional diversity achieved through multiple infrastructures (e.g., streets, plots, nodes) that contribute to the complexity of urban form. Redundancy provides alternative access to services and functions while minimizing travel time during crises. For example, Marcus and Colding (2014) highlight how land subdividable fosters urban form diversity. In high-uncertainty scenarios, redundancy enables buffers or evacuation options. Post-earthquake studies in Christchurch (2010–2011) demonstrate how additional street alternatives improved resilience during the reconstruction phase [86]. Mixed-use developments (both horizontal and vertical) also support spatial and functional diversity, especially ground-floor uses that facilitate rapid evacuation during sudden disasters such as storm surges [87]. These six concepts align with the IPCC's recommendations on enhancing adaptive resilience. While the six components offer clear contributions to enhancing urban form resilience, the literature also highlights important trade-offs that prevent their universal application. For example, increased connectivity can improve accessibility and emergency response, yet excessive network integration may accelerate hazard propagation or system-wide failure. Similarly, polycentric and modular structures can localize disruptions, but may lead to higher land consumption or reduced efficiency if poorly coordinated. Diversity and multifunctionality expand adaptive capacity, though they may introduce management complexity and conflict between competing uses. These nuances indicate that resilience strategies are context-dependent and require careful calibration rather than assuming linear benefits.

These six concepts provide a framework for integrating reactive and proactive adaptation responses across both short-term and long-term timescales. In this study, they are mapped onto the three resilience capacities of urban form—absorptive, adaptive, and restorative as defined by Liang et al. (2024) in the context of climate change. The intersection of these dimensions forms the basis of the conceptual framework illustrated in Figure 8.

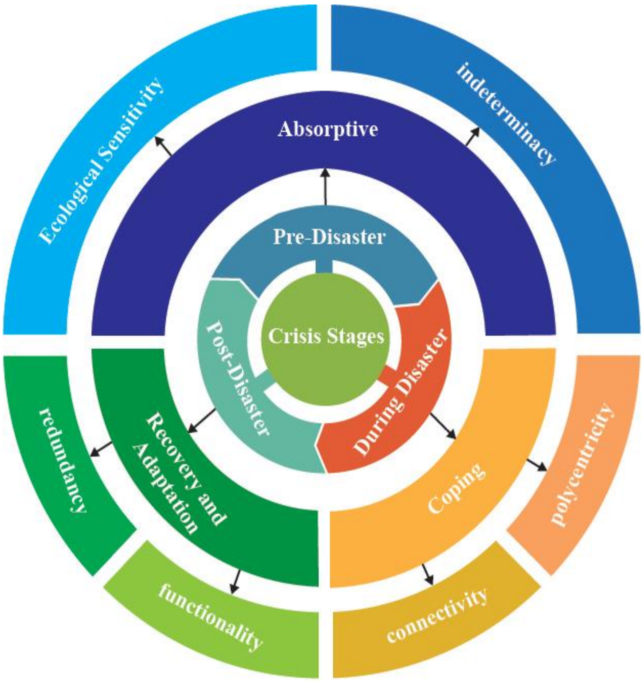

Figure 8. Conceptual framework of urban form resilience

Although the synthesis revealed areas of convergence, several divergent perspectives remain within the literature. Some scholars argue that resilience should prioritize system stability and rapid recovery [23, 25], whereas others conceptualize it as a transformational and adaptive process involving structural change rather than preservation [15, 33]. Similarly, while Sharifi and Yamagata (2018) emphasize the morphological configuration of urban form as the primary determinant of resilience, alternative frameworks highlight governance, socio-economic dynamics, and equity considerations as equally essential components [32, 88]. These divergent viewpoints indicate that the six-component framework proposed in this study represents one conceptual pathway within a broader and evolving field, rather than a universally agreed model. Acknowledging these differences strengthens the interpretive depth of the findings and situates the contribution within ongoing scholarly debate.

