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A Comparative Evaluation of General Systems Theory, Complexity Theory, and Complex Adaptive Systems in Addressing Urban Challenges

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ABSTRACT

Urban systems are increasingly recognized as dynamic, multi-scalar networks shaped by nonlinear interactions, feedback loops, and adaptive behaviors. Addressing the "wicked problems" of rapid urbanization—from socio-economic inequality to climate risks—requires theoretical frameworks capable of capturing complexity and informing adaptive governance. This study critically and comparatively examines three major approaches—General Systems Theory (GST), Complexity Theory, and Complex Adaptive Systems (CAS)—in the context of urban systems, through a systematic literature review combined with a bibliometric analysis of publications indexed in Web of Science and Scopus between 2000 and 2025. Using bibliometrix and Biblioshiny, the analysis traces conceptual trends, keyword co-occurrence patterns, thematic clusters, author keyword distributions, and thematic evolution. Indicators such as publication growth, thematic mapping, and conceptual development provide insights into the intellectual trajectory of urban complexity research. The findings demonstrate a clear theoretical progression: GST provides a holistic framework emphasizing structural stability but has limited capacity to capture adaptive processes; Complexity Theory advances the field by foregrounding nonlinearity, self-organization, and co-evolutionary dynamics; CAS extends these perspectives by emphasizing decentralized interactions, adaptive learning, and path dependence. The bibliometric mapping shows a sharp increase in CAS-related urban studies after 2015, reflecting its growing recognition as a promising framework. Yet, this surge does not imply CAS has displaced other paradigms; planning theories, socio-spatial perspectives, and governance models remain dominant. Rather, CAS emerges as a complementary approach that enriches existing theories, clarifies theoretical boundaries, identifies research gaps, and enhances the ability to interpret and respond to complex urban transformations. This study underscores that while GST, Complexity Theory, and CAS each provide distinct contributions, CAS holds particular potential as a flexible and complementary lens for advancing both urban theory and practice.

Kentsel Zorlukların Ele Alınmasında Genel Sistem Teorisi, Karmaşıklık Teorisi ve Karmaşık Uyumlanabilir Sistemlerin Karşılaştırmalı Değerlendirmesi

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ÖZET

Kent sistemleri, giderek daha fazla doğrusal olmayan etkileşimler, geri besleme döngüleri ve uyum sağlayıcı davranışlarla şekillenen dinamik ve çok ölçekli ağlar olarak görülmektedir. Hızlı kentleşmenin yol açtığı sosyo-ekonomik eşitsizlikten iklim risklerine uzanan zor problemler (wicked problems) ile başa çıkmak, karmaşıklığı yakalayabilen ve uyumlanabilir yönetişime rehberlik edebilecek kuramsal çerçeveler gerektirmektedir. Bu çalışma, Genel Sistemler Teorisi (GST), Karmaşıklık Teorisi ve Karmaşık Uyumlanabilir Sistemler'i (CAS), kentsel sistemler bağlamında, 2000–2025 yılları arasında Web of Science ve Scopus veri tabanlarında yayımlanan araştırmalar üzerinden sistematik literatür taraması ve bibliyometrik analiz yoluyla karşılaştırmalı biçimde incelemektedir. Bibliometrix ve Biblioshiny kullanılarak yapılan analiz; kavramsal eğilimleri, anahtar kelime eş-oluşumlarını, tematik kümelenmeleri, yazar anahtar kelimelerinin dağılımını ve tematik evrimi ortaya koymaktadır. Yayın artış trendleri, tematik haritalama ve kavramsal gelişim göstergeleri, kentsel karmaşıklık araştırmalarının düşünsel seyrine dair önemli ipuçları sunmaktadır. Bulgular, kuramsal bir ilerleme çizgisi ortaya koymaktadır: GST yapısal bütüncüllüğü vurgulamakta ancak uyumlanabilir süreçleri yakalamakta sınırlı kalmaktadır; Karmaşıklık Teorisi doğrusal olmama, öz-örgütlenme ve eş-evrim dinamiklerini ön plana çıkarmaktadır; CAS ise bu yaklaşımları genişleterek merkezi olmayan etkileşimleri, uyumlanabilir öğrenmeyi ve yol bağımlılığını kentsel değişimlerin anlaşılmasında temel mekanizmalar olarak öne çıkarmaktadır. Bibliyometrik haritalama, 2015 sonrasında CAS odaklı kentsel çalışmaların keskin biçimde arttığını göstermektedir; ancak bu artış, CAS'in diğer paradigmaların yerini aldığı anlamına gelmemektedir; kentsel çalışmalar hâlen planlama teorileri, sosyo-mekânsal yaklaşımlar ve yönetişim modelleri etrafında şekillenmektedir. CAS, bu bağlamda mevcut yaklaşımları zenginleştiren, teorik sınırları netleştiren, araştırma boşluklarını belirleyen ve karmaşık kentsel dönüşümleri yorumlama kapasitesini güçlendiren tamamlayıcı bir çerçeve olarak öne çıkmaktadır. Bu çalışma, GST, Karmaşıklık Teorisi ve CAS'in her birinin kentsel araştırmalara özgün katkılar sunduğunu, CAS'in ise özellikle esnek ve tamamlayıcı bir mercek olarak kent kuramı ve uygulamalarının geliştirilmesinde önemli bir potansiyel taşıdığını vurgulamaktadır.

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INTRODUCTION

Urban systems are increasingly recognized as complex socio-ecological and socio-technical networks characterized by nonlinear interactions, emergent behaviours, and adaptive dynamics. The accelerating pace of urbanization, coupled with climate change, resource constraints, and socio-economic inequality, has intensified the demand for theoretical frameworks capable of capturing these dynamics and informing adaptive governance. Traditional linear and reductionist approaches have proven insufficient to address the wicked problems embedded in contemporary urban environments, highlighting the need for integrative, systems-based perspectives (Rittel & Webber, 1973; Folke et al., 2010). Despite a growing body of research, there remains limited systematic comparison of the major theoretical lenses used to study urban complexity, leaving uncertainty about their relative contributions and complementarities.

Systems theory, Complexity theory, and Complex Adaptive Systems (CAS) have emerged as key conceptual lenses for understanding the structure and behaviour of interconnected urban systems. While General Systems Theory (GST) provides a foundational holistic framework, it often struggles to account for emergent and adaptive properties in socio-technical contexts. Complexity theory advances this by emphasizing nonlinearity and self-organization, offering insights into feedback-driven dynamics and urban resilience. CAS extends these perspectives further, focusing on decentralized interactions, adaptive learning, and the co-evolutionary processes that underpin urban governance and planning (Bettencourt & West, 2010).

In recent years, there has been a marked increase in the application of CAS frameworks in urban studies, reflected in both conceptual discourse and empirical research. Recent research conceptualises cities explicitly as Complex Adaptive Systems, highlighting adaptive governance and resilience frameworks (Gorjian, 2025). A preliminary bibliometric analysis of the last two decades indicates a significant rise in CAS-related publications in urban governance, resilience, and sustainability planning, particularly after 2015. This trend suggests a paradigm shift toward adaptive, network-based approaches to managing urban complexity, aligning with broader transitions in systems science and resilience thinking (Meerow & Newell, 2019; Fazey et al., 2021). Yet, while CAS has gained momentum, a comprehensive evaluation of how it compares with GST and Complexity Theory in urban contexts is still missing. This gap motivates the present study.

This study aims to critically synthesize the literature on GST, Complexity theory, and CAS in the context of urban systems and to evaluate their relative strengths and limitations. By combining systematic review with bibliometric mapping of research published between 2000 and 2025, the paper identifies key conceptual trajectories, overlaps, and divergences. In doing so, it highlights underexplored areas of research and clarifies the comparative value of each framework for studying urban complexity. While the paper underscores the growing role of CAS, it also emphasizes that GST and Complexity Theory continue to provide valuable perspectives, making a comparative approach essential. The findings contribute to theoretical refinement, provide a foundation for integrating CAS principles into urban governance and planning frameworks, and support the development of more adaptive, network-based strategies for addressing complex urban challenges.

SYSTEM AND COMPLEXITY THEORIES IN RELATION TO URBAN SYSTEMS

Since the dawn of humanity, various inquiries have been developed based on fundamental knowledge in an attempt to take scientific steps. While in the earliest periods of history these inquiries were primarily oriented toward finding solutions to pressing problems, over time they gradually shifted toward a pursuit driven by curiosity. Science is a cumulative process, and the evolving and expanding body of knowledge over time constitutes the foundation of contemporary scientific research. In line with the needs of an ever-changing and developing world, recent advancements have also been accompanied by paradigm shifts. As a result of progress in the fundamental sciences, complexity science and the associated discourse on systems thinking have emerged, offering comprehensive perspectives for addressing a wide range of contemporary problems.

