Available online at https://journals.sjp.ac.lk

JOURNAL OF REAL ESTATE STUDIES

ISSN 3051-4878 [PRINT] | E-ISSN 3051-4886 [ONLINE]

Integrating Ecosystem Services into Urban Planning: A Conceptual Review through a Social–Ecological–Technological Systems (SETS) Perspective

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ABSTRACT

The primary goal of urban planning is to create sustainable urban development. However, urban growth is frequently accompanied by persistent socioeconomic and environmental problems, particularly in developing countries such as Sri Lanka. Environmental pollution, traffic congestion, poverty, housing shortages, unequal access to services, and flooding are common issues associated with rapid urbanization. This paper aims to understand how ecosystems and ecosystem services have been considered in planning practice over time. This paper which is based off on a review of the recent literature, aims to explore the concept of Social–Ecological–Technological Systems (SETS) and the importance of incorporating urban ecosystem services into urban planning. According to the literature analysis, there has been a paradigm shift in urban planning with regard to the consideration of ecosystem services. The socio-ecological-technological systems perspective emphasizes that urban issues cannot be understood in isolation. Society, technology, and environmental systems are deeply interconnected and should therefore be conceptualized as an integrated system rather than as independent systems. Therefore, the SETS framework provides a holistic foundation for managing complex urban issues. It highlights how actively maintaining ecosystem functionality can support urban sustainability much more than simply conserving ecosystems. Compared to traditional planning practices that overlook ecological dynamics, or Social-Ecological Systems, which tend to neglect technological dimensions, the SETS framework is more sustainable, resilient, and inclusive in its approach to urban development because it builds on embedding ecosystem services as the core of urban planning practices. This research concludes that in order to achieve sustainable and resilient outcomes in urban development, there must be a strong emphasis on stakeholder integration as well as a shift from grey infrastructure to green infrastructure approaches.

ARTICLE INFO

Article History:
Received 22 November 2025
Revised 18 December 2025
Accepted 29 January 2026

Keywords:

Social–Ecological–Technological Systems (SETS); Socio-ecological systems (SES); Urban ecosystems; Green–blue infrastructure; Urban Planning

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Doi: **10.31357/jres.v23i01.9033**

1. INTRODUCTION

Rapid land use change breaks up ecological landscapes and disrupts how water moves through them, which lowers biodiversity and reduces the benefits these ecosystems provide. When natural land is replaced by buildings, utility networks, roads, and other sealed surfaces, the area absorbs less heat and rainwater, which increases exposure to hazards such as flooding, drought and extreme heat. Climate change increases the risk of above extreme events in recent years (Ali et al., 2025). In many developing countries, such as Sri Lanka, the pace of urban growth has increased quickly over the last few decades. As urbanization increases, people, infrastructure, and economic activity become more concentrated in urban areas, which increases exposure to hazards and raises overall risk. Low-income communities in urban areas often have limited resources and less ability to adapt, which makes them especially at risk from climate-related hazards (Das, 2025). These negative externalities of urban growth often affect vulnerable and marginalized communities the most.

Biodiversity loss and declining ecosystem health can worsen social and economic harms, which makes ecosystem restoration important for reducing how exposed local communities are to extreme climate events. In recent years, these combined pressures have underscored a clear need for ecosystem-based urban planning that integrates ecosystem services as a core component of spatial development decisions. Studies suggest that bringing back ecological functions can improve how cities cope with stress, support healthier ecosystems, and contribute to more sustainable and livable urban areas (Marques et al.,2022; Wang et al., 2025; Chang et al., 2020).

Research Objectives and Methodology

Grey infrastructure solutions have, over time, been the primary means of addressing urban issues, but this research examines the evolution of ecosystem service integration into urban planning and identifies the key factors for effectively implementing ecosystem-oriented strategies. Specifically, the study reviews published research to track how ecosystem services have been incorporated into urban planning over time and highlights the practical aspects that should be considered when applying ecosystem-based approaches.

A literature review was conducted using the keywords “urban ecosystem services,” “green infrastructure,” “nature-based solutions,” “urban planning,” “Socio-Ecological Systems,” and “SETS framework” to identify studies exploring the intersections of ecological, social, and urban planning dimensions. This literature review explores how SES and SETS thinking have influenced and challenged urban planning practices in recent years, drawing on research on ecosystem services, green infrastructure, and nature-based solutions. A qualitative narrative synthesis approach was used to integrate and interpret findings across the selected studies. Google Scholar was used as the primary database to identify peer-reviewed literature from diverse disciplines, including urban planning, ecology, sustainability science, and climate change adaptation. The literature search included studies published over the past 30 years.

The paper is organized into five sections. Section One introduces the consequences of contemporary urban planning practices and emphasizes the urgent need to transition toward an ecosystem-based approach. Section Two outlines the research objectives and describes the methodology employed in the study. Section Three reviews how ecosystem services have been incorporated into urban planning over time, tracing the shift from conventional gray infrastructure approaches to SES and SETS frameworks that integrate social, ecological, and technological dimensions. Section Four demonstrates how SETS informed green and blue infrastructure can address the limitations of traditional infrastructure focused planning practices. Finally, Section Five emphasizes the interconnectedness of social, ecological, and technological systems and highlights the importance of adaptive, inclusive, and co-produced urban planning strategies.

2. LITERATURE ANALYSIS

This literature examines how ecological services and ecosystems have been integrated into urban planning practices over time. The conceptual frameworks identified in the literature can be categorized into three main types:

(1) urban areas as closed, human-dominated systems,

(2) urban areas as social–ecological systems (SES),

(3) urban areas as social–ecological–technological systems (SETS).

The practical implementation of SETS frameworks in urban planning practice is further examined in this literature review, which highlights the circumstances in which these frameworks can be successfully applied.

Urban regions as controlled systems

Urban planning has long been influenced by systems thinking. Engineering disciplines greatly influenced urban planning approaches during the 19th century. By the mid-20th century, urban planning evolved into a more analytical discipline, employing systematic frameworks to guide planning practices (Pourmohammadi, 2022). Consequently, early planning practices were prescriptive and procedural, following an engineering control framework (Pourmohammadi, 2022; Ahern, 2013). These methods emphasized efficiency and depended on linear, predictable models that presumed straightforward cause and effect connections (Parker, 2012). Infrastructure systems were evaluated based on quantifiable outcomes but frequently overlooked the intricate, nonlinear relationships among social, ecological, and technological systems that influence urban landscapes (McPhearson et al., 2016). In addition, earlier planning methods emphasized quantifiable outcome and overlooked stakeholder issues (Oliveira & Pinho, 2010).

This technocratic, "fail-safe" approach was centered on speed, reliability, and cost-effectiveness, and overlooked the adaptive and dynamic nature of real urban systems. For example, constructed gray infrastructure is primarily created for one specific function, like stormwater control or transit. It does not offer various benefits, such as promoting biodiversity, supporting recreational activities, and managing pollution. Consequently, conventional gray infrastructure has become more vulnerable, facing challenges from aging, climate change, and extreme natural events. These systems often aim to regulate natural processes instead of promoting them; for instance, they direct stormwater via pipes rather than encouraging natural absorption (Schifman, 2017). Traditionally, infrastructure systems were created to manage (and occasionally control) environmental processes, ensuring that essential services and resources are accessible when and where required (Markolf et al., 2018). Heightened flood risk, elevated urban heat, and the decline of ecological services such as pollination are merely some of the adverse impacts that gray infrastructure systems often generate. For example, rainwater is often channeled through pipes instead of allowing it to infiltrate naturally, as these systems are mainly designed to manage natural processes instead of enhancing or supporting them (Schifman, 2017). Consequently, urban expansion and the development of associated gray infrastructure have led to habitat fragmentation, a decline in biodiversity, disruption of hydrological connections and flow patterns, and alterations in material cycles. Furthermore, the hydrological and biological effects of these infrastructure systems reach beyond urban limits and are not confined to the local scale (Alberti, 2005).

The primary causal factor behind these adverse impacts is that traditional urban planning practices have focused primarily on zoning-based approaches and have been restricted within administrative jurisdictions, thereby overlooking broader-scale ecological relationships (Ahern, 2013). In this context, policymakers have acknowledged the shortcomings of housing centered urban planning, zoning-based urban planning rules and regulations as well as the necessity of strengthening the link between urban planning practices and more general urban issues (Coskun, 2024). Furthermore, rather than focusing on the more comprehensive organization of land use, infrastructure, and environmental systems, traditional urban planning has mainly addressed the housing and infrastructure demands of a growing population.

In the past, social and ecological dimensions related to infrastructure systems were frequently disregarded in favor of a strong technical focus. The ecological dimension relates to ecological processes, material and energy flows, and their dynamic interactions, whereas the social dimension includes decision-making procedures, governance frameworks, and equitable concerns. Ignoring these ecological and social dimensions can result in unforeseen effects and new vulnerabilities when using technocratic strategies. Furthermore, inflexible infrastructure designs may lead to lock-in, which can degrade system performance in changing circumstances. Infrastructure design must therefore acknowledge that lock-in results from interactions between social, ecological, and technological systems. An understanding of these interconnections improves the adaptive capacity of infrastructure systems and supports more flexible design approaches (Markolf et al., 2018; Frantzeskaki et al., 2010). Additionally, this viewpoint better equips infrastructure to handle a variety of unpredictable future circumstances.

Conventional urban planning approaches have viewed urban regions as systems primarily controlled by humans. Consequently, ecological functions and processes were frequently overlooked in land-use decision-making. Frantzeskaki et al. (2024) emphasize that urban planning often overlooks how individual systems such as infrastructure, society, the economy, and the environment interact and function together within the urban system. As a result, limited attention was given to how ecological processes and patterns operate in urban contexts. Wetlands and forests serve as vital habitats that are often altered or fragmented without regard for their roles in biodiversity conservation, nutrient cycling, or flood mitigation. Recognizing the divide between ecosystems and their processes from urban systems overlooked the ecological bases essential for urban resilience (McPhearson et al., 2016). Moreover, urban communities became more vulnerable to disturbances such as flooding, heat waves, and ecological degradation because the natural systems that help absorb and adapt to external stresses were not considered. Planning decisions in the past, often underestimate ecosystem services like urban cooling, water management, and air purification, as they are mainly recognized for their recreational or aesthetic value instead of being essential for urban sustainability.

This growth focused urban strategies emphasized land ownership and economic development in short term more than ecosystem interconnection. Consequently, ecological integrity was often jeopardized during housing and infrastructure development, resulting in ecosystem degradation and a decline in ecosystem services. As a result, urban areas play a significant role in environmental change across various scales, making them essential for the sustained operation of societies and ecosystems (Frank et al., 2017). A rising volume of studies highlights the importance of incorporating natural systems into urban planning and design. Conventional urban planning methods have mainly concentrated on zoning strategies and have been limited to administrative boundaries, neglecting wider ecological connections (Ahern, 2013). In this context, policymakers have recognized the limitations of housing focused and zoning focused urban planning rules and regulations, as well as the necessity to enhance the connection between urban planning and wider urban issues (Coskun, 2024). Additionally, instead of concentrating only on narrow administrative goals, they are moving toward more all-encompassing ecological frameworks.

Urban regions as Complex Socio-Ecological systems

In the early 2000s, researchers and urban planners began to acknowledge that human societies rely on ecosystems, which are influenced by human actions. This resulted in the urban socio-ecological paradigm, which perceives urban spaces not merely as aggregates of buildings, structures, infrastructure systems, etc., or natural elements like wetlands, forests, waterways, etc., but as intricate socio-ecological systems (SES) where human, ecological, and built environments are profoundly interlinked. Similar to natural ecosystems, urban ecosystems encompass biotic components like humans, flora, and fauna, as well as abiotic components such as water, air, and their interactions. Urban regions were envisioned as urban ecosystems where individuals, infrastructure, and nature engage through the movement of energy, materials, and information (Pickett et al., 2013). Consequently, it became clear that concentrating solely on social or ecological aspects provides an incomplete view of the sustainability of urban communities (Folke, 2006).

This understanding showed that urban systems extend beyond the city center into suburban and peri-urban regions, where human and ecological processes continuously interact with one another (Wittig, 2009). The dynamic feedbacks and interactions between social and ecological systems extended well beyond the administrative boundaries of urban areas. Additionally, it was emphasized that urban areas are open and dynamic systems that generate patterns and structures without central oversight. In complex urban systems, spatial patterns arise organically from the interplay of social and ecological processes. No single factor can completely account for these emerging behaviors. For instance, emergent phenomena like traffic jams, social networks, or urban heat islands cannot be comprehended by analyzing components separately. Urban regions comprise interrelated elements such as governance networks, material and energy flow and infrastructure, along with social and economic activities that function across various scales and mutually impact each other (Meerow et al., 2016). Consequently, urban ecosystems were considered intricate systems and are not standalone entities. Choices regarding land utilization, including residential areas, infrastructure networks, roadways, and transportation, are strongly interconnected with political, social, and environmental influences.

Viewing cities as socio-ecological systems emphasizes their adaptability the capacity to respond, learn, and develop in the face of environmental, social, and technological changes. Urban systems are thus viewed as dynamic and adaptive entities influenced by ongoing feedback loops between ecological processes and social structures (Frank, 2017). Acknowledging cities as intricate Socio-Ecological Systems (SES) signifies an essential transition from simplistic, infrastructure-focused models to strategies that emphasize their adaptability and ecological interconnectedness. Conventional planning methods, grounded in linear and predictable frameworks, do not adequately account for the nonlinear dynamics, uncertainties, and thresholds inherent in complex urban systems (Carpenter, 2002; Folke, 2006). Consequently, comprehending socio-ecological systems offers a basis for creating interventions that are informed by ecological principles and are socially acceptable, recognizing unpredictability and emergent behavior.

Urban regions as Socio-Ecological-Technological Systems (SETS)

In recent years, researchers have progressively framed urban areas as linked networks of socio-ecological and socio-technical connections, highlighting that society, technology, and the environment create a unified, interdependent nexus instead of distinct systems (Sharifi, 2023; Lee et al., 2025). The Socio-Ecological-Technological Systems (SETS) framework clearly emphasizes this systemic interdependence, showcasing both ecological relationships and the effects of technological changes on ecosystems, unlike previous methods that viewed socio-technical or socio-ecological systems separately. Socio Ecological Systems (SES) frameworks frequently disregarded technological aspects, while Socio-Technical Systems (STS) approaches often ignored ecological processes (Ahlborg et al., 2019). The SETS framework tackles these shortcomings by framing social, ecological, and technological systems as interconnected and evolving together, with technology facilitating human–environment interactions. Incorporating technological systems into socio-ecological perspectives is crucial for comprehensively grasping system dynamics, causal links, and policy implications.

Urban problems cannot be wholly comprehended without taking into account technological systems. Urban regions are increasingly acknowledged as intricate and evolving systems (McPhearson et al., 2022). The Social Ecological Technological Systems (SETS) framework highlights how three main dimensions such as social, ecological, and technological interact to shape urban environments (Lee et al., 2025). The social dimension includes aspects such as governance, planning, policy, finance, institutional capacity, stewardship, labor, cultural norms, perceptions, and values, which influence how cities are managed and developed. The ecological dimension encompasses elements like climate, biodiversity, species traits, ecosystem structure and function, and community-scale interactions that determine the health and resilience of natural systems within urban areas. The technological dimension involves infrastructure systems such as dams, levees, pipes, irrigation systems, sensors, automated systems, and construction materials, which support the functioning of cities. (Lee et al., 2025; Krueger et al.,2022).

Urban ecosystems deliver numerous services to urban inhabitants, such as food production, air cleansing, climate control (cooling), carbon storage, runoff management, noise suppression, recreational activities, and advantages for psycho-physical and social well-being. These services result from nutrient cycling, water cleaning, habitat provision, and carbon sequestration, connecting ecosystem functions to social, economic, and health results (Costanza et al., 1997; Rounsevell et al., 2010). They may also be seen as streams of materials, energy, and information from natural resources, which, when paired with human and constructed capital, enhance human welfare. The sustainable management of these ecosystems guarantees the ongoing availability of these essential services (de Groot et al., 2002). Ecosystem Services (ES) are advantaging that human derive from natural processes such as the physical, chemical, and biological processes that support human health (De Groot et al., 2002; Haase, 2015). Urban ecosystems include green areas like parks, urban woodlands, graveyards, empty lots, individual gardens, street trees, green rooftops, green facades, and blue structures such as streams, lakes, ponds, engineered swales, and stormwater management basins (Grunewald et al., 2017).

This SETS framework offers a comprehensive method for comprehending and overseeing cities as intricate adaptive systems defined by ongoing interactions between social, ecological, and infrastructural components. The Social-Ecological-Technological Systems (SETS) framework extends this concept by recognizing that ecosystem services depend not only on ecological processes but also on technological infrastructure (e.g., green roofs, drainage systems) and social systems (e.g., governance, institutions, equity, and community stewardship). These services are sustained only when all three dimensions interact effectively Socio-Ecological-Technological Systems framework emphasizes that urban systems are shaped by the interplay of social, ecological, and technological elements. These three dimensions do not operate independently; rather, their interactions influence city functions and determine the development, distribution, and sustainability of urban ecosystem services. Unlike traditional approaches that consider ecosystem services only as ecological results, the SETS framework highlights that these services emerge from the complex interplay of social behaviors, technological systems, and ecological dynamics (McPhearson et al., 2022; Ahlborg et al.,2019). The SETS framework offers a comprehensive perspective for evaluating urban sustainability by combining social, ecological, and technological elements.

Applying the SETS Framework in Urban Planning

This section reviews the literature on how ecosystem functionality is conceptualized and implemented in urban planning using the Socio-Ecological-Technological Systems (SETS) framework.

Ecosystem Functionality

Urban Ecosystem Services (UES) represent a paradigm shift in urban planning, moving the focus from merely conserving ecosystems to maintaining their functionality to support human well-being. Traditional planning practices emphasized the conservation of ecosystems, biodiversity, and species as ends in themselves, rather than recognizing their functional role in supporting human well-being. In contrast, the SETS approach highlights ecological functional benefits, such as clean water, fertile soil, carbon storage, pollination, and climate regulation in the decision-making process (de Groot et al., 2002; Barbier et al., 2011). By emphasizing ecosystem functionality, this approach integrates ecological integrity with socioeconomic objectives, promoting sustainable and community-centered planning.

Urban resilience

The notion of Socio-Ecological Systems (SES) resilience acknowledges that social and ecological systems are deeply interconnected and evolve together, making it unfeasible to fully understand or achieve resilience by examining either system in isolation. SES resilience provides conceptual and analytical frameworks for understanding and enhancing the capacity of interlinked social and ecological systems to withstand disturbances, adjust to changes, and, when required, undergo transformations that maintain critical functions, structures, and feedback mechanisms over time (Kim et al., 2022). Therefore, achieving resilience necessitates deliberate and carefully designed alterations in social and environment interactions, backed by suitable institutional setups, governance structures, and effective interventions. Such initiatives must also consider threshold limits that, when exceeded, might result in irreversible or unsustainable socio-ecological situations. Broadening this viewpoint, the resilience of Socio-Ecological-Technological Systems (SETS) emphasizes the vital importance of technological systems as essential parts of urban resilience. Technology facilitates interactions between society and ecosystems while also generating new possibilities for adaptation and change. Incorporating urban planning and design into a SETS framework can yield various co-benefits, such as improved climate change mitigation and adaptation, enhanced pandemic preparedness and response, better human health and well-being, and the advancement of social equity and justice (Sharifi, 2023).

Nature-Driven Solutions

Urban ecosystems including wetlands, forests, and green areas were initially valued primarily from a biological perspective, with limited attention to human interactions and societal benefits (Frantzeskaki et al., 2024). Over time, the Socio-Ecological-Technological Systems (SETS) framework has emphasized the interdependent relationships among social, ecological, and technological systems in urban environments, highlighting the role of nature-based solutions in addressing urban challenges.In this context, nature-based solutions balance social and ecological considerations while integrating technical interventions, harnessing ecological processes to address societal concerns (Khromova and Langemeyer, 2025). Unlike conventional "gray" infrastructure, the SETS framework underscores how ecological services can help address urban issues such as biodiversity loss, climate change, and human well-being (McPhearson et al., 2022). Green and blue infrastructure and nature-based solutions illustrate the practical application of SETS (Bere-semeredi et al., 2023; Benedict & McMahon, 2006). These strategically designed and interconnected systems enhance biodiversity, conserve environmental assets, and provide numerous benefits to human populations.

Policymakers increasingly recognize these ecosystems and their services as dynamic, integrated systems that can inform and support sustainable urban development strategies (Frantzeskaki et al., 2024). By incorporating green and blue infrastructure into urban planning, cities can increase resilience, restore ecological balance, and promote sustainable and equitable urban development (McPhearson et al., 2022). By offering a conceptual framework to understand these complex interdependencies, the SETS paradigm guides the sustainable transformation of urban environments (McPhearson et al., 2016).

Ecosystem Services and urban morphology

Ecosystem services, such as clean air and climate regulation, can be greatly influenced by urban morphology, which refers to the physical makeup of cities, including green areas. The physical layout and organization of land use are largely determined by urban planning (Bierwagen, 2005). However, a thorough understanding of how these services are produced within urban areas, as well as their spatial distribution across cities and surrounding regions, is necessary to effectively enhance ecosystem services and urban resilience. The ecosystem services cascade model connects ecological systems to social values and human well-being by showing how ecosystem processes and structures are converted into functions, services, and eventually human benefits (Haines-Young & Potschin, 2010). The way that natural ecosystems benefit humans is explained by a theory called the Ecosystem Service Cascade (Zhang et al., 2022). The Socio-Ecological-Technological Systems (SETS) paradigm builds on this model by highlighting feedback loops in which technology mediates the effects of human activities on ecosystems and services, such as land use, pollution, or restoration. This integration informs adaptive management tactics and offers a thorough grasp of how urban ecosystems support human life.

Lock-In Effects in Urban Infrastructure

In the past, social and ecological aspects were frequently subordinated to technical considerations in infrastructure planning. The social dimension includes issues of equality, governance, and decision-making, whereas the ecological dimension deals with processes, material and energy fluxes, and their interactions. Ignoring these factors might result in unanticipated vulnerabilities, and rigid infrastructure designs can cause lock-in, which lowers system performance as circumstances change. Infrastructure design can be made more adaptable and flexible by acknowledging that lock-in results from interactions between social, ecological, and technological systems. This knowledge enables urban systems to address a variety of future challenges. The SETS paradigm advocates place-based, context-sensitive approaches that strike a balance between justice, biodiversity, and human well-being rather than universal answers (Markolf et al., 2018).

Cross-Scale Feedbacks

Urban ecosystems have an impact on suburban areas, peri-urban woods, agricultural areas, and watersheds that supply vital supplies to urban dwellers. Urban regions depend heavily on external ecosystems for essential resources including food, water, electricity, and building materials, even if they can produce some ecosystem services on-site (Burkhard et al., 2012). Consequently, urban regions depend on continuous flows of ecosystem services from both nearby and distant ecosystems (McPhearson et al., 2022). At the same time, urban activities significantly influence the supply, distribution, and functioning of ecosystem services at local, regional, and even global scales (Sandhu & Wratten, 2013). Considering these interactions and dependencies across scales, it is essential to understand how urban systems affect and are affected by ecosystems beyond their administrative boundaries to design resilient and sustainable cities (Gunderson and Holling, 2002). The SETS framework highlights the constraints of uniform, one-size-fits-all solutions while encouraging adaptive and resilient planning approaches by emphasizing these cross-scale interactions and feedbacks (Lee et al., 2025).

Knowledge Co-Production

Urban issues are complex and operate across multiple scales, requiring transformative change collaboratively developed with diverse stakeholders (Webb et al., 2023). The SETS approach emphasizes the interdependence of social, ecological, and technological systems. These system components can belong to multiple categories and highlight the need to integrate different viewpoints for a deeper understanding of complex urban systems (Lin et al., 2025). The benefits urban communities gain from ecosystem services, such as green spaces, clean air, and stormwater management, depend on the cooperation of social, ecological, governance, and infrastructure systems. Therefore, this framework provides a lens to identify the trade-offs and synergies among provisioning, regulating, and cultural ecosystem services, while examining how their relative importance shifts across contexts (McPhearson et al., 2022). Misalignment between the scale of service provision and community needs can reduce their effectiveness.

This framework challenges fragmented decision-making and therefore promotes transdisciplinary collaboration, encouraging researchers and communities to co-produce knowledge, manage services, address environmental risks, and enhance justice and inclusion. Therefore, aligning ecological functions, infrastructure development, and governance with community demands is essential for enhancing the efficiency and value of urban ecosystem services (McPhearson et al., 2022). This concept views urban resilience as an ongoing, iterative process that involves learning, innovation, and cooperation across networks, communities, infrastructures, and governance. Huang et al. (2024) state that the framework emphasizes co-creation, anticipatory planning, and changing fragile urban systems into more resilient and adaptive communities.

3. DISCUSSION

The ecosystem services that cities provide have frequently been overlooked in traditional urban planning, which prioritizes infrastructural development and economic expansion over ecological integrity. In the past, a strong technical focus was often prioritized over social and ecological aspects of infrastructure systems. Instead of viewing the natural environment as a vital and dynamic system that supports urban communities, traditional urban planning techniques viewed it as a limitation to be handled or controlled. This perspective, which emphasizes conservation alone rather than incorporating ecosystem services into planning and management, reflects a limited understanding of environmental dynamics. This tradition view has contributed to the degradation of natural systems and the loss of critical ecosystem services, including air purification, climate regulation, and flood risk management. Consequently, command and control based urban planning often overlooked the interdependencies between social dimension and ecological processes, and technological systems. Ignoring these ecological and social dimensions can result in unforeseen effects and new vulnerabilities when using technocratic strategies.

This reductionist perspective framed nature as extrinsic to urban systems rather than as an active, co-evolving component, separating ecological functions from human well-being. Moreover, rigid infrastructure designs might result in lock-in, which deteriorates system performance under changing socio ecological conditions. Policy makers have emphasized in recent years how important it is for infrastructure design to recognize that lock-in arises from the interplay of social, ecological, and technological systems.

In contrast, the aforementioned socio-ecological systems perspective highlights the significance of maintaining environmental services to promote urban sustainability and resilience, with planning that actively improves these services while advancing social fairness. The Socio-Ecological-Technological Systems (SETS) framework further recognizes that ecosystem services emerge from dynamic interactions among social, ecological, and technological factors. This framework highlights how governance, policy, cultural norms, and infrastructure, influence the generation, distribution, and sustainability of these ecosystems services and urban health. Rigid infrastructure solutions intended to manage stressful situations are the main emphasis of traditional hard engineering. Green and blue infrastructure, on the other hand, uses adaptable, environmentally friendly solutions that complement natural processes and serve a variety of purposes. By doing so, green and blue infrastructure integrates ecological principles into urban planning (Bixler et al., 2019). Therefore, SETS provides a strong foundation for adaptive, resilient, and equitable urban planning and development.

Understanding socio-ecological and technological relationships enhances the adaptability of infrastructure systems and promotes more flexible design approaches. This perspective also better prepares infrastructure to deal with a range of unforeseen future situations. Ecosystem services are not set outputs that natural systems automatically provide to society. Rather, they are the result of interactions between nature and communities. The advantages of green and blue infrastructure are contingent upon their design, governance, and community perception and use. Therefore, who benefits from green and blue infrastructure systems depends on the design of the infrastructure, institutional regulations, and the capacities and values of the local community. Ecosystem services are context-dependent and differ according to social groups, geographical circumstances, and government structures. These advantages are therefore quite context-sensitive (Andersson et al., 2022; Keeler et al., 2019).

The Socio-Ecological-Technological (SETS) paradigm emphasizes the significance of co-design and co-production by incorporating knowledge from various stakeholders. Nevertheless, it is currently unclear how to successfully incorporate these strategies into reality (Haase et al., 2014; Fang et al., 2023; O'Donnell et al., 2025; Prescott et al., 2021). Water, housing, roads, electricity, and health are only a few examples of the specialized sectors that make up urban governance. These organizations typically have few connections, little coordination, and little community involvement. However, in order to effectively implement green and blue infrastructure initiatives and to promote resilient and sustainable urban development, a deeper understanding of urban governance is essential (Bixler et al., 2019). In order to promote sustainability and resilience and ensure that ecological, social, and technical aspects are taken into account holistically, new techniques in urban planning are urgently needed.

4. CONCLUSION

The conceptualization of ecosystems and their functions in urban planning has undergone three major shifts. Historically, urban planning prioritized infrastructure development to address urban challenges, often overlooking the functionality of ecosystems and the provision of ecosystem services. The second shift, emerging in the early 2000s with the Socio-Ecological System (SES) framework, emphasized the importance of considering ecosystem functions to support urban resilience and sustainability. More recently, the Socio-Ecological-Technical Systems (SETS) framework has highlighted the dynamic interconnections among social, ecological, and technical systems. Ecosystem services emerge from these interactions, and a deep understanding of them can guide land use and infrastructure decisions to create urban environments that are resilient, sustainable, and adaptable. Operationalizing ecosystem-based infrastructure requires planning strategies that are flexible, inclusive, and co-produced, integrating social, ecological, and technical considerations.

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