4.10. Integrating urban morphology with ecological–social dynamics

While the six identified components provide a robust conceptual foundation for understanding how urban form contributes to resilience, the reviewed literature also emphasizes that resilience emerges not solely from the static configuration of spatial elements but from their dynamic interactions with ecological and social processes over time. Advanced theories in urban morphology and socio-ecological resilience (e.g., Cumming & Peterson, 2017; Marcus & Colding, 2014; Walker & Salt, 2006) highlight that built form participates in continuous feedback loops in which physical structures influence ecological performance and human behavior, which in turn reshape spatial patterns across temporal scales. From this perspective, urban form operates as both a structural substrate (e.g., blocks, networks, land-use patterns) and a processual system shaped through flows of people, energy, materials, and ecological functions. Ecological sensitivity, for example, not only reflects the spatial distribution of green infrastructure but also influences ecosystem services such as cooling, stormwater absorption, and habitat continuity, which then modify long-term land-use decisions and development pressures. Similarly, connectivity affects movement patterns, accessibility, and social interaction, generating behavioral dynamics that can either reinforce or weaken resilience capacities over time. Thus, the transformation of "spatial construction into adaptive capacity" occurs through nonlinear, iterative, and cross-scale mechanisms, in which disturbances (e.g., floods, heatwaves, economic shocks) trigger behavioral or ecological responses that feedback into spatial reconfiguration. This dynamic understanding aligns with the adaptive cycle model of socio-ecological systems (Holling, 2001) and the multiscale network logic discussed in recent resilience-oriented urbanism (Sharifi & Yamagata, 2018). Although the present study focuses primarily on synthesizing morphological concepts, this theoretical lens clarifies how each of the six components ecological sensitivity, indeterminacy, polycentricity/ modularity, connectivity, multifunctionality, and redundancy participates in larger socio-ecological dynamics. These interactions justify their placement within absorptive, adaptive, and restorative capacities and reinforce the need for future research to operationalize these dynamic relationships using spatial metrics, simulation models, or GIS-based ecological performance indicators. This integrative perspective provides the conceptual bridge between urban form (as physical pattern) and ecosystem–social dynamics (as evolving processes), thereby addressing the theoretical gap noted by reviewers and situating the proposed framework within contemporary debates in urban morphology and resilience science.

4.11. Mapping the six resilience components onto urban form indicators

To operationalize the six conceptual components of urban form resilience and clarify how they function across different temporal phases of a disturbance, the reviewed indicators were mapped onto the three resilience capacities absorptive, adaptive, and restorative following Liang et al. (2024). This mapping demonstrates how each concept manifests through measurable attributes of urban form at different crisis stages (before, during, and after disturbance). Table 7 organizes these relationships to enhance transparency and provide a replicable structure for future assessment frameworks.

Table 7. Operational Framework for Urban Form Resilience (Crisis Stages – Resilience Capacities – Concepts – Indicators)

Crisis Stage	Resilience Capacity	Urban Form Resilience Concepts	Indicators
Before Crisis	Absorptive Capacity	Ecological Sensitivity	Protected ecological areas Impervious surface ratio Development intensity
		Indeterminacy	Distribution of green spaces Distribution of open spaces Area of unrealized / latent development potential
During Crisis	Coping	Polycentricity	Degree of decentralized / distributed land uses Degree of polycentric infrastructure systems (waste, water, energy)
		Connectivity	Block size Accessibility to urban facilities Spatial distribution of emergency shelters
After Crisis	Recovery and Adaptive Capacity	Redundancy	Number of alternative buildings for emergency use Accessibility to evacuation routes Multiplicity of street networks
		Multifunctionality	-Land-use diversity Availability of multi-use spaces over time and conditions Availability of spaces adaptable for temporary activities

5. Limitations and future research

This study while grounded in a rigorous and systematically applied qualitative meta-synthesis faces several methodological and scope-related limitations that should be acknowledged to contextualize the findings. A first limitation concerns the use of Scopus as the sole database for the literature search. Scopus provides extensive interdisciplinary coverage in urban studies, environmental planning, geography, and sustainability science, and preliminary cross-checking indicated that the core conceptual literature on urban form resilience was largely captured within this database. Nonetheless, relying on a single indexing platform introduces the possibility of indexing bias, and relevant studies included in other databases such as Web of Science or Google Scholar may have been missed. A second limitation relates to the intentional exclusion of several Scopus subject areas during the search strategy. Fields such as psychology, medicine, chemistry, and materials engineering were excluded because they examine resilience primarily through biological, clinical, or behavioral lenses that fall outside the conceptual scope of urban morphology. More critically, disciplines such as Engineering, Earth and Planetary Sciences, and Energy were also excluded. Although these areas are central to infrastructure performance, geophysical hazards, and energy-system resilience, preliminary scoping showed that their contributions generally emphasize technical or hazard-specific modeling rather than the spatial, configurational, and morphological dimensions of urban form on which this study focuses. Their exclusion allowed the meta-synthesis to maintain conceptual coherence, but it may also limit the integration of insights from engineering and earth sciences—representing a conceptual rather than procedural form of selection bias. A further limitation pertains to the reliability of the data extraction and coding process. While document analysis is well suited to qualitative meta-synthesis, and although the coding process followed a structured extraction form, the analysis was conducted primarily by a single researcher. Measures were taken to mitigate subjectivity, including a two-step coding procedure with a temporal separation to reassess coding stability, as well as peer debriefing in which an external expert reviewed portions of the coded material. These strategies strengthened internal consistency; however, a formal inter-rater reliability assessment was not performed. Likewise, the data extraction form was not pilot-tested on a subset of articles before full implementation. The absence of these procedures limits the extent to which coding reliability and tool validity can be formally demonstrated. Future studies should incorporate a formal inter-rater reliability protocol by involving multiple independent coders. This would allow for the statistical assessment of coding consistency and further strengthen the methodological robustness of meta-synthesis research on urban form resilience.