Foundations of Systems Thinking and General Systems Theory (GST)

Systems theory provides a foundational framework for understanding how interconnected elements combine to form coherent wholes that pursue shared objectives while maintaining dynamic equilibrium within their environment. A system is defined as a whole composed of elements coherently organized and interconnected to achieve a specific purpose. This definition highlights four essential characteristics: the system's components, the interconnections between them, the presence of a shared purpose, and the integrated wholeness they collectively generate (Meadows, 2008; Tursun, 2021). Contemporary research underscores that these attributes are not static; systems adapt under environmental stressors, and resilience emerges as a key systemic property (Folke et al., 2010).

Ludwig von Bertalanffy first introduced systems thinking in the 1940s. In his seminal *General Systems Theory* (1972), he proposed an alternative to the reductionist, mechanistic paradigm dominant in biology (Taşdelen, 2016). Since then, systems theory has been applied across numerous disciplines. In organizational contexts, it provides a framework for analysing inputs, processes, outputs, and feedback loops to facilitate systemic inquiry into organizational learning and change (Gilley, Eggland, & Gilley, 2002; Swanson & Holton, 2001). Yawson (2013) views systems theory as a conceptual framework for analysing how interacting elements work together to generate specific outcomes.

General Systems Theory (GST) examines the openness of systems, their boundaries, and the stable patterns of relationships within those boundaries (Schneider & Somers, 2006). Defining boundaries is essential for understanding environmental interactions and identifying leverage points for transformation (Wang, 2004; Preiser et al., 2018). Koopmans (2017, p. 21) interprets Bertalanffy's work as analysing "the behaviour of a system in terms of its constituent components and the interrelationships between these components [subsystems]." GST also distinguishes between open and closed systems: open systems freely exchange energy, information, and resources with their environment, whereas closed systems retain these elements internally. In practice, most systems fall between these extremes, with open systems being especially relevant to urban contexts because they are shaped by flows of people, resources, and information (Kast & Rosenzweig, 1981; Turner & Baker, 2019).

A central analytical dimension in GST is system stability, which describes how systems respond to disturbances. A system is asymptotically stable if it returns to its original state after disruption and unstable if it transitions into a new regime (von Bertalanffy, 1972; Walker et al., 2004). GST further differentiates among asymptotic stability, neutral stability, and instability, each capturing how systems maintain or transform their state in the face of perturbations. This conceptualization has been influential, though it tends to privilege equilibrium-oriented understandings of systems.

While GST embodies holism—the notion that "the whole is greater than the sum of its parts"—its mechanistic orientation struggles to account for emergent, nonlinear dynamics, especially in social and urban contexts where human agency and indeterminacy are significant factors (Kast & Rosenzweig, 1981; Yorks & Nicolaides, 2012). This limitation is particularly evident in social systems, where defining system boundaries and predicting behaviour is difficult due to individual agency, freedom of choice, and contextual uncertainty (Wang, 2004). These challenges have led to critiques of GST's applicability to complex socio-ecological and socio-technical systems.

These limitations have prompted the integration of complexity science as a complementary paradigm that addresses adaptive, nonlinear, and co-evolutionary processes and reframes resilience as an emergent systemic property underpinned by adaptive capacity within complex social–ecological systems (Turner & Baker, 2019; Fazey et al., 2021; Folke et al., 2010). Recent scholarship further stresses that the shortcomings of GST created the conceptual foundation for Complexity Theory and, later, Complex Adaptive Systems (CAS), which provide more robust ways of analysing emergence, adaptation, and governance in urban systems (Gorjian, 2025; Shukla et al., 2025).

Complexity Theory

Complexity theory investigates systems composed of numerous interacting components whose collective behaviour cannot be explained by examining individual parts in isolation. Nicolis (1995) defines nonlinear science as aiming “to provide the concepts and techniques necessary for a unified description of a broad class of phenomena in which simple deterministic systems give rise to complex behaviour through the emergence of unexpected spatial structures or evolutionary events.”

Traditional science relied on reductionism, decomposing phenomena into constituent elements to achieve certainty (Westhorp, 2012). While this paradigm facilitated major scientific advances, particularly during the Industrial Revolution (Cilliers, 2005; deMattos, Miller, & Park, 2012), the emergence of wicked problems, climate crises, and global interdependencies has exposed its limitations (Turner & Baker, 2019). This inadequacy underscored the need for holistic approaches that account for unpredictability and nonlinearity. Byrne (1998) argued that the central contribution of complexity in the social sciences is precisely the rejection of reducibility: reality cannot be reduced to the sum of its parts, as interactions and temporal dynamics play a decisive role. Small changes in one component may trigger large and unpredictable effects elsewhere, illustrating the sensitivity of complex systems to initial conditions.

Complexity theory addresses this gap by focusing on interactions, feedback loops, and emergent properties. Richardson (2004) encapsulates this paradigm shift: “the whole is different from the sum of its parts and their interactions,” while Gleick (2008, p. 304) succinctly summarizes, “Simple systems give rise to complex behaviour. Complex systems give rise to simple behaviour. And most importantly, the laws of complexity apply universally.” These perspectives emphasise that complex systems cannot be fully explained by linear causality or equilibrium-oriented models; instead, they evolve, transform, and adapt through historical contingency and emergent dynamics.

Complexity science emerged from mid-20th-century developments in physics, biology, and mathematics. Prigogine’s theory of dissipative structures demonstrated how systems far from equilibrium can self-organize into new patterns (Prigogine & Stengers, 1984). Lorenz’s chaos theory revealed deterministic yet unpredictable dynamics (Lorenz, 1993). Hayles (1990) reframed chaos not as absolute disorder but as a form of complex order, situated between order and disorder. Waldrop (1992) subsequently characterised complexity as “a science at the edge of order and chaos,” reinforcing the idea that systems often perceived as random may actually display hidden patterns and organizing principles. These insights converged at the Santa Fe Institute, forming a transdisciplinary science of complexity (Waldrop, 1992).

Complex systems share defining characteristics such as openness, non-equilibrium dynamics, nonlinearity, emergent behaviour, adaptive structures, and multiple timescales acting as system “memory” (Cilliers, 2005; Byrne, 1998; Preiser et al., 2018). Martin and Sunley (2007) add that distributed representation, self-organization, and unpredictability are also fundamental, while De Roo, Hillier, and Van Wezemael (2012) highlight temporality, noting that complex systems develop and transform over time rather than remaining static. Cilliers (2005) further detailed their attributes: openness, operation under disequilibrium, dynamic feedbacks, interdependence among components, and emergent properties arising from interactions rather than isolated parts. These features underscore that complexity is not anomaly but a defining systemic property.

Urban systems exemplify these dynamics: cities operate as dense networks of agents generating emergent socio-spatial patterns through nonlinear interactions (Bettencourt, 2013). Recent research emphasizes that urban resilience and sustainability transitions demand adaptive governance and networked learning to navigate uncertainty (Meerow & Newell, 2019; Pelling et al., 2015). Accordingly, complexity theory reframes cities not as static entities but as historically contingent, evolving systems where adaptation, co-evolution, and emergent dynamics form the basis of resilience and transformation.

Complex Adaptive Systems (CAS)

Complex Adaptive Systems (CAS) are generally defined as "open dynamic systems that can self-organize their structural configurations through the exchange of information, energy, and other resources in their environment, transforming these resources to support action" (Larson, 2016). These are self-organizing systems over which external forces exert little to no direct control. In CAS, self-organization means that no single component or external actor controls collective patterns; instead, local interactions generate system-level order. Such collective, emergent patterns are irreducible, arising from lower-level interactions but not explainable by them (Larson, 2016).

As the components of the systems learn to adapt to external influences, the systems become dynamic, characterized by ongoing organic interactions both within and between them. This adaptive capacity allows CAS to operate between order and chaos, avoiding both rigid stability and complete disorder, and enabling learning and transformation into new emergent states (Turner & Baker, 2019). Once CAS learn to adjust to their new environments, they tend to evolve into new states; in the complexity literature, this process is referred to as "emergence" (Turner & Baker, 2019).

The key principles of CAS include path dependence, historical contingency, nonlinearity, emergence, irreducibility, adaptability, and self-organization (Lindberg & Schneider, 2013). Path dependence reflects sensitivity to initial conditions: seemingly similar systems may evolve differently due to their unique histories. Small changes in one part of the system may trigger disproportionate, unpredictable consequences, while large inputs may have minimal effects (Hammer, Edwards, & Tapinos, 2012). Such dynamics underscore why CAS outcomes cannot be linearly predicted.

The significance of these principles becomes particularly evident when applied to urban systems. CAS theory increasingly informs urban governance and resilience studies, highlighting path dependence, historical contingency, and adaptive capacity as critical mechanisms (Walker et al., 2004). Cities exemplify CAS: they function as open, adaptive networks of agents and institutions whose decentralized interactions generate emergent socio-spatial patterns and iterative learning processes (Bettencourt & West, 2010; Ahern, 2011). Urban systems operate far from equilibrium, continuously reorganising in response to shocks and stresses. This makes CAS perspectives especially valuable for analysing resilience, sustainability transitions, and adaptive governance (Folke et al., 2010; Meerow & Newell, 2019). Recognizing cities as CAS underscores the need for decentralized governance, iterative learning, and network-based coordination to foster adaptability in complex urban environments (Folke et al., 2010).

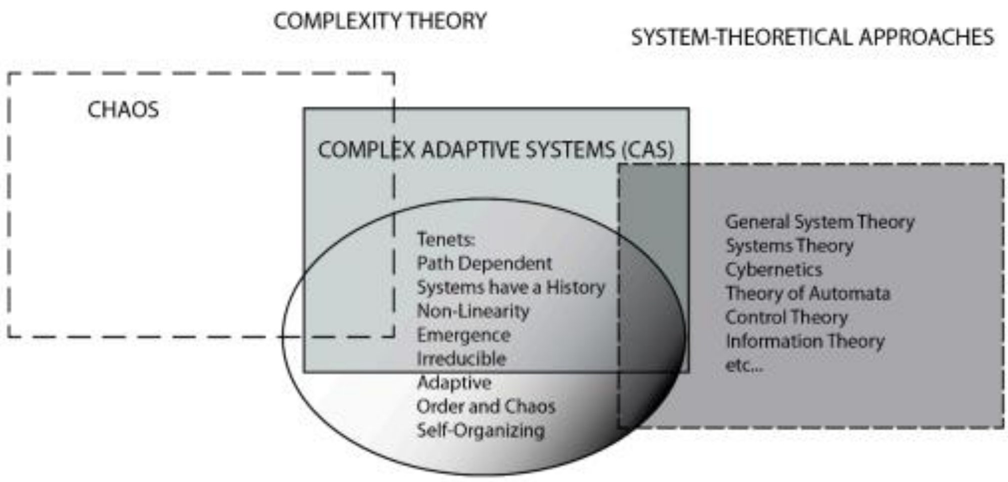
The notion of CAS also connects directly to the "edge of chaos" concept: systems that thrive between order and chaos display both stability and flexibility, enabling innovation and adaptation (Waldrop, 1992; Hayles, 1990). This balance is particularly relevant for cities, where excessive rigidity undermines adaptability, while unchecked disorder threatens resilience. CAS perspectives therefore highlight the importance of navigating this delicate middle ground.

There is ongoing debate regarding the theoretical positioning of CAS. One perspective situates

CAS and complexity theory as subsets of the broader systems theory framework. Yawson (2013), for example, presents complexity theory as a branch of GST, suggesting that CAS and chaos theory remain nested under a general systems paradigm. However, Yawson (2013) also identifies elements—nonlinear dynamics, chaos, and adaptation—that cannot be fully explained by GST, underscoring the distinction between these approaches. A second perspective frames CAS as a distinct paradigm: Goldstein, Hazy, and Lichtenstein (2010) argue that although overlaps exist, CAS goes beyond GST by incorporating irreducibility, self-organization, and emergent behaviour (see Figure 1).

Figure 1

Complexity Theory and Theoretical Systems Approaches (Goldstein, Hazy, and Lichtenstein, 2010).



For the social sciences, it is suggested that future research should incorporate CAS principles, including path dependence, historical contingency, nonlinearity, emergence, irreducibility, adaptability, balance between order and chaos, and self-organization. Interactions within organizations and cities are inherently complex and are better explained through the lens of CAS compared to other theoretical system approaches. By reframing social and urban systems as CAS, scholars and practitioners gain a more nuanced framework for understanding how resilience, governance, and sustainability emerge from decentralized, adaptive, and historically contingent processes. This shift not only refines theoretical debates but also carries direct implications for urban policy and governance, where flexibility and adaptive learning are critical under conditions of rapid change and uncertainty (Shukla et al., 2025; Gorjian, 2025).

Understanding the Complexity of Urban Systems

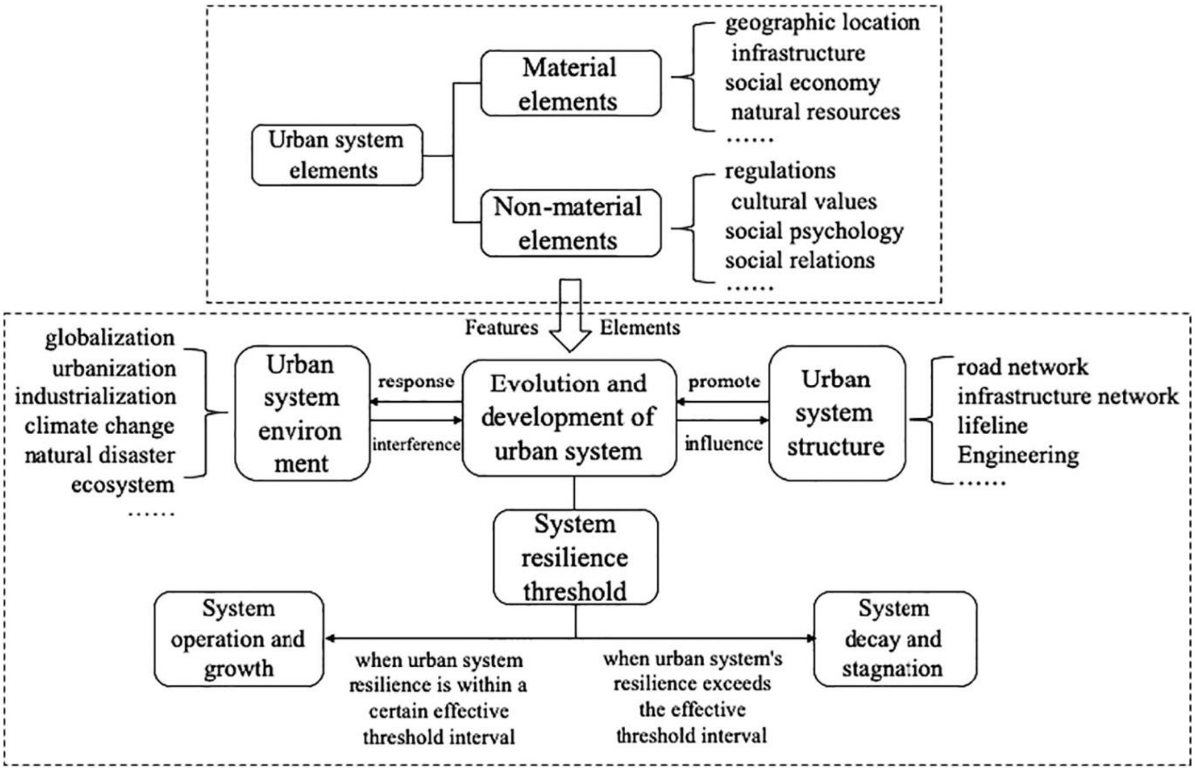
Understanding cities, the dynamics within them, and the relationship among these dynamics is essential for effective urban planning. Therefore, it is first necessary to understand the kinds of problems that cities generate. In her 1961 book The Death and Life of Great American Cities, Jane Jacobs emphasized in the chapter "What Kind of Problem is a City?" that urbanism is fundamentally scientific on an epistemological level. Cities are defined as problems of complexity. Over time, science has become one of the fundamental methods for observing urbanism. Complexity science, which has developed since the early twentieth century, is an experimental and debated paradigmatic approach for observing, investigating, and theoretically interpreting the world we live in. It has become a highly useful tool for defining what kind of problem a city is and how we can better understand it. Complexity science is the most contemporary tool for understanding how synergies and emergent phenomena are generated from the dynamic relationships and interactions of entities ranging from atoms to human beings (Jacobs, 1962).

The formation of a complex urban system is influenced by the stochastic effects of environmental changes both within and outside the city. It is the outcome of the nonlinear interactions among multiple factors under the combined action of various elements such as social and economic transformations and cultural adaptation. When examining the responses of an urban system to diverse risks and impacts, it is essential to fully understand the system's composition and interaction mechanisms, and to consider the relational linkages between the different elements within the system and the dynamics of the system as a whole, thereby contributing to the advancement of urban system cognition and research as a scientific endeavour (Shi et al., 2019).

The urban system is a spatial framework shaped by human–land interactions, characterized by a defined structure, functions, and regional linkages. It emerges from the interplay of cultural, economic, environmental, and resource-related factors and, as a dynamic and open system, never exists in isolation. External forces such as globalization, urbanization, and industrialization drive its transformation, enabling the evolution of urban functions. Structurally, the urban system comprises three core components: the system environment (natural and socio-economic context), system elements (material and non-material components such as infrastructure, resources, regulations, and cultural values), and system structure (the spatial configuration formed through the interaction of these elements, embodied in networks and urban infrastructure) (see Figure 2) (Shi et al., 2019).

Figure 2

Composition of a complex urban system (*Shi et al., 2021).*



Considering all these frameworks, accurately understanding the theoretical approaches addressing the challenges of complex urban systems requires examining which theories have been explored within which problem domains in the literature and defining these boundaries accordingly. In this context, a bibliometric analysis was conducted to evaluate studies employing theoretical frameworks for urban problems, along with the key terms and methodologies utilized in these works.

METHODOLOGY

This study employed a bibliometric approach to examine the intersection between urban planning and complex adaptive systems. Data were collected from two major scientific databases: Web of Science (WoS) and Scopus, using a combination of controlled search queries specifically designed to capture relevant literature. The analyses were conducted using the Bibliometrix package and the Biblioshiny interface available in RStudio.

Data Collection

For WoS, the search string was formulated as:

TS = ("urban" OR "city" OR "urban planning" OR "city planning" OR "spatial planning" OR "land-use planning") AND TS = ("complex adaptive systems" OR "complex adaptive system" OR "complexity theory" OR "urban complexity" OR "complex systems" OR "adaptive systems" OR "systems theory" OR "systems science" OR "system thinking" OR "urban system" OR "system approach" OR "causal loop" OR "systems approach" OR "dynamic complexity" OR "system modeling")

For Scopus, the equivalent query was constructed as:

TITLE-ABS-KEY ("urban" OR "city" OR "urban planning" OR "city planning" OR "spatial planning" OR "landuse planning") AND TITLE-ABS-KEY ("complex adaptive systems" OR "complex adaptive system" OR "complexity theory" OR "urban complexity" OR "complex systems" OR "adaptive systems" OR "systems theory" OR "systems science" OR "system thinking" OR "urban system" OR "system approach" OR "causal loop" OR "systems approach" OR "dynamic complexity" OR "system modelling")

The search was restricted to peer-reviewed journal articles and English-language publications only, ensuring the inclusion of high-quality scientific outputs. The initial search yielded 4,965 records from Scopus and 3,139 records from WoS.

Data Cleaning and Integration

To remove duplicates and merge the datasets, the records from both databases were exported in BibTeX format and processed using standardized bibliometric cleaning procedures. The intersection of the two datasets was identified and removed to avoid double-counting, resulting in a final dataset of 6,277 unique publications. The following R code snippet illustrates the merging process (see Figure 3):

Figure 3

R Script for Merging WoS and Scopus Bibliometric Data

```
library(bibliometrix)
A= convert2df("combined_wos.bib", dbsource="wos", format="bibtex")
B = convert2df("scopus.bib", dbsource="scopus", format="bibtex")


mergedf=mergeDbSources(A,B, remove.duplicated = TRUE)

library(openxlsx)

write.xlsx(mergedf,file="mergeddata.xlsx")
```

Only original research and review articles were retained for analysis, excluding conference proceedings, book chapters, and grey literature.

FINDINGS

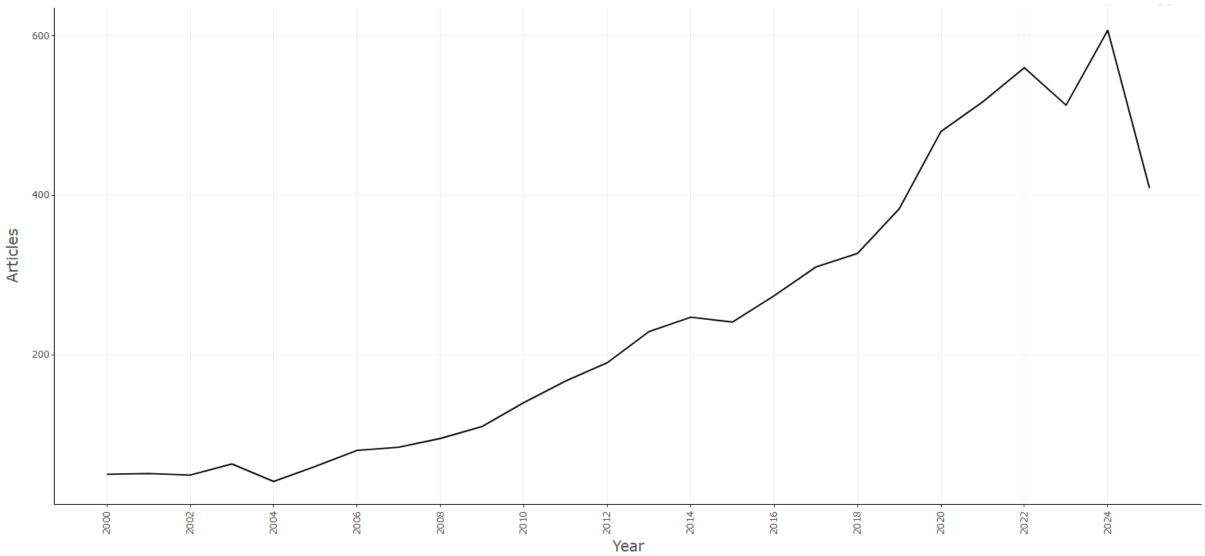
This section presents the findings of a bibliometric and conceptual mapping analysis of the academic literature that focuses on the themes of urban systems, systems thinking, and complex systems theory within the framework of urban planning. Temporal trends, keyword patterns, and conceptual clusters are collectively evaluated to analyse how the field has evolved over the past twenty-five years and to identify dominant thematic concentrations. In this context, the section begins by examining the change in the number of published articles over time, with the aim of revealing the theoretical and historical foundation of the field and identifying its key developmental phases.

As shown in Figure 4, the annual volume of scholarly publications related to the analysed domain has experienced substantial growth between 2000 and 2025. From a relatively modest baseline in the early 2000s, a marked acceleration is observed beginning around 2010 coinciding with the consolidation of sustainability frameworks and growing interest in systems-based urban modelling. The most pronounced surge occurred between 2018 and 2021, with the number of publications peaking at over 600 articles in 2021. This trend reflects not only the field's growing academic significance but also its responsiveness to global policy shifts such as the UN Sustainable Development Goals (SDGs), increasing attention to climate-induced urban vulnerabilities, and the impact of the COVID-19 pandemic on urban resilience discourses.

Overall, this temporal trajectory illustrates the transformation of the topic into a mature, data-rich, and policy-relevant research domain, setting the stage for the deeper thematic and structural analyses that follow.

Figure 4

Annual Publication Trends on Complexity and Systems Approaches (2000–2025)

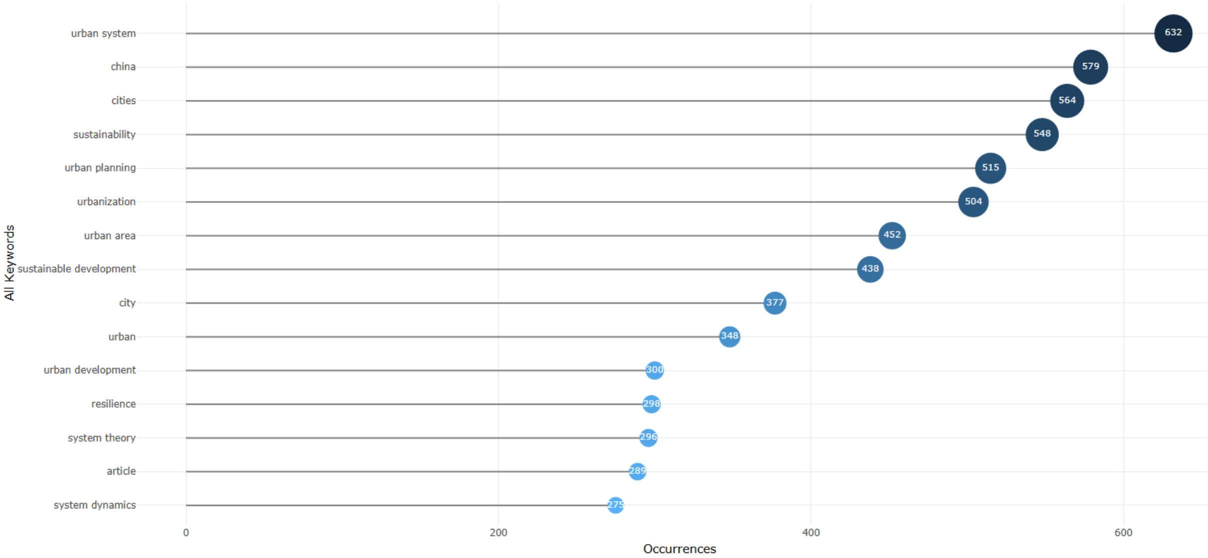


Source: Prepared by authors using Biblioshiny.

Figure 5 provides a keyword frequency distribution for all terms identified within the studied corpus, enabling a structured analysis of thematic prominence in urban and systems-based research. The visual representation highlights dominant conceptual anchors that frame current academic discourse. The term with the highest frequency is "urban system" (632), followed by "china" (579), "cities" (564), "sustainability" (548), and "urban planning" (515). This distribution strongly suggests that the urban system concept has become a foundational axis within contemporary literature. The dominance of "urban system" reflects the growing adoption of an interdisciplinary framework wherein cities are viewed as complex, interlinked systems composed of interacting ecological, technological, economic, and social subsystems. This systemic framing aligns with principles from complex systems theory, emphasizing feedback mechanisms, adaptability, and emergent behaviours in urban dynamics. While "system theory" (296) and "system dynamics" (275) appear less frequently than broader urban terms, their continued presence in the core vocabulary underscores their enduring relevance in analytical modelling and theoretical structuring of urban processes. Additionally, terms like "resilience" (298) and "sustainable development" (438) capture the mounting concern with the vulnerability and adaptability of urban environments in the face of environmental risks and socio-political pressures. The substantial appearance of terms such as "urbanization", "urban area", and "urban development" confirms the systemic attention paid to spatial and infrastructural transformation processes. In conclusion, this analysis affirms that a new integrated urban paradigm is emerging anchored in systems theory, informed by sustainability imperatives, and responsive to complex urban challenges through adaptive planning and governance.

Figure 5

Co-occurrence of Keywords in Urban Systems and Complexity Studies

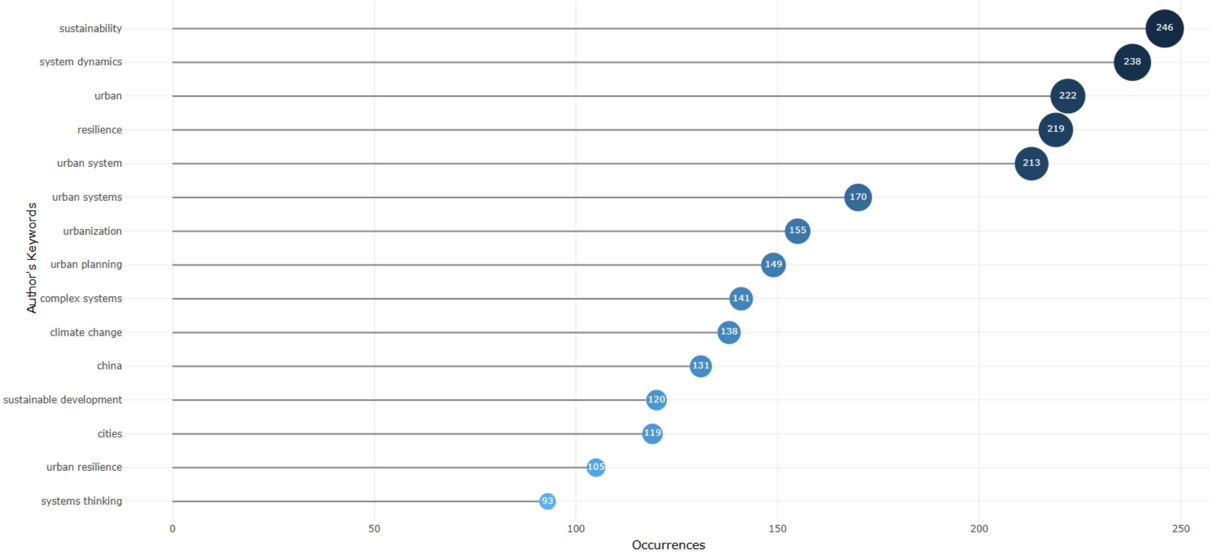


Source: Prepared by authors using Biblioshiny.

Figure 6 presents a frequency-based conceptual mapping of author-defined keywords across a corpus of urban and systems-oriented literature spanning 2000–2025. The size and ordering of the bubbles indicate the relative prominence of each term within the academic discourse. The most frequently occurring term is "sustainability" (246), followed by "system dynamics" (238), "urban" (222), and "resilience" (219). This distribution underscores the dominant role that sustainability frameworks and resilience paradigms have assumed in contemporary urban studies. Of particular note is the substantial representation of "system dynamics", "complex systems" (141), and "systems thinking" (93). These terms reflect a paradigmatic shift toward treating cities not as static or mechanistic entities, but as complex, adaptive systems characterized by feedback loops, nonlinearity, and emergent behaviour. The theoretical foundation of complex systems theory has thus become instrumental in modelling urban processes across multiple spatial and temporal scales. Furthermore, the prominence of terms such as "urban system" (213) and "urban systems" (170) signals an increasing academic interest in multi-scalar system modelling and the interdependencies that define urban environments. The presence of stressor-related keywords like "climate change", "urban resilience", and "sustainable development" illustrates the evolving need to address global environmental risks through systemic approaches. In sum, this keyword analysis affirms that urban research is increasingly informed by systems theory, dynamic modelling, and resilience-based planning, providing critical insights into the governance and sustainability of cities in the face of global uncertainty.

Figure 6

Author Keyword Co-occurrence in Urban Complexity and Systems Research

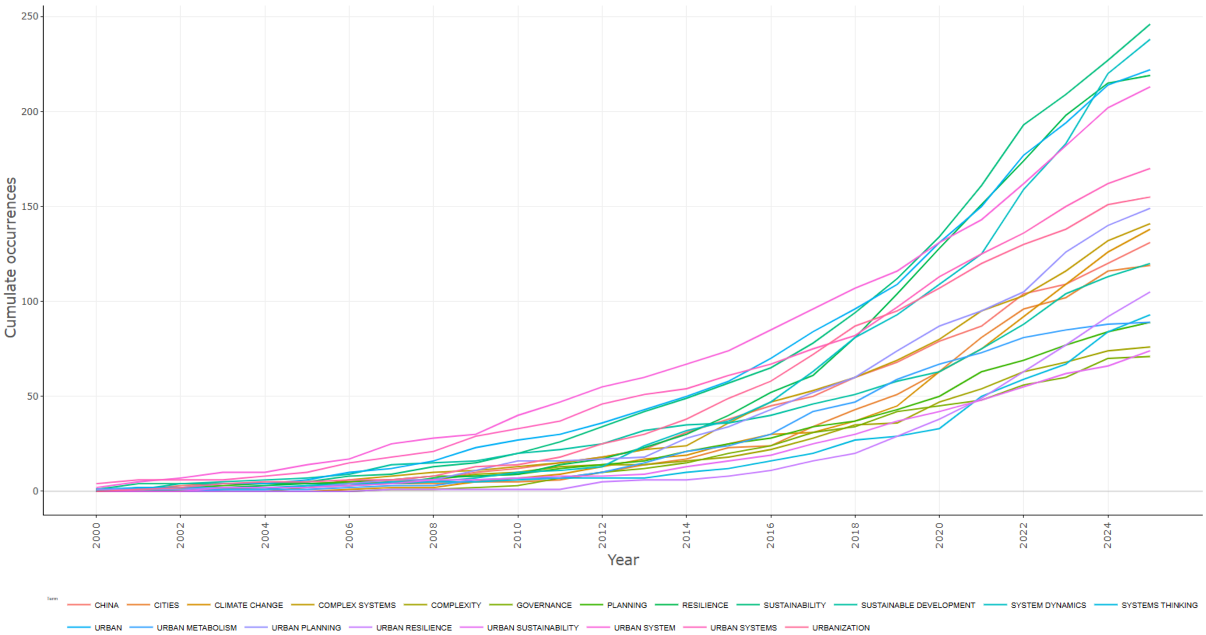


Source: Prepared by authors using Biblioshiny

Figure 7 illustrates the cumulative academic occurrence of selected key terms between 2000 and 2025. The figure provides a longitudinal insight into the evolution of research interests, particularly highlighting concepts such as complex systems theory, systems thinking, urban systems, urban resilience, and sustainable development. A noticeable trend is the steep rise in terms like "systems thinking", "system dynamics", and "urban resilience" particularly after 2015. This surge suggests a paradigmatic shift in urban research—from reductionist and siloed approaches to more holistic and integrative frameworks. Within the framework of complex systems theory, this trend reflects the growing recognition of cities as dynamic, non-linear, and interdependent systems composed of nested subsystems and feedback loops. The concurrent rise of "urban system" and "urban sustainability" indicates an increasing academic focus on cities not merely as spatial configurations, but as socio-ecological-technological systems with emergent properties. Meanwhile, the steady growth of terms like "governance" and "planning" emphasizes the necessity of incorporating institutional and policy dimensions into urban complexity analysis. Hence, the integration of systems thinking, complexity theory, and the adaptive capacity of cities forms a crucial triad for understanding and shaping resilient urban futures. These theoretical lenses become particularly salient in addressing global challenges such as climate change, rapid urbanization, and ecological degradation.

Figure 7

Cumulative Keyword Occurrence Trends in Urban Systems and Complexity Research (2000–2025)



Source: Prepared by authors using Biblioshiny.

Figure 8 depicts a word cloud visualization of the most frequently used keywords across the selected urban and systems-related literature. The size of each term correlates with its relative frequency, offering a conceptual mapping of dominant and co-occurring themes. The most prominent terms include: “urban system”, “sustainability”, “china”, “urban planning”, “cities”, “urbanization”, and “sustainable development”. These core concepts reflect the transformation of urban research into a multifaceted discourse incorporating systems theory, sustainability science, planning, and global urban governance. The appearance of keywords such as “system theory”, “system dynamics”, “complex systems”, and “simulation” signals a growing reliance on complex systems approaches to conceptualize and analyse urban phenomena. These approaches enable the modelling of cities as adaptive, multi-layered systems with emergent behaviours and dynamic feedback loops. Additionally, the presence of terms like “climate change”, “resilience”, “vulnerability”, “governance”, and “infrastructure” illustrates a heightened concern with systemic stressors and institutional mechanisms for managing urban risk and adaptation. Overall, the word cloud reveals an emerging interdisciplinary integration of complexity theory, dynamic modelling, urban sustainability, and resilience planning indicating that the research community increasingly perceives cities not as isolated physical entities but as evolving socio-technical systems embedded in global environmental and policy contexts.

Figure 8

Word Cloud of Key Terms in Systems Thinking and Urban Studies

Source: Prepared by authors using Biblioshiny.

Figure 9 presents a hierarchical cluster dendrogram derived from co-occurrence patterns of keywords found in the analysed literature. The dendrogram visualizes the semantic and contextual similarity among terms, enabling a deeper understanding of thematic proximity and conceptual groupings within the corpus.

Three primary clusters are evident:

Blue Cluster (left): Composed mainly of theoretical and infrastructural elements, this group includes terms such as “system theory”, “system dynamics”, “economics”, “water supply”, and “human”. These terms suggest a focus on systems modelling frameworks and the integration of human-environmental variables.

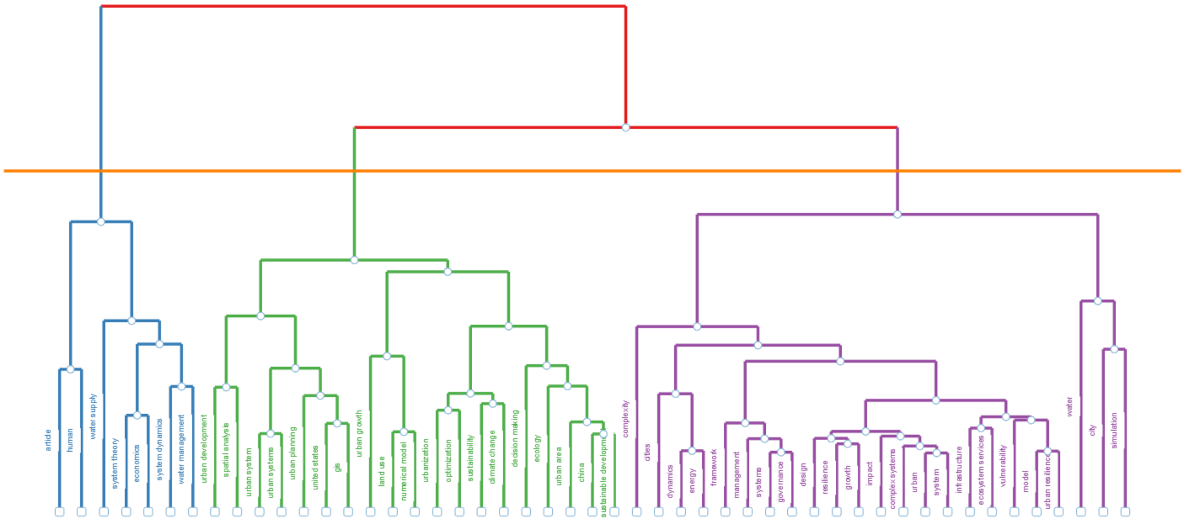
Green Cluster (center): This group reflects themes of urban transformation, sustainability, and spatial decision-making. Terms like “urban growth”, “optimization”, “climate change”, “decision making”, and “urban area” dominate this cluster, pointing to research that explores spatial planning in relation to environmental dynamics.

Purple Cluster (right): This is the most diverse in scope, encapsulating urban complexity, governance, resilience, and ecosystem services. It includes terms such as “governance”, “complex systems”, “vulnerability”, “urban resilience”, and “infrastructure”. This cluster corresponds to multidisciplinary approaches that deal with systemic risk, adaptive capacity, and governance of urban ecosystems.

The vertical linkage distance in the dendrogram denotes the degree of conceptual dissimilarity, while the orange threshold line indicates the cutoff level used to define clusters. Terms linked below this line share higher conceptual coherence. Overall, this structure reveals that urban systems research is characterized by interrelated but distinct thematic streams—namely, systems theory modeming, sustainability-driven planning, and resilience-oriented governance. The dendrogram thus offers a useful roadmap for understanding how different research priorities converge within the broader domain of complex urban systems.

Figure 9

Dendrogram of Co-occurring Terms in Complex Adaptive Urban Systems Literature



Source: Prepared by authors using Biblioshiny

DISCUSSION

The comparative framework highlights fundamental differences in how General Systems Theory (GST), Complexity Theory, and Complex Adaptive Systems (CAS) conceptualize and analyse urban systems. Each approach offers a unique lens shaped by its ontological assumptions and methodological priorities, which directly influence its capacity to interpret and respond to urban complexity.

Unit of Analysis: GST frames the system as a coherent whole composed of interrelated structural components. Bertalanffy's (1972) foundational work and Meadows' (2008) systemic modelling emphasize the integrity of components and their contribution to maintaining systemic equilibrium. In contrast, Complexity Theory shifts the focus from components to the interactions and feedback mechanisms between them, arguing that system behaviour emerges from nonlinear relationships rather than individual elements (Nicolis, 1995; Byrne, 1998). CAS extends this interactional view further by centring on decentralized agents embedded within networked structures, where adaptive behaviours and learning processes drive systemic change (Holland, 1992; Lindberg & Schneider, 2013). In urban contexts, this distinction is critical: cities function less as static wholes and more as adaptive networks of agents and institutions (Bettencourt, 2013).

Primary Focus: GST emphasizes stability, equilibrium, and structural coherence, which align with early organizational and engineering applications (Kast & Rosenzweig, 1981). Complexity Theory challenges this paradigm by prioritizing nonlinear processes, self-organization, and emergent patterns, providing a better fit for systems characterized by uncertainty and dynamic change (Cilliers, 2005; Waldrop, 1992). CAS explicitly foregrounds adaptation, learning, and co-evolutionary dynamics, making it particularly suitable for socio-ecological and socio-technical systems such as cities, where iterative feedback and historical contingency shape development pathways (Folke et al., 2010).

System Boundaries: GST assumes relatively fixed and well-defined boundaries necessary for analyzing inputs, outputs, and feedback loops (von Bertalanffy, 1972). Complexity Theory introduces boundary permeability, recognizing the influence of environmental exchanges and contextual shifts (Preiser et al., 2018). CAS conceptualizes boundaries as dynamic, continuously renegotiated through adaptive processes and multi-level interactions (Folke et al., 2010). This has direct implications for urban studies, where cities are open systems constantly shaped by external flows of people, information, and resources.

Temporal Dynamics and Control: GST prioritizes equilibrium and the return to stability after disturbance, reflecting a mechanistic and often linear temporal view (Walker et al., 2004). Complexity Theory integrates evolutionary change and bifurcation points, highlighting the role of chaos and unpredictability in system behaviour (Lorenz, 1993). CAS further advances this by incorporating historical contingency, path dependence, and multi-scalar dynamics as defining features of adaptive change (Goldstein et al., 2010). Correspondingly, control mechanisms evolve from centralized in GST to distributed in CAS, reflecting a shift from hierarchical management to networked, decentralized governance models—an essential transition in addressing urban wicked problems (Meerow & Newell, 2019). This progression also underscores an ontological shift: from mechanistic equilibrium in GST, to dynamic nonlinearity in Complexity Theory, and finally to adaptive, historically contingent systems in CAS.

Adaptability and Emergence: While GST treats adaptability as secondary and often constrained, Complexity Theory identifies it as a latent potential arising from nonlinear interactions. CAS elevates adaptability to a defining systemic property, where emergent behaviours are not anomalies but the core drivers of system evolution (Folke et al., 2010; Goldstein et al., 2010). This framing aligns strongly with urban systems, where adaptability and emergent dynamics underpin resilience and sustainable transformation. Empirical studies applying CAS to domains such as water resource resilience, energy transitions, and waste management further illustrate the adaptive and emergent dynamics of urban systems (Xu et al., 2025; Yan & Wang, 2025; Subbanarasimha & Venumuddala, 2025). In this sense, CAS explicitly operates “between order and chaos” (Hayles, 1990), a property that fosters innovation and learning within complex urban environments.

Theoretical Positioning: The literature remains divided on whether CAS is a subset of General Systems Theory or a distinct paradigm. While Yawson (2013) situates CAS under the GST umbrella, scholars such as Goldstein et al. (2010) argue that CAS is irreducible and must be treated as separate. This debate reflects broader conceptual tensions in systems thinking, with urban studies increasingly favouring the latter view.

In summary, the comparative assessment presented in Table 1 outlines the theoretical progression from the structure- and equilibrium-oriented perspective of GST, through the interaction-driven dynamics of Complexity Theory, to the adaptive and decentralized framework of CAS. Rather than reiterating individual indicators, the table emphasizes a broader trend increasingly evident in urban systems research: a shift from stability-focused models towards approaches capable of explaining emergence, co-evolution, and adaptive governance. This transition reflects not only a conceptual change but also a methodological requirement for addressing contemporary urban challenges. The bibliometric evidence confirms this trajectory: GST remains marginal in urban studies, Complexity Theory shows steady growth, while CAS exhibits a clear post-2015 surge to around 20–25 publications per year. The post-2015 increase in CAS-oriented studies provides bibliometric evidence supporting this development. By linking systems theory with urban governance approaches, the table positions CAS as a suitable framework for analysing and managing the complex dynamics of modern cities.

Table 1

Comparative Dimensions of Systems Approaches in Urban Complexity

Indicator	General Systems Theory (GST)	Complexity Theory	Complex Adaptive Systems (CAS)
Unit of Analysis	Structural components and the integrated whole (von Bertalanffy, 1972, pp. 30–55; Meadows, 2008, pp. 11–29)	Interactions and feedback between components (Nicolis, 1995, pp. 3–19; Byrne, 1998, pp. 45–58)	Decentralized agents and networked interactions (Holland, 1992, pp. 15–32; Lindberg & Schneider, 2013)
Primary Focus	Stability, equilibrium, structural coherence (Kast & Rosenzweig, 1981)	Nonlinear dynamics, self-organization, emergent patterns (Cilliers, 2005; Waldrop, 1992, pp. 78–94)	Adaptation, iterative learning, co-evolution, resilience (Folke et al., 2010)
System Boundaries	Relatively fixed, predefined (von Bertalanffy, 1972, pp. 30–55)	Permeable, context-dependent (Preiser et al., 2018; Cilliers, 2005)	Dynamic and continuously renegotiated (Folke et al., 2010)
Temporal Dynamics	Stability and return to equilibrium (Walker et al., 2004)	Evolutionary change, bifurcations, chaotic regimes (Lorenz, 1993, pp. 102–115; Waldrop, 1992, pp. 78–94)	Multi-scalar dynamics, historical contingency, path dependence (Goldstein et al., 2010, pp. 67–85)
Complexity Perception	Reducible to subsystems and structural relationships	Nonlinear, emergent dynamics	Emergence as a defining systemic property (Goldstein et al., 2010)
Control Mechanism	Centralized or hierarchical	Semi-centralized, influenced by feedback loops	Decentralized, distributed governance (Meerow & Newell, 2019)
Adaptability	Secondary and limited	Latent potential arising from interactions	Core systemic feature (Folke et al., 2010)
Emergence	Indirect and secondary	Explicitly defined	Fundamental and irreducible to lower levels (Goldstein et al., 2010)
Applications	Organizational theory, engineering (Kast & Rosenzweig, 1981)	Social sciences, biology, urban studies (Byrne, 1998)	Urban networks, socio-ecological systems, adaptive governance (Bettencourt, 2013)
Ontological Basis	Systems as coherent wholes, focus on stability and structure (von Bertalanffy, 1972)	Reality as dynamic, shaped by nonlinearity and feedback (Byrne, 1998; Cilliers, 2005)	Open, adaptive, historically contingent systems shaped by decentralized interactions (Holland, 1992)
Chaos/Order Balance	Assumes predictable order and equilibrium	Recognises chaotic dynamics as generative; “science at the edge of order and chaos” (Waldrop, 1992)	Explicitly operates between order and chaos, fostering adaptability and innovation (Hayles, 1990; Turner & Baker, 2019)
Theoretical Positioning	Often framed as “grand theory” encompassing other approaches (Yawson, 2013)	Sometimes seen as a subset of GST, sometimes as a distinct paradigm	Increasingly positioned as distinct paradigm; overlaps acknowledged but irreducibility and emergence make it unique (Goldstein et al., 2010)
Bibliometric Trend (2000–2025)	Very low and stable: typically 1–3 publications per year.	Steady growth: ~5–10 annually in early 2000s, rising to 80+ publications by 2025	Clear post-2015 surge: from <5 annually before 2010 to ~20–25 publications per year by 2025

Source: Literature review and combined bibliometric analysis of Scopus and Web of Science datasets (2000–2025). Figures reflect publications in the context of urban studies.

CONCLUSION

This study compared three major approaches used to analyse urban systems—General Systems Theory (GST), Complexity Theory, and Complex Adaptive Systems (CAS)—to evaluate their theoretical boundaries and practical relevance. The comparative analysis demonstrates that each framework contributes distinct insights into the multifaceted and dynamic nature of cities. GST provides a foundational lens for understanding structural integrity and component interrelations, making it a valuable starting point for systemic urban analysis. Complexity Theory extends this view by focusing on nonlinear interactions, feedback loops, and emergent behaviours, offering a more dynamic understanding of urban transformation processes. CAS builds on both approaches, placing adaptation, decentralized interaction networks, and historical path dependence at the core, which makes it particularly well-suited for addressing urban contexts characterized by uncertainty, rapid change, and "wicked problems."

The comparative framework presented highlights not only the strengths and limitations of each theory but also their complementary nature. GST's structural analysis capacity, the interaction-focused perspective of Complexity Theory, and CAS's adaptive learning dynamics together provide a multi-layered lens for understanding urban complexity. Nevertheless, the growing body of post-2015 literature applying CAS in urban studies indicates that CAS offers the most robust framework for capturing the socio-ecological and governance dynamics of contemporary cities. As the comparative assessment in the discussion demonstrates, the theoretical progression from GST through Complexity to CAS highlights why adaptability, emergence, and decentralized governance have become defining concerns in urban studies. This trajectory reflects a broader paradigm shift in urban research, where adaptive, network-based and resilience-oriented approaches are increasingly favoured over static or linear models. Its emphasis on decentralized networks, adaptive learning, and emergence as a defining system property establishes CAS as a critical theoretical basis for sustainable urban transformation and resilience.

These findings carry direct implications for urban policy and governance. Cities are not merely physical entities but adaptive networks of actors and processes operating across multiple scales. Thus, theoretical approaches are not only academic models but also analytical tools for policy design. CAS's network-based and adaptive governance perspective provides a valuable foundation for developing flexible strategies under conditions of uncertainty and change. Case-based analyses in rapidly urbanising regions demonstrate the policy relevance of CAS for urban resilience and governance under uncertainty (Shukla et al., 2025). In particular, CAS-informed approaches can strengthen urban resilience, support sustainability transitions, and enhance adaptive planning capacities, ensuring that urban governance frameworks remain responsive to dynamic socio-ecological challenges.

By comparatively delineating the boundaries of closely related paradigms, this article contributes to clarifying both their differences and complementarities, offering a more precise understanding of emerging theoretical frameworks in urban studies. In doing so, it underscores why CAS increasingly stands out as the most effective approach for interpreting contemporary urban complexity, while recognizing the continued relevance of GST and Complexity Theory as complementary analytical lenses.

Ethical Statement

This article is derived from the doctoral dissertation conducted by Sevde Derman Siddiqui under the supervision of Ülkü Duman at the Department of City and Regional Planning, Graduate School of Natural and Applied Sciences, Gazi University.

Ethics Committee Approval

This article does not require ethical committee approval.

Conflict of Interest

There is no conflict of interest of this article.

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Author Contributions

Research Design (CRediT 1): Author 1 (%50) Author 2 (%50)

Data Collection (CRediT 2): Author 1 (%100)

Research - Data Analysis - Validation (CRediT 3-4-6-11): Author 1 (%60) Author 2 (%40)

Writing the Article (CRediT 12-13): Author 1 (%50) Author 2 (%50)

Revision and Improvement of the Text (CRediT 14): Author 1 (%40) Author 2 (%60)

Sustainable Development Goals (SDG)

SDG 11 – Sustainable Cities and Communities

SDG 13 – Climate Action

REFERANSLAR

Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning, 100*(4), 341–343. https://doi.org/10.1016/j.landurbplan.2011.02.02

Bettencourt, L. M. A. (2013). The origins of scaling in cities. *Science, 340*(6139), 1438–1441. https://doi.org/10.1126/science.1235823

Bettencourt, L. M. A., & West, G. (2010). A unified theory of urban living. *Nature, 467*(7318), 912–913. https://doi.org/10.1038/467912a

Byrne, D. (1999). *Complexity theory and the social sciences: An introduction* (pp. 45–58). London: Routledge. https://doi.org/10.4324/9780203003916

Cilliers, P. (2005). Complexity, deconstruction and relativism. *Theory, Culture & Society, 22*(5), 255–267. https://doi.org/10.1177/0263276405058052

deMattos, P., Miller, D., & Park, E. (2012). Decision making in trauma centers from the standpoint of complex adaptive systems. *Management Decision, 50*(9), 1549-1569.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology and Society, 15*(4), 20. https://doi.org/10.5751/ES-03610-150420

Gilley, J. W., Eggland, S. A., & Gilley, A. M. (2002). *Principles of human resource development* (pp. 33–47). Cambridge, MA: Perseus.

Gleick, J. (2008). *Chaos: Making a new science* (pp. 102–118). New York: Penguin.

Goldstein, J. A., Hazy, J. K., & Lichtenstein, B. B. (2010). *Complexity and the nexus of leadership: Leveraging nonlinear science to create ecologies of innovation* (pp. 67–85). New York: Palgrave Macmillan. https://doi.org/10.1057/9780230115117

Gorjian, M. (2025). Complexity Theory in Sustainable Urban Development: A Systematic Review of Adaptive Governance, Computational Models, and Resilience Frameworks. Preprints.

Hayles, N. K. (1990) Chaos Bound, Ithaca, NY: Cornell University Press. — (1991) Chaos and Order, Chicago: University of Chicago Press.

Holland, J. H. (1992). *Complex adaptive systems* (pp. 15–32). Reading, MA: Addison-Wesley.

Jacobs, J. (1962). The Death and Life of Great American Cities. New York: Random House.

Kast, F. E., & Rosenzweig, J. E. (1981). *General systems theory: Applications for organization and management* (pp. 88–101). New York: Wiley.

Larson, C. (2016). Evidence of shared aspects of complexity science and quantum phenomena. *Cosmos and History The Journal of Natural and Social Philosophy, 12*(2), 160-171.

Lindberg, C., & Schneider, M. (2013). Combating infections at Maine Medical Center: Insights into complexity-informed leadership from positive deviance. *Leadership, 9*(2), 229-253.

Lorenz, E. (1993). *The essence of chaos* (pp. 102–115). Seattle: University of Washington Press.

Meadows, D. H. (2008). *Thinking in systems: A primer* (pp. 11–29). London,UK: Earthscan Publishes.

Meerow, S., & Newell, J. P. (2019). Urban resilience for whom, what, when, where, and why? *Urban Geography, 40*(3), 309–329.https://doi.org/10.1080/02723638.2016.1206395

Nicolis, G. (1995). *Introduction to nonlinear science* (pp. 3–19). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511626289

Preiser, R., Biggs, R., De Vos, A., & Folke, C. (2018). Social-ecological systems as complex adaptive systems: Organizing principles for advancing research methods and application. *Ecology and Society, 23*(3), 46. https://doi.org/10.5751/ES-10358-230346

Richardson, K. (2004). Systems theory and complexity: Part 1. *Emergence: Complexity & Organization, 6*(3), 75–90.

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences, 4*(2), 155–169. https://doi.org/10.1007/BF01405730

Schneider, M., & Somers, M. (2006). Organizations as complex adaptive systems: Implications of complexity theory for leadership research. *The Leadership Quarterly, 17*(4), 351–365. https://doi.org/10.1016/j.leaqua.2006.04.006

Shi, Y., Zhai, G., Xu, L., Zhou, S., Lu, Y., Liu, H., & Huang, W. (2021). Assessment methods of urban system resilience: From the perspective of complex adaptive system theory. *Cities, 112*(2021), 103141.

Subbanarasimha, R. P., & Venumuddala, V. R. (2025). Embracing complexity in smart city services: A case of waste management. *Journal of Innovation & Knowledge, 10*(1), 1–11.

Shukla, N., Das, A. & Mazumder, T.N. (2025). Complexities of urban resilience in the global south: key insights from Surat city, India. *Mitig Adapt Strateg Glob Change* **30**, 43.

Swanson, R. A., & Holton, E. F. (2001). *Foundations of human resource development* (pp. 56–69). San Francisco: Berrett-Koehler.

Taşdelen, Ö. (2016). *Biyoloji öğretmen adaylarının sistem düşüncesi ve biyolojik mantık yaklaşımlarına yönelik algı ve becerilerin değerlendirilmesi.* Ankara: Doktora Tezi, Gazi Üniversitesi, Eğitim Bilimleri Enstitüsü.

Turner, J. R., & Baker, R. (2019). Complexity theory in practice: Understanding systems and leadership. *Systems, 7*(3), 45–63. https://doi.org/10.3390/systems7030045

Tursun, M. (2021). *Sistem düşüncesine dayalı muhasebe eğitiminin öğrencilerin öğrenme yaklaşımları, tutumları ve akadeik başarılarına etkisi.* Malatya: Doktora Tezi, İnönü Üniversitesi, Sosyal Bilimler Enstitüsü.

von Bertalanffy, L. (1972). *General system theory: Foundations, development, applications* (pp. 30–55). New York: Braziller.

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society, 9*(2), 5. https://doi.org/10.5751/ES-00650-090205

Waldrop, M. M. (1992). *Complexity: The emerging science at the edge of order and chaos* (pp. 78–94). New York: Simon & Schuster.

Wang, T. (2004). From general system theory to total quality management. *The Journal of American Academy of Business, Cambridge, 4*, 394-400.

Westhorp, G. (2012). Using complexity-consistent theory for evaluating complex systems. *Evaluation, 18*(4), 405-420.

Xu, C., Han, Y., Qi, L., Wang, J., & Yao, W. (2025). Adaptive evaluation of urban water resource carrying capacity: Development and empirical study of the URCA model. *Journal of Hydrology, 634*, 130650.

Yan, J., & Wang, H. (2025). Does the Development of Digital Finance Enhance Urban Energy Resilience? Evidence from Machine Learning. *Sustainability*, *17*(14), 6434.

Yawson, R. (2013). Systems theory and thinking as a foundational theory in human resource development—A myth or reality? *Human Resource Development Review, 12*(1), 53-85.

Yorks, L., & Nicolaides, A. (2012). A Conceptual Model for Developing Mindsets for Strategic Insight Under Conditions of Complexity and High Uncertainty. *Human Resource Development Review, 11*(2), 182-202.