ARCHITECTURAL SCIENCES AND SUSTAINABLE APPROACHES: URBAN RESILIENCE

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Architectural Sciences and Sustainable Approaches: Urban Resilience

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PREFACE

Dear Professors and Colleagues,

We are pleased bring to life that Architectural Sciences and Sustainable Approaches: Urban Resilience, which was published as an e-book by IKSAD Publishing House with the editors Prof. Dr. Ömer ATABEYOĞLU and Prof. Dr. Ertan DÜZGÜNEŞ.

This book project, entitled "Architectural Sciences and Sustainable Approaches: Urban Resilience," aims to address sustainability-oriented approaches to urban resilience from theoretical, methodological, and practical perspectives. The volume seeks to establish a multi-layered platform of discussion, ranging from the scale of individual buildings to the entirety of the urban fabric. Within this framework, it welcomes contributions from scholars and researchers working in architecture, urban design, landscape architecture, urban and regional planning, environmental engineering, and related disciplines.

With the valuable contributions of our chapter authors working in the professional disciplines of landscape architecture, architecture, city and regional planning, urban design and sustainability, we have completed Architectural Sciences and Sustainable Approaches: Urban Resilience book study has been completed with 24 book chapters. We would like to thank you, our esteemed authors, for their contributions to the preparation of the book.

We would also like to thank the editorial board and IKSAD Publishing House. We wish to continue this process we have started in the coming years.

In addition, we would like to express our sincere appreciation to Prof. Dr. Atila GÜL, the book coordinator of IKSAD Publishing House, for his guidance and support throughout the publication process.

We hope that our book '***Architectural Sciences and Sustainable Approaches: Urban Resilience'*** will be helpful to the readers.

Best regards.

15.10.2025

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1. Introduction

The rapid pace of urbanisation, the intensifying impacts of climate change, and the inadequacy of existing infrastructure systems have significantly increased the risks of flooding, particularly in cities experiencing heavy rainfall (Guan, Wang & Xiao, 2021). Under these conditions, redefining the relationship between cities and water and enhancing urban resilience through nature-based solutions has become increasingly critical. In this context, the sponge city approach has emerged as an innovative and integrated model for sustainable urban water management (Sun, Deng, Pan, Chiang, Sable & Shah, 2020). Rather than prioritising the rapid drainage of stormwater from urban surfaces, the sponge city model emphasises the retention, infiltration, groundwater recharge, and reuse of rainwater. Integrated into the urban fabric through nature-based solutions such as permeable landscapes, green roofs, rain gardens, and open drainage infrastructure, this system provides both hydraulic and ecological functions (Chan, Griffiths, Higgitt, Xu, Zhu, Tang, Xu, Yuyao & Thorne, 2018; Guan et al., 2021; Qiao, Liao & Randrup, 2020).

The sponge city concept was first officially introduced into China's policy agenda in 2013, primarily to reduce urban flood risks, improve water quality, and restore urban ecosystems (Zevenbergen, Fu & Pathirana, 2018). This approach treats water not as a threat but as a resource that must be managed and recovered, aiming to align the urban water cycle with natural processes (Yu, 2012; Cosier & Shen, 2009). Components such as rain gardens, permeable surfaces, green roofs, and biofiltration zones constitute the core elements of sponge cities (Xiang, Liu, Shao, Mei & Zhou, 2019). In addressing challenges such as floods and droughts, sponge city initiatives contribute to the creation of more resilient, sustainable, and livable cities while preserving ecosystem services (Esbah, 2021).

While some studies in the literature focus on the hydraulic performance and engineering aspects of sponge city systems (Hou, Guo, Wang, Li, Xue, Liu & Zeng, 2020; Jia, Wang, Zhen, Clar & Yu, 2017; Liv et al., 2017; Xia, Zhang, Xiong, He, Wang, 2017), a substantial portion of the research highlights the multidimensional impacts of the model. Sponge city practices have been evaluated across various domains, including urban planning (Chan et al., 2018; Fang, 2020; Wei, Jiazhuo, Han, Chen, Chunyang, Lian & Jin, 2017), landscape architecture (Jiang, Hua & Shao, 2022; Shi, Li, Shi, Xiu & Chu, 2021; Zhang, 2017), community participation (Chan, Lu, Zhu, Balzan, Pezzoli, Johnson, Zhu, Ruan, Luo, Li & Xu, 2023; Wang, Cai, Zuo, Bartsch & Huang, 2021), policy development (Guo, 2023; Tu & Tian, 2015), and economic sustainability (Liang, 2018; Ma, Liu & Wang, 2023; Zhu, Xu, Yin, Xu, Wu & Jia, 2022). For instance, Li, Zhang & Xie (2019) emphasise that sponge cities not only improve water management but also offer environmental and social benefits such as mitigating the urban heat island effect, supporting biodiversity, and enhancing quality of life. Conversely, Chan et al. (2018) stress the importance of local contextual factors, governance models, and levels of public participation in the successful implementation of sponge city practices.

The application of sponge city models varies across countries depending on climatic, cultural, and institutional contexts. While China has integrated the model into large-scale national urban transformation projects, European countries such as Germany, the Netherlands, and Denmark have incorporated similar practices into their existing green infrastructure policies (Walker, Ashley, Nowell, Gersonius & Evans, 2012). For example, the "Water Squares" initiative in Rotterdam combines public spaces with temporary water storage functions, while Copenhagen integrates flood risk reduction with multifunctional water management strategies (Liao, 2012). These examples demonstrate the adaptability of the sponge city model to local needs and its potential as a flexible and context-sensitive approach.

In the context of Türkiye, studies on sponge cities have typically focused on themes such as climate change, flood risk, and urbanisation (Bayramoğlu & Seyhan, 2022; Kırmızıbayrak, Demircan & Irmak, 2024; Meral, 2025; Tuğaç, 2022; Yörüklü, 2021). The pressures of rapid urban growth, infrastructure deficiencies, and the increasing frequency of flash floods underscore the urgency of adopting this approach in Türkiye (Atar, 2023). Recent flood events in major cities, such as Istanbul, Ankara, and Izmir, have highlighted the inadequacy of current infrastructure in addressing climate-induced disasters (Limoncu & Bayülgen, 2005). However, national policy documents such as the 2023–2027 Strategic Plan and the Climate Change Adaptation Strategy reference green infrastructure and nature-based solutions; a comprehensive framework for implementing these approaches has yet to be established (Republic of Türkiye Ministry of Environment, Urbanisation and Climate Change, 2022).