6. Implications for practice

The conceptual framework developed in this study has important implications for urban planners, designers, and policymakers seeking to enhance the resilience of urban environments. Translating the six core components ecological sensitivity, indeterminacy, polycentricity, connectivity, multifunctionality, and redundancy into actionable strategies enables practitioners to operationalize resilience within real-world planning and design processes.

6.1. Translating conceptual components into planning strategies

- Ecological sensitivity

Planners should integrate natural systems into the spatial structure of cities by preserving ecological corridors, minimizing impervious surfaces, and prioritizing nature-based solutions. This component underscores the need to align land-use decisions with underlying ecological processes.

- Indeterminacy

Indeterminacy encourages the design of flexible spatial configurations capable of accommodating unknown future needs. Practically, this can involve adopting adaptable building typologies, reserving strategic parcels for future transformation, and designing public spaces that can support multiple uses over time.

- Polycentricity and modularity

Urban systems can be strengthened by distributing essential services, mobility networks, and social infrastructure across multiple centers. Modularity allows districts or neighborhoods to function independently during disruptions. For example, incorporating decentralized energy microgrids or localized water-retention systems enhances resilience to system-wide failures.

- Connectivity (permeability)

Enhancing permeability through fine-grained street networks, improved walkability, and multimodal accessibility can accelerate emergency response and distribute risks more evenly across the urban fabric.

- Multifunctionality

Urban spaces should be designed to perform multiple social, ecological, and infrastructural functions. A public park in a flood-prone area, for instance, can double as a stormwater retention basin while also serving recreational and ecological purposes.

- Redundancy

Redundancy requires planning for overlapping functions and alternative routes or facilities. This may include ensuring multiple access points to critical infrastructure, providing a diversity of building uses within a district, or maintaining backup systems for mobility and utilities.

6.2. Illustrative application examples for practitioners

- Modularity in neighborhood design

A planner designing a new neighborhood might apply modularity by establishing decentralized energy nodes, distributed green spaces, and local service clusters. These modules allow the neighborhood to maintain partial functionality even if one unit fails.

- Multifunctionality in public space design

An urban designer working in a flood-prone area could implement multifunctionality by designing plazas or parks with integrated water-retention landscapes that capture runoff during storms while serving as community gathering spaces during normal conditions.

6.3. Application of the framework in a hypothetical scenario

To illustrate the practical use of the six-part framework, consider a coastal neighborhood facing rising sea levels and recurrent storm surges:

Ecological Sensitivity: The redesign incorporates protective dune systems, restored wetlands, and vegetated buffers to absorb wave energy.

Indeterminacy: Buildings and public spaces are designed with adaptable ground floors, allowing transformation from commercial use to emergency shelters during extreme events.

Polycentricity and Modularity: The neighborhood includes multiple micro-centers each equipped with independent water supply points, local energy generation, and essential services to ensure continuity during disruptions.

Connectivity: A permeable street grid facilitates rapid evacuation, while multimodal routes ensure redundancy in movement corridors.

Multifunctionality: Waterfront parks function both as recreational spaces and tidal retention zones designed to temporarily store excess water.

Redundancy: Critical mobility paths, energy networks, and service routes are duplicated, ensuring that failure in one subsystem does not incapacitate the entire neighborhood.

This scenario demonstrates how the components can be integrated into a cohesive design strategy that not only mitigates climate risks but also enhances the adaptive capacity of coastal urban environments.

7. Conclusion

As the consequences of climate change intensify, cities being among the most complex and vulnerable human systems are increasingly exposed to a wide range of environmental, economic, and social crises. One of the most pressing challenges in this context is the need to reconsider how urban form is shaped and organized. Urban form not only provides the physical setting for human life but also plays a decisive role in a city's capacity to adapt to and withstand climate-related hazards. In this regard, urban resilience—particularly as expressed through spatial form—has gained growing importance as a contemporary approach in urban planning and design. This study, through a conceptual meta-synthesis and systematic literature review, has explored the multilayered and complex dimensions of resilience within the framework of urban form. It proposes a comprehensive conceptual framework based on six key components: ecological sensitivity, indeterminacy, polycentricity, connectivity, multifunctionality, and redundancy. Together, these components offer a coherent and structured understanding of how urban form can enhance resilience to natural and environmental hazards. The proposed framework articulates urban resilience across three phases of crisis preparedness, response, and recovery and links them to spatial design interventions. In the preparedness phase, emphasis is placed on identifying vulnerable areas and proactive spatial design to reduce risk. During the response phase, the functional resilience of urban spaces becomes central, while in the recovery phase, the focus shifts toward equitable and inclusive rebuilding processes. These temporal-functional layers are integrated with various spatial scales of intervention. The findings demonstrate that urban form resilience arises from the synergistic and integrated interaction between morphological components and socio-ecological structures across multiple spatial scales. The study emphasizes that a resilient urban form emerges from the intelligent and integrated interaction between physical elements and socio-ecological structures. In other words, the sustainability and adaptability of cities are directly dependent on the spatial organization, development patterns, and their capacities to respond to disruptions. Given the increasing threats posed by environmental change and climate-induced risks, the conceptual framework presented here can serve as a basis for rethinking spatial planning and design. It provides a foundation for adaptive, evidence-based, and place-specific policymaking in urban risk management. Ultimately, by identifying existing gaps in the literature and emphasizing the need for interdisciplinary research, this study lays the groundwork for future empirical investigations, simulation-based modeling, and resilience-oriented spatial strategies thus contributing meaningfully to both theoretical and applied knowledge in the field of resilient urban form. In the age of compound hazards, climate transformation, and environmental uncertainty, a purely technical or engineering approach to resilience is insufficient. What is required is a multi-scalar, integrative, and context-sensitive perspective one that understands urban form not merely as a physical container of urban life, but as a living, adaptive, and transformative mechanism in the face of ongoing and future crises.

Authors Contribution

All the authors have participated sufficiently in the intellectual content, conception and design of this work or the analysis and interpretation of the data (when applicable), as well as the writing of the manuscript.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests

The author states that there is no conflict of interest.

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Appendix A. List of Articles Included in the Final Meta-Synthesis (49 Studies)

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Appendix B. Data extraction form (primary categories)

Category	Description
Author(s)	Full name(s) of the author(s) of the study.
Year of Publication	The year the article was published.
Title of Study	Full title of the article.
Journal	Name of the journal in which the study was published.
Country / Study Context	Geographical location, case study area, or contextual setting of the research.
Definition / Interpretation of Resilience	How the study conceptualizes resilience (e.g., physical, spatial, socio-ecological, infrastructural).
Definition / Interpretation of Urban Form	The conceptualization of urban form elements (e.g., density, connectivity, polycentricity).
Physical / Spatial Urban Form Characteristics Examined	Specific morphological indicators (e.g., block size, street network structure, land-use mix, open spaces).
Type of Hazard Addressed	Disaster or environmental risks examined (e.g., flooding, heatwaves, earthquakes, sea-level rise).
Spatial Scale of Analysis	Macro, meso, or micro scale (or multiple scales, if applicable).
Proposed Indicators of Urban Form Resilience	Indicators explicitly linked to enhancing resilience (e.g., redundancy, multifunctionality, modularity).
Methodological Approach of the Study	Qualitative, quantitative, GIS-based, theoretical, etc.
Key Findings Relevant to Urban Form Resilience	Extracted conceptual statements or theoretical contributions.
Contribution to Emerging Concepts	How the study supports or challenges core components identified in this meta-synthesis.
Notes and Analytical Memos	Additional interpretive insights derived during coding.