This study aims to assess the potential of the sponge city approach within Türkiye's urban water management policies by examining the concept's theoretical foundations and international implementation practices. The chapter first outlines the core principles and evolution of the sponge city model, followed by a comparative analysis of practices in China, Europe, and other regions. It concludes with a context-specific model proposal for adapting sponge city strategies to Türkiye's urban planning landscape.

2. Theoretical Framework of the Sponge City Approach

2.1. The Concept of Sponge City and Its Theoretical Foundations

One of the major challenges cities face in the 21st century is the disruption of the natural water cycle due to increasing urbanisation pressures. This disruption leads to a range of multifaceted consequences, including heightened flood risks, water scarcity, ecological imbalances, and infrastructural deficiencies (Zha, Luo, Zhu, Wang, Lyu, Zhou, ... & Wang, 2021). In particular, the rise in sudden and intense precipitation events associated with climate change has exacerbated urban flooding in areas dominated by impervious surfaces, straining the resilience capacities of cities. The sponge city approach has emerged in this context as a contemporary urban water management model that aims to reconfigure the relationship between cities and water through a nature-based paradigm (Sun et al., 2020). Its core principle is not the rapid discharge of stormwater, but its on-site retention, filtration, and reuse (Yin, Xu, Jia, Yang, Sun, Wang & Liu, 2022). This approach views water not as a threat, but as a fundamental component of the urban ecosystem. Sponge cities are envisioned as ecological systems that can "absorb, retain, process, and release water when needed" (Li et al., 2019).

Through large-scale Sustainable Drainage Systems (SuDS), this model mimics the natural water cycle by absorbing, storing, and reusing stormwater. Unlike the conventional approach, where stormwater is rapidly transported via expanding pipe networks to watercourses, the sponge city model emphasises source control through nature-based techniques (Green Blue Urban, 2025). As a result, it fundamentally transforms both the planning logic and water management practices of urban landscapes.

The institutionalisation of the sponge city model began in China in 2013, when it was integrated into national urban development policies. However, its intellectual roots trace back to earlier approaches such as Low Impact Development (LID) and Green Infrastructure, which emerged in the late 20th century (Chan et al., 2018). Central to the sponge city paradigm are principles such as the reconstruction of the hydrological cycle within urban environments, biomimicry of natural processes, and the restructuring of the human-nature interface in cities. Accordingly, sponge cities are not merely technical infrastructure projects but comprehensive urban strategies that require rethinking landscape design, spatial planning principles, and modes of civic participation (Nguyen, Ngo, Guo, Wang, Ren, Li, Ding & Liang, 2019).

This approach rests upon a multi-layered theoretical foundation informed by diverse disciplines. It draws from the literature of ecological modernisation, systems theory, urban ecology, and resilience. The theory of ecological modernisation emphasises the role of technological innovation, planning reform, and development aligned with ecological principles in addressing environmental challenges (Mol & Sonnenfeld, 2000). In this regard, sponge cities are positioned as modern planning strategies that integrate ecological sustainability into urban infrastructure. By reducing environmental risks through nature-based solutions and enhancing the quality of life, sponge cities directly align with the objectives of this theory.

From an urban ecology perspective, cities are understood not only as human-made constructs but as bio-physical systems shaped by interactions between water, soil, air, and living organisms. The sponge city model operationalises this perspective by ensuring the cyclical management of surface water, rainfall, and groundwater as components of the urban ecosystem (Pickett, Cadenasso & Grove, 2004). Systems theory and the adaptive governance of urban systems offer valuable conceptual tools for understanding the complex, multi-actor structures that define sponge cities. When cities are conceptualised as interwoven systems composed of infrastructure, ecology, economy, and society, the need for integrated, flexible, and adaptive responses becomes apparent. Sponge cities reflect this by reimagining cities not merely as conduits for water but as dynamic, regenerative systems capable of managing water intelligently (Chester & Allenby, 2019).

The concept of resilience is another foundational pillar of the sponge city model. In light of the growing intensity of climate-related hazards, such as floods, droughts, and extreme weather, sponge cities serve not only as tools for risk mitigation but also as strategic frameworks for urban adaptation and climate resilience (Ahern, 2011).

The sponge city model consists of a wide array of technical and planning components. These include the expansion of permeable surfaces, green roofs and walls, bioswales, rain gardens, rainwater harvesting systems, water-retentive parks, green corridors, and open-channel drainage infrastructure (Zhou, 2014). These systems can be implemented at both central (e.g., watershed-level) and local (e.g., household-level) scales. This multi-scalar structure enhances the model's adaptive capacity, setting it apart from conventional water management systems. Decentralised, nature-compatible, and contextually flexible solutions-such as water retention, delay, filtration, and reuse-constitute the core operational principles of sponge cities (Chan et al., 2018).

By moving beyond traditional engineering paradigms, the sponge city model integrates nature-based infrastructure with participatory governance mechanisms and social awareness components. For the model to be implemented effectively, it requires the coordinated functioning of its physical, administrative, ecological, and societal dimensions (Table 1).

Table 1. Core components of the sponge city model (Guan et al., 2021; Luan, Yin, Xu, Wang, Yang, Zhang & Tang, 2019; Nguyen, Ngo, Guo & Wang, 2020; Xiang et al., 2019; Yang, Xu & Shi, 2017; Zhao, Gao & Zuo, 2019)

Component Type	Subcomponents	Description
Physical	Green roofs Permeable pavements Rain gardens Water-retaining parks Open drainage systems	Nature-based physical infrastructure elements that enable the absorption and storage of rainwater.
Managerial	Integrated urban water management Disaster risk management Institutional cooperation Financing and incentive models	Strategic governance and inter-agency coordination in planning, regulation, and resource utilisation processes.
Ecological	Ecosystem services Biodiversity support Soil permeability Microclimate regulation	Support for the natural water cycle through the strengthening of urban ecosystems and the enhancement of climate adaptation capacity.
Social	Participatory planning Community awareness Educational programs Urban quality of life	Public acceptance of the sponge city approach ensures sustainability and promotes social inclusiveness.

Physical components such as green roofs, permeable surfaces, and open drainage systems enable effective stormwater management through nature-based solutions. However, these structural interventions yield sustainable outcomes only when supported by administrative coordination, ecological balance, and public participation. The components presented in Table 1 demonstrate that the sponge city model must be integrated not only technically but also in managerial, environmental, and social dimensions. Such a holistic structure aims to enhance urban resilience against challenges such as climate change, flood risk, and water scarcity.

2.2. Thematic Dimensions of Sponge City Practices

The sponge city approach is not merely a physical infrastructure design, but a multidimensional proposal for transforming urban systems. Within this framework, sponge city practices can be analysed under four main thematic dimensions: urban planning, water management and climate change adaptation, public participation and governance, and ecological and technological components. This thematic structure enables a comprehensive evaluation of the sponge city model, encompassing not only its technical infrastructure but also its administrative and social dimensions.

First, in the context of urban planning, the sponge city approach is directly related to decisions on site selection, land use, and the planning of open and green spaces. While conventional planning paradigms often increase the prevalence of impervious surfaces, sponge city planning promotes a morphological structure that protects the natural water cycle and manages water at its source (Ma et al., 2023). In this regard, physical strategies such as permeable surfaces, multifunctional parks, and stormwater corridors are integrated into land use plans, and new planning tools are developed in alignment with the topographic and hydrological characteristics of urban areas (Chan et al., 2018). This makes the spatial integration of sponge city principles particularly imperative in rapidly urbanising regions.

Second, water management and climate change adaptation, central pillars of the sponge city model, are critical components that determine the model's sustainability and functionality. Sponge city practices rely on integrated processes such as on-site water retention, filtration, and reuse, rather than traditional drainage systems. The underlying objective is to redefine rainwater as a "resource" rather than a "waste" product. Additionally, these practices provide multiple benefits, including flood risk reduction during extreme rainfall events, mitigation of the urban heat island effect, and the replenishment of groundwater resources (Qiao et al., 2023). As such, sponge cities have become key instruments in climate change adaptation policies, especially in areas such as disaster risk management, drought mitigation, and microclimate regulation.

Third, the dimension of public participation and governance represents the social foundation for the success of sponge city initiatives. The effective operation of technical infrastructure depends not only on engineering solutions but also on the inclusion of the public in decision-making processes, the incorporation of local knowledge, and the implementation of awareness-raising practices (Chan et al., 2018). Participatory planning enables micro-scale interventions at the neighbourhood level, facilitating the development of solutions that are more responsive to local needs. Moreover, educating and engaging citizens on individual practices, such as water conservation, the use of permeable materials, and rooftop gardens, is essential for widespread behavioural change and long-term success.

Ultimately, both ecological and technological components support the nature-based structure of sponge cities, thereby enhancing their overall performance. The sponge city approach actively utilises ecosystem services, such as natural filtration, carbon sequestration, and biodiversity support, while also integrating innovative technologies to strengthen monitoring, control, and assessment mechanisms. For example, sensor-based water level monitoring systems, smart drainage infrastructure, and satellite-assisted land permeability mapping technologies enhance the efficiency of sponge city infrastructure and optimise maintenance processes (Zevenbergen et al., 2018). From an ecological perspective, elements such as green roofs, bio-retention ponds, and urban wetlands function not only as water-absorbing systems but also as integral parts of urban ecology. These four thematic dimensions demonstrate that sponge city practices are not merely physical interventions, but also governance, ecological, and societal transformation strategies

3. Advantages and Challenges of the Sponge City Approach

The sponge city approach stands out as an innovative model offering comprehensive solutions to contemporary urbanisation challenges through its multifaceted environmental, social, and economic benefits. This model makes a significant contribution to addressing critical urban issues, including climate change, flood risks, and the sustainable management of water resources. However, despite its potential, the implementation of sponge cities is not without challenges; it faces various technical, institutional, and societal obstacles. Therefore, for this approach to be implemented effectively and sustainably, it is essential to evaluate not only its strengths but also the structural and contextual difficulties it entails.

Sponge city systems offer an effective method for mitigating flood risks by controlling surface runoff at its source. Through permeable surfaces, rain gardens, bio-retention basins, and green roofs, water is absorbed into the soil, thereby reducing runoff and relieving pressure on conventional drainage systems (Chan et al., 2018). For instance, in China's pilot sponge cities, surface runoff has been reduced by up to 70%, resulting in a significant decline in urban flood incidents. These practices aim to restore the disrupted urban hydrological cycle by retaining, filtering, and reusing rainwater instead of discharging it. This not only enhances groundwater recharge but also reduces reliance on greywater systems, offering great potential especially for water-stressed cities (Zevenbergen et al., 2018).

Green infrastructure elements not only serve water management functions but also contribute to urban ecological vitality. Vegetated surfaces, wetlands, and urban waterways provide microhabitats that support biodiversity. These areas also function as carbon sinks, improve air quality, and mitigate the urban heat island effect by reducing ambient temperatures (Kabisch, Qureshi & Haase, 2015). Additionally, they serve as recreational spaces, enhancing the quality of life for urban residents. Given their modularity, flexibility, and adaptability to local conditions, sponge city systems strengthen urban resilience and offer a long-term solution to climate-related challenges (Chester & Allenby, 2019). Unlike traditional engineering approaches, sponge city projects create visible and publicly accessible spaces, fostering community awareness and offering educational opportunities regarding the role of water in urban life. When supported by participatory planning processes, these interventions strengthen social inclusiveness and emphasise the social dimension of sustainability (Wong & Brown, 2009).

Nonetheless, sponge city implementations face significant physical constraints, especially in densely built urban environments. Key barriers include limited available space, incompatibility with existing infrastructure systems, and the resistance of the ageing urban fabric to transformation (Zhou, 2014). Moreover, the long-term maintenance requirements and environmental sensitivity of permeable surfaces increase the technical complexity of these systems. Sponge cities are complex systems requiring multi-actor governance rather than purely physical infrastructure. In many countries, urban water management responsibilities are dispersed across different institutions, resulting in unclear mandates, a lack of coordination in planning processes, and implementation delays (Liu & Fan, 2023). Ensuring sustainability in implementation requires integrated governance models and the strengthening of local institutional capacity.

While nature-based solutions offer long-term economic benefits, their initial capital investment and maintenance costs are relatively high. In low-income areas, the limited financial resources of local governments often hinder the sustainable management of such projects (Chester & Allenby, 2019). Additionally, insufficient incentive mechanisms restrict private sector participation and make large-scale adoption more difficult. The success of sponge city projects depends on the degree to which communities adopt and integrate them into their daily practices. However, public awareness of these systems remains limited in many urban contexts.

The exclusion of communities from the process diminishes social acceptance and undermines long-term sustainability (Wong & Brown, 2009). Education programs, awareness campaigns, and participatory planning tools are therefore critical to addressing this gap.

For sponge city systems to function effectively, regular monitoring, maintenance, and performance evaluation processes must be established. Yet, in many cases, these mechanisms are not institutionalised, and standardised criteria or indicators for measurement are lacking (Zhou, 2014). This makes it challenging to assess project outcomes and limits the availability of evidence-based information for decision-makers.

In summary, while the sponge city model presents a wide array of advantages, such as environmental sustainability, climate change adaptation, enhancement of ecosystem services, and social benefits, these are often counterbalanced by technical, governance-related, and financial challenges during implementation. Most obstacles stem from structural constraints and gaps in institutional capacity. Nevertheless, these issues are surmountable through well-designed policies, institutional alignment, and participatory planning practices.

4. A Global Assessment of Sponge City Practices

The rapid pace of urbanisation has made the control of surface runoff and the management of stormwater increasingly critical. In this context, a range of solutions developed across different countries, often under varying terminologies and implementation frameworks, have contributed to both improving the urban water cycle and mitigating the adverse effects of climate change. These practices aim to reduce surface runoff and promote on-site water management through components such as permeable surfaces, green infrastructure elements, and rainwater harvesting systems. The strategies adopted in different national contexts vary considerably in terms of implementation scope, effectiveness, and future objectives (Table 2).

Table 2. A comparative analysis of sponge city and stormwater management practices at the international scale (Greening Solution, 2024)

Country	Terminology	Project Area (km²)	Surface Runoff Reduction Rate
China	Sponge City	4,500	70%
United States	Green Infrastructure, Low Impact Development (LID)	Not Specified	85% (Philadelphia)
United Kingdom	Sustainable Urban Drainage Systems (SUDS)	Not Specified	30% (London)
Germany	Stormwater Management	Not Specified	40% (Hamburg)
Singapore	ABC Waters	200	30%
Japan	Stormwater Management, Uchimizu	Not Specified	20% (Tokyo)
South Korea	Stormwater Management System	Not Specified	25% (Seoul)
China	Permeable pavements, green roofs, rain gardens	Achieve sponge functions in 70% of urban areas by 2030	
United States	Green roofs, rain gardens, and permeable pavements	Increase policy and funding support, expand implementation areas	
United Kingdom	Wetlands, rain gardens, green roofs	Expand use of SUDS technology in urban development	
Germany	Green roofs, infiltration systems, stormwater harvesting systems	Enhance research and application, promote ecological management	
Singapore	Stormwater harvesting systems, wetlands, and bioretention ponds	Continue the ABC Waters program, strengthen governance	
Japan	Rainwater storage tanks, infiltration systems, and green infrastructures	Develop and implement technology	
South Korea	Green roofs, rain gardens, and permeable pavements	Strengthen research and application, promote sustainable development	

China's Sponge City Program stands out as the most comprehensive and ambitious initiative in terms of project scope and strategic objectives, aiming to establish sponge functionality across 70% of urban areas by

2030. In the United States, the Low Impact Development (LID) approach has been adopted, achieving up to an 85% reduction in surface runoff in cities such as Philadelphia. However, these implementations have mainly remained limited to the local level. Although the United Kingdom and Germany have expanded green infrastructure strategies, their implementation scale and impacts have been more modest, yielding approximately 30% runoff reduction in London and 40% in Hamburg. In Asia, countries such as Singapore, Japan, and South Korea have developed smaller-scale, technology-oriented solutions, achieving runoff reductions of 20-30% through rainwater harvesting, wetland restoration, and green infrastructure interventions. Overall, sponge city practices vary significantly depending on national water management policies, local climatic conditions, institutional capacities, and levels of urbanisation. A common feature of successful cases is the integration of nature-based solutions with institutional support and long-term planning. This highlights the importance of implementing the sponge city approach in a multi-actor, context-sensitive, and spatially integrated manner within urban planning processes.

5. Evaluating the Sponge City Approach within the Context of Türkiye

5.1. Current Policies and Regulations in Türkiye

In Türkiye, the applicability of the sponge city model has gained increasing significance in recent years within the framework of national policy documents and institutional structures that have been shaped around climate change, disaster risk management, and sustainable urbanisation. The Climate Change Adaptation Strategy and Action Plan (2023-2027), published by the Ministry of Environment, Urbanization and Climate Change, provides a direct foundation for the sponge city approach by setting objectives such as the expansion of nature-based solutions in cities, increasing permeable surfaces, and enhancing the resilience of urban infrastructure to climate change (MoEUCC, 2022). In particular, the need to scale up green infrastructure in flood-prone areas and integrate stormwater management systems is emphasised.

Türkiye's 11th and 12th Development Plans also identify sustainable urbanisation, nature-based solutions, and climate-resilient infrastructure as key policy priorities. The 12th Development Plan (2024-2028) highlights a "green development" paradigm and sets targets for promoting green infrastructure practices and rainwater harvesting systems in urban areas (Presidency of Strategy and Budget, 2023). These development plans thus offer a framework for integrating sponge city components into national planning, investment, and legal structures.

Following Türkiye's ratification of the Paris Agreement, the Updated Nationally Determined Contribution (NDC, 2023) and the draft Climate Law currently under preparation also support the sponge city model through objectives such as water management, green infrastructure, increased permeability, and disaster risk reduction. These policy documents clearly state that nature-based solutions must be supported not only from a technical standpoint but also through institutional, financial, and administrative mechanisms.

The Spatial Strategy Plan (2053) outlines a long-term urbanisation vision aimed at building resilient cities. It directly references the sponge city approach through objectives such as restructuring the urban water cycle, managing water at its source, and integrating green-blue infrastructure networks (MoEUCC, 2023). Similarly, the Rainwater Harvesting Guide Document (2022) is regarded as an initial step toward the technical and structural transformation required to recognise rainwater as a valuable resource rather than as waste.

Meanwhile, water policies in Türkiye have evolved in parallel with international developments. Influenced by global frameworks such as the Rio Summit (1992), World Water Forums (1997–present), and the EU Water Framework Directive (2000/60/EC), Türkiye has adopted a basin-based and multi-stakeholder approach to water governance. Public institutions such as the Ministry of Agriculture and Forestry, the General Directorate of State Hydraulic Works (DSİ), and the General Directorate of Water Management play key roles in water governance. At the same time, think tanks like SUEN contribute to policy development. Through basin-level and provincial coordination mechanisms, localised water governance is increasingly feasible.

Despite these advances, integration of water policy with urban planning and design remains limited in Türkiye. Nature-based solutions are not yet clearly defined within the current legal framework, and the long-pending Water Law Draft, which has been under development since the 1990s, has yet to be enacted (Tunçay, 2022). This legal gap represents a critical opportunity to establish a robust regulatory foundation for implementing the sponge city model.

According to the Falkenmark Index, Türkiye is a water-stressed country. While the annual per capita water availability was 1,652 m^3 in 2000, this figure declined to 1,346 m^3 in 2020 and is projected to fall to 1,120 m^3 by

2030 (ATB, 2021). This trend highlights the urgent need to manage both rainwater and greywater as valuable urban resources through nature-based solutions (Esbah, 2021). In alignment with this necessity, TARAP (2022) recommends adopting risk-based, preventive, and nature-based strategies in urban planning.

Nevertheless, current technical regulations are still heavily reliant on grey infrastructure solutions. Legislative documents, such as the Regulation on Rainwater Collection, Storage, and Discharge Systems (2017) and the Regulation on Wastewater Collection and Disposal Systems (2017), do not adequately incorporate nature-based approaches. Although a 2021 amendment to the Zoning Regulation made rainwater harvesting systems mandatory for parcels over 2,000 m², broader dissemination of these systems and their integration with green infrastructure remain necessary.

Moreover, protective regulations for urban streambeds under the İSKİ Law have proven insufficient. For example, the reduction of stream buffer zones from 100 meters to 10 meters in 2013 and the physical alteration of 64% of streambeds in Istanbul necessitate a re-evaluation of current protection strategies (Tunçay, 2022). In summary, while strategic and institutional developments in Türkiye increasingly support the transition to sponge cities, updating legal frameworks, integrating nature-based solutions into planning systems, and strengthening the implementation capacity of local governments remain essential.

5.2. Urban Water Management in Türkiye and the Need for the Sponge City Approach

Türkiye is among the countries where the impacts of climate change are being experienced with increasing frequency and severity, while rapid urbanisation continues to exert growing pressure on the natural water cycle. In recent years, particularly in major metropolitan areas, sudden and intense rainfall events have highlighted the inadequacy of existing urban infrastructure in coping with such extreme weather conditions. The increasing proportion of impervious surfaces, urban development in streambeds, insufficient drainage systems, and disruptions to the natural flow of water have collectively rendered cities highly vulnerable to flooding with almost every rainfall event.

This situation not only causes physical damage but also leads to loss of life, destruction of infrastructure, economic losses, and heightened social vulnerability. Current urbanisation and water management policies are insufficient to mitigate these risks. Thus, there is a pressing need for a new paradigm in which water is regarded not as a threat, but as a natural asset that must be managed sustainably. Within this context, the sponge city model, centred around nature-based solutions and on-site water management, offers a strategic alternative for building flood-resilient cities in Türkiye. To better understand the urgency of this need, it is necessary to examine recent flood and inundation events that have occurred across Türkiye in recent years (Figure 1).

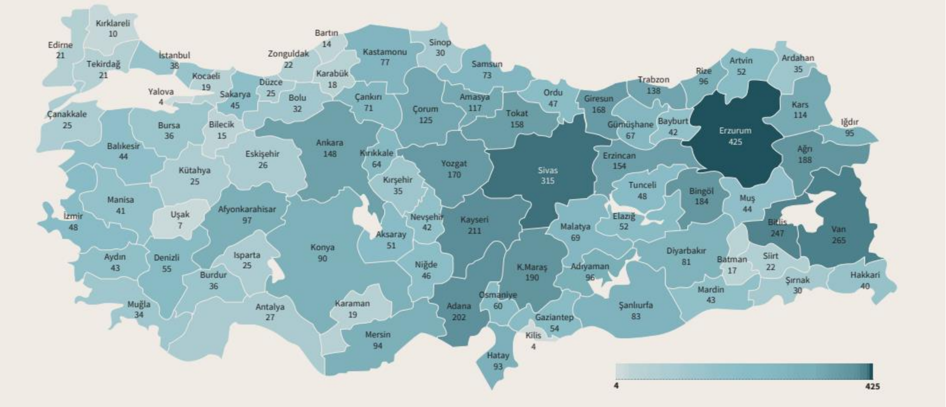

Figure 1. Provincial Distribution of Flood and Inundation Events in Türkiye (AFAD, 2018)

In Türkiye, floods and inundations predominantly occur as a result of the overflow of rivers and streambeds, typically triggered by natural phenomena such as sudden and intense rainfall or snowmelt. However, human-induced interventions-particularly the misuse of stream corridors through unplanned urbanisation, construction, landfilling activities, and alteration of natural watercourses-significantly exacerbate flood risks. In mountainous regions, floods may also lead to secondary hazards such as landslides, posing serious threats to settlements located on mountain slopes. Additionally, though less frequent, hydrological events such as lake overflows driven by atmospheric conditions or tsunamis in coastal zones can also constitute localised flood threats. An analysis of the spatial distribution of flood and inundation events since 1950 indicates that provinces such as Erzurum, Sivas, Van, and Bitlis are among the most affected. In contrast, incidents in provinces like Uşak, Kilis, and Yalova have been relatively rare. Overall, a geographic trend reveals a higher frequency of flood events toward the eastern and northern regions of the country.

5.3. A Contextualised Sponge City Model for Türkiye

In recent years, the combination of sudden and intense precipitation events, inadequate infrastructure systems, and rapid, unplanned urbanisation has significantly increased flood risk in Türkiye-particularly in major metropolitan areas, while simultaneously undermining urban resilience capacities. Urban flooding incidents in cities such as Istanbul, Ankara, Izmir, and Bursa are not solely the result of infrastructural deficiencies; they are also driven by the expansion of impervious surfaces and the disruption of the natural water cycle. As a nature-based and sustainable approach capable of addressing these challenges, the sponge city model holds strategic potential for integration into Türkiye's urban water management policies. However, the model's applicability must be assessed within a multi-layered framework involving local government capacities, spatial planning practices, public awareness levels, and legal-institutional compatibility.

The proposed sponge city model for Türkiye should be structured around three core dimensions: spatial and morphological adaptation, governance integration, and community engagement and awareness.

First, concerning spatial and morphological adaptation, sponge city interventions must be designed in harmony with local topography, climate conditions, soil characteristics, and existing infrastructure systems. In this context, areas with high rainfall levels, such as the Black Sea coastal region, as well as metropolitan zones and rapidly growing secondary cities (e.g., Kocaeli, Antalya, Gaziantep), may be designated as priority pilot areas. In these locations, increasing permeable surface coverage, developing water-retentive parks, and integrating open drainage systems into urban design are essential. Sponge infrastructure criteria should be incorporated into urban regeneration projects, and mandatory standards for sponge city components should be introduced in zoning and land-use planning processes to ensure institutionalisation.

Second, governance integration is crucial to the success of sponge city applications, particularly given Türkiye's fragmented and multi-actor institutional landscape. Currently, stormwater management, infrastructure services, green space planning, and disaster risk reduction are carried out by different public institutions with limited horizontal and vertical coordination. Therefore, a centralised strategic framework should be developed to guide the planning and implementation of sponge city initiatives at the local level. Institutional cooperation protocols must be established among the Ministry of Environment, Urbanisation and Climate Change, local municipalities, water and sewerage authorities, and disaster response agencies such as AFAD. Furthermore, enhancing the technical capacities of municipalities, introducing financial incentive mechanisms, and establishing dedicated funding for sponge infrastructure investments would facilitate the dissemination of the model.

Third, the applicability of the sponge city model in Türkiye must also be approached from a societal perspective, just as a technical or administrative issue. The lack of public awareness regarding rainwater management, green infrastructure, and the role of permeable surfaces may hinder the social acceptance and long-term sustainability of nature-based practices. Accordingly, public education campaigns, neighbourhood-scale participatory design workshops, and awareness programs focused on sustainable water use should be considered integral components of the model. Universities, professional chambers, and civil society organisations should be actively involved in the process to foster knowledge exchange between scientific research and local experience.

The proposed sponge city model, which integrates all these components, holds both risk-reduction and resource-conversion potential for Türkiye. Transforming rainwater from a waste product into a valuable element of an integrated urban water cycle; reimagining green infrastructure as not only aesthetic but also functional and resilience-enhancing; and integrating planning, infrastructure, and governance into a multi-level, coordinated system constitute the foundational principles of this model. It should not only be tailored for large metropolitan areas but also offer scalable, flexible, and context-sensitive solutions for small and medium-sized cities experiencing water stress. For the successful implementation of sponge city practices in Türkiye, pilot cities should be selected based on diverse climate zones, risk profiles, and socioeconomic conditions (Table 3).

Table 3. Proposed cities for pilot sponge city implementation in Türkiye

Country	Justification	Implementation Priority
İstanbul	High urban density, infrastructure stress, and elevated flood risk	Permeable surfaces, rainwater harvesting, and green roofs
Trabzon	Black Sea climate, sudden precipitation events, and landslide susceptibility	Vertical water management and open-channel drainage systems
Konya	Arid climate conditions and declining groundwater levels	Water-retentive open spaces, harvesting, and reuse strategies
Antalya	Tourism-driven pressure, water scarcity, and coastal vulnerability	Sustainable water planning through nature-based solutions

Gaziantep	Rapid urban growth, urban heat island effect, and unregulated development	Integration of green infrastructure and microclimate regulation
Eskişehir	Planned urban structure and a high concentration of student population	Community engagement and campus-scale sponge city interventions

The successful implementation of the sponge city approach in Türkiye depends not only on physical infrastructure investments but also on aligning existing planning, permitting, and infrastructure regulations with this new paradigm. In this regard, a comprehensive restructuring of legal, administrative, and institutional frameworks is essential.

First, integrating sponge city principles into urban planning processes would facilitate a transformative shift in spatial decision-making. It is crucial to establish minimum permeability standards in master and detailed development plans and to incorporate parks, green areas, and neighbourhood-scale rainwater collection zones as core planning elements. Furthermore, the mandatory inclusion of water-retentive infrastructure in zoning plan notes would guide local planning practices in line with the objectives of sponge cities. Such regulatory amendments should be prioritised, particularly in areas at high risk of natural disasters.

Second, revising building permit procedures to include rainwater management criteria would ensure that individual buildings contribute to the broader sponge city system. The promotion, and in certain zones, the requirement of interventions such as green roofs, permeable paving materials, and rainwater harvesting tanks in new constructions would help scale up sustainable water management at the building level. These practices should be integrated into the building inspection system through enforceable technical standards, and municipalities should be granted both inspection authority and support mechanisms in this regard.

Third, updates to existing stormwater and infrastructure legislation are required to standardise and expand technical implementation. While current regulations constitute important steps in urban water management, they do not yet comprehensively reflect the core principles of the sponge city model. Therefore, more detailed legal frameworks are needed for practices such as permeable surfaces, nature-based solutions, open-channel systems, and rainwater harvesting. Additionally, updating standardised technical drawings and implementation catalogues used in infrastructure projects would further reinforce implementation capacity.

Another key area of reform involves aligning urban transformation legislation with the principles of sponge cities. Urban renewal projects offer a unique opportunity to redesign the physical environment. In this context, it is imperative to incorporate nature-based solutions and urban water management components into compulsory transformation initiatives in disaster-prone areas. The integration of sponge infrastructure into urban renewal would serve the dual purpose of enhancing environmental sustainability and reducing disaster risks.

Furthermore, the establishment of financial and administrative incentive mechanisms is a necessary complement to legal reform and a crucial element for implementation. Central government support programs targeting municipalities that implement sponge city projects should be structured through dedicated financing channels, such as those managed by İLBANK or the Turkish Environment Agency. They may include low-interest loans, grants, or earmarked funds. Legal provisions that support such financial incentives would directly enhance the implementation capacity of local governments. In parallel, tax regulations and public-private partnership models should be developed to encourage private sector investment in sponge city initiatives.

Finally, a robust legal infrastructure is also necessary in areas such as education, capacity building, and data governance. Certified training programs for municipal staff and relevant professional groups should be made mandatory by regulation to ensure the quality of implementation. Intelligent infrastructure systems that facilitate the monitoring of variables such as precipitation, surface runoff, and groundwater levels should be promoted. Data sharing should be conducted via open-data digital platforms to ensure transparency and coordination.

In conclusion, the sponge city model to be developed for Türkiye must serve not only as a tool for climate change adaptation, but also as an integrated strategy for sustainable urbanisation, disaster risk reduction, water resource conservation, and enhancement of urban quality of life. When considered alongside the proposed conceptual framework, pilot implementation areas, and corresponding legal and institutional arrangements, the practical feasibility of the model would be significantly strengthened.

6. Conclusion and Policy Recommendations

In today’s urban landscape, where multidimensional challenges such as rapid urbanisation, climate change, natural disaster risk, and resource scarcity increasingly intersect, strengthening the environmental, social, and infrastructural resilience of cities has become imperative. This requires the development of technical and managerial approaches that are aligned with the Sustainable Development Goals. Within this context, the sponge city approach offers a comprehensive model that redefines water as a valuable resource rather than waste, integrating nature-based solutions into urban infrastructure.

International case studies demonstrate that although the sponge city model operates within a universal framework, it can be flexibly adapted to suit local conditions. Sponge city practices in countries such as China, Germany, the Netherlands, Denmark, the United States, and Australia have been shaped by varying implementation scales, governance structures, and technical components. This comparative analysis allows for the formulation of a localised sponge city model tailored to Türkiye's climatic, geographical, and institutional context. The increasing frequency of floods, declining water resources, and mounting urbanisation pressures in recent years indicate that sponge city principles are no longer optional but a necessity in Türkiye.

However, the model's applicability goes beyond technical interventions. It necessitates a multi-layered strategy that includes regulatory reform, institutional coordination, and community engagement. To strengthen the viability of the sponge city approach in Türkiye, the following policy recommendations are proposed:

- Development of a National Strategic Framework: A National Sponge City Strategy Document should be prepared under the leadership of the Ministry of Environment, Urbanisation and Climate Change. This document should define technical standards, planning principles, and sectoral integration strategies, and be aligned with the Climate Change Adaptation Strategy and Action Plan, the Spatial Strategy Plan, and national development plans.

- Strengthening Local Government Capacity: Dedicated financing mechanisms should be established to enhance the technical and financial capacities of municipalities (e.g., İLBANK loans, environmental grants, a Sponge Infrastructure Fund). Certified training programs and practical guidebooks should be developed for municipal staff to ensure they acquire the institutional capacity to plan, implement, and monitor sponge city initiatives effectively.
- Integration into Planning and Permitting Processes: It should be made mandatory to include green/blue infrastructure components, such as minimum permeability standards, rainwater collection zones, and open drainage systems, in master and implementation plans. Building permit procedures should incorporate green roofs, rainwater harvesting, and on-site storage systems as standard requirements. These interventions must also be subject to sustainable compliance through the building inspection system.
- Regulatory Updates: Urban stormwater and infrastructure regulations should explicitly define sponge city components and include technical standards for solutions such as permeable paving materials, biofiltration systems, and rain gardens. Nature-based solutions should be mandated in urban transformation projects, especially in areas at risk of disasters, to promote the widespread adoption of sponge city practices.
- Designation of Pilot Implementation Areas: Sponge city practices should be tested in cities with diverse climatic and socio-spatial

characteristics. For instance, pilot projects in Istanbul could focus on increasing permeable surface coverage, in Konya on water collection and reuse, in Trabzon on flood risk management, and in Antalya on integrating water efficiency with aesthetic values. This diversity will help test the model's scalability and adaptability.

- Enhancing Public Awareness and Participation: Sponge city initiatives are not merely engineering projects but also processes of social learning. Public awareness campaigns should be conducted to inform citizens about the urban water cycle, permeable surfaces, and nature-based solutions. Participatory design workshops at the neighbourhood level should be encouraged. Universities, professional chambers, and civil society organisations should play an active role in this process to bridge scientific knowledge with local needs.
- Establishing Data-Driven Monitoring and Evaluation Systems: To assess the performance of sponge city interventions, environmental indicators such as precipitation, surface runoff, and groundwater levels should be monitored via digital platforms. Smart sensors, Geographic Information Systems (GIS), and remote sensing technologies should be utilised as primary tools, and data should be shared with the public through open-access platforms.

This comprehensive policy framework positions the sponge city approach not only as an environmental intervention but as a broader strategy for administrative, spatial, and social transformation in Türkiye. By adapting the model to its local context, Türkiye can take a concrete and practical step toward both mitigating climate change and promoting sustainable urban development. Embedding nature-based solutions into everyday urban life will not only help reduce current risks but also play a formative role in shaping the cities of the future.

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Designing Child-Friendly Urban Resilience: Seasonal Strategies for Public Playgrounds

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1. Introduction

The urgent climate agenda, increasing urbanization, and urban inequalities are making risks such as thermal stress, air quality, flooding, and icing, which directly affect children's daily lives, more visible in public spaces. Playgrounds, as one of the places where these risks are felt earliest and most intensely, are at the center of the child-friendly urban resilience debate. In this context, our conceptual framework is based on an interdisciplinary approach that combines children's rights, public health, and urban design; the aim is to provide an evidence-based starting point for how climate-resilient, inclusive, and year-round public children's playgrounds can be designed and operated.

The concepts of child-friendly cities and urban resilience have gained increasing significance, particularly in the design of public play environments. Research indicates that outdoor play is essential for children’s physical, social, and cognitive development, and that prioritizing children’s needs in urban planning can enhance both child well-being and the overall resilience of cities (Askew, 2018; Brown et al., 2019; Elshater, 2018; Geddes, 2021; Jansson et al., 2022; Krishnamurthy, 2019). Seasonal variations directly influence the usability and safety of play areas; therefore, the development of season-responsive strategies is necessary to ensure that such spaces remain accessible and safe throughout the year (Bäckström et al., 2023; Cherian & Subasinghe, 2022; Kennedy et al., 2021; Qi et al., 2022; Vanos et al., 2016). Recent studies emphasize the positive impacts of shading solutions, the integration of natural elements, and biophilic and nature-based design approaches on children’s health and play experiences (Bäckström et al., 2023; Brussoni et al., 2017;

Flax et al., 2020; Russo & Andreucci, 2023; Vanos et al., 2016). Furthermore, social factors such as inclusivity, accessibility, and children's active participation emerge as critical determinants for ensuring that play areas are sustainable and resilient (Derr & Tarantini, 2016; Jansson et al., 2022; Jian et al., 2025; Moore et al., 2020, 2022).

In establishing this framework, two critical research and practice gaps are identified. First, seasonality is predominantly conceptualized as a matter of "maintenance scheduling" in most contemporary applications, rather than as an integral parameter in design decision-making. Second, there is a notable methodological limitation in simultaneously evaluating surface materials, shading typologies, and vegetative layering across different climatic contexts (cold, hot–dry, and hot–humid) in conjunction with considerations of child ergonomics and safety. Addressing these deficiencies requires the systematic integration of microclimatic indicators—such as heat accumulation, ultraviolet radiation exposure, wind comfort levels, drainage performance, and icing potential—into the pre-design phase. This expanded approach moves beyond equipment specification alone, emphasizing the interplay between shading strategies and geometric configuration, the relationship between permeability and water management, the strategic use of windbreak vegetation, the preferential selection of deciduous species to optimize solar gain during winter, and the implementation of multi-layered design solutions aimed at mitigating urban heat island effects during summer.

Findings indicate that climate-related demands, which vary throughout the year, play a decisive role in determining both the usage patterns and safety of playgrounds. The frequency and nature of playground use change significantly with the seasons, as seasonal variations directly influence their usability and safety. Consequently, it is essential to develop season-responsive strategies that ensure playgrounds remain accessible and safe throughout the year. However, current playground designs often fall short in addressing climatic demands, resulting in lower quality and user-unfriendly features. Adverse weather conditions—such as reduced daylight hours, sub-zero temperatures, wind, rain, and snow during winter—not only affect the physical condition of playgrounds but also limit their usability. During these periods, maintenance activities may be reduced, and fixed equipment surfaces can become slippery, increasing the risk of accidents (Soini et al., 2025). Caregivers, who prioritize protecting children from harm, view meteorological changes as a significant concern (Silver et al., 2014). Since children tend to have more frequent contact with surfaces and experience changes in body temperature more rapidly than adults, factors such as the contact temperature and handle thickness of playground equipment become critical for ensuring safety (Vanos et al., 2016).

Conceptually, child-friendly urban resilience encompasses more than disaster preparedness; it integrates spatial justice, health equity, and ecological integrity to safeguard the right to play year-round. The primary target group of this study comprises children aged 0–14 who utilize public playgrounds, as well as the accompanying adults. The scope is limited to open-space public play areas, with the objective of generating strategies adaptable to diverse climatic contexts. Within this framework, the study establishes a comprehensive content map that spans design principles, material and surfacing strategies, planting and biophilic interventions, shading typologies, water and snow management approaches, accessibility and inclusive-use scenarios, as well as maintenance and operational models.

This compilation examines seasonal strategies for public playgrounds within the framework of child-friendly urban resilience, addressing their implications for urban planning, design, and implementation processes.

2. Material and Method

This study presents a literature review complemented by qualitative field observations carried out in Erzurum. It focuses on the seasonal resilience of children's playgrounds in urban settings, with particular attention to cities exposed to extreme climatic conditions. The scoping review was conducted in line with the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines. The contextual field observations from Erzurum are presented separately in Section 3.4 and were not included in the database screening process.

Erzurum, the area where qualitative observations were made, is located in the Eastern Anatolia Region of Türkiye. With an altitude of over 1,850 meters, it is one of the highest cities in the country and is characterized by its harsh continental climate. Winters are long, cold, and snowy, while summers are short, mild, and dry. The annual average temperature is around 5–6 °C, and frost occurs for approximately half of the year. These climatic characteristics directly affect the year-round use of children's play areas. Heavy snow cover, icing, low temperatures, and strong winds create challenges in terms of access and safety during the winter months, while high sunshine duration and ultraviolet radiation during the summer months make shading, thermal comfort, and material durability critical issues. Erzurum's topography and seasonal extreme conditions necessitate climate-sensitive and seasonal adaptation strategies.

The literature review encompasses peer-reviewed journal articles, academic books, conference proceedings, and institutional reports addressing themes such as child-friendly urban design, playground safety, climate-sensitive design strategies, and seasonal adaptation in public open spaces. Searches were run in Scopus, Web of Science Core Collection, ScienceDirect, Taylor & Francis Online, and Google Scholar between 1–15 July 2025, covering 1 January 2000–31 July 2025. The core Boolean string was:

("playground*" OR "play area*" OR "play space*") AND (season* OR winter OR summer OR spring OR autumn OR "cold climate" OR "hot climate") AND (safety OR thermal OR "UV" OR "wind" OR "icing" OR "drainage") AND (child* OR children)

Inclusion criteria comprised:

- Studies examining the relationship between climatic conditions and the usability of playgrounds.
- Research addressing the safety, accessibility, and comfort of playgrounds under extreme seasonal conditions (heat, cold, wind, precipitation).
- Publications providing design strategies or policy recommendations for enhancing children’s climate adaptation in outdoor play environments.
- Sources published in English or Turkish to ensure relevance to both local and international contexts.

- “Outdoor public playground settings (parks/streets; except indoor-only).”
- “Participants: children 0–14 and/or caregivers/municipal stakeholders.”
- “Study types: observational, experimental, design guidelines, and policy documents.”

Exclusion criteria included:

- Studies focusing exclusively on indoor play environments without considering outdoor seasonal challenges.

(E1: indoor-only; E2: non-child focus; E3: non-seasonal; E4: non-playground; E5: language out of scope; E6: not peer-reviewed)

In parallel with the literature review, we carried out qualitative field observations between May 2024 and June 2025 in Erzurum, Türkiye. Observations were organized in four season-specific waves (summer 2024, autumn 2024, winter 2024–25, spring 2025), with baseline site-walks conducted at approximately 2–3-week intervals within each wave; additional spot-checks were triggered within 24–72 hours after salient weather events (e.g., heavy snowfall, freeze–thaw cycles, heatwaves, or intense rainfall). Spatially, the campaign covered all identifiable public parks located across every neighborhood included in the study (n = 16) within Erzurum’s central districts (Yakutiye, Palandöken, Aziziye), encompassing 158 playgrounds. These observations recorded the physical condition of play equipment, the presence or absence of seasonal adaptation measures (e.g., shade structures, windbreaks, snow removal strategies), and patterns of use by children and caregivers under differing weather conditions. The purpose of these observations was to contextualize theoretical findings with real-world evidence, thus ensuring that the review was grounded in spatial and climatic realities.

Data obtained from academic sources and field notes were analyzed using thematic synthesis, resulting in four primary thematic categories:

1. The effects of extreme heat on playground safety and usability.
2. The challenges posed by cold, snow, and ice.
3. The impacts of precipitation and wind on playground design and maintenance.
4. Spatial and design strategies for ensuring year-round functional playgrounds.

Records identified through database searching: n=941; after deduplication: n=549; records screened by title/abstract: n=549; excluded (reasons E1–E6): n=324; full-text articles assessed: n=225; excluded with reasons: n=168; included in the scoping synthesis: n=57. This combined methodological approach allowed for the development of a comprehensive, evidence-based understanding of how seasonal factors influence children’s access to and experiences in urban playgrounds, while identifying adaptable design principles applicable across diverse climatic contexts. No formal risk-of-bias appraisal was conducted; this is consistent with scoping review aims.

The literature review revealed a significant research gap regarding the potential seasonal risks in children's playgrounds and the corresponding preventive measures that can be implemented. Addressing this gap positions the present study to contribute novel insights into climate-sensitive design and operational strategies for public play areas.

3. Findings and Discussion

3.1. Seasonal Patterns of Playground Use

Patterns of playground use exhibit a marked seasonality, reflecting both climatic conditions and socioecological dynamics. In cold-climate contexts such as Finland, observational and survey-based research has revealed that while families visit playgrounds throughout the year, the frequency of visits varies substantially between seasons. During the summer months, weekly visitation rates peak at an average of three to four times per week, reflecting favorable thermal conditions, extended daylight hours, and the integration of playground visits into daily outdoor routines. In contrast, winter usage drops sharply to approximately once per week on average, constrained by reduced daylight, low temperatures, and snow or ice accumulation. Transitional seasons such as spring and autumn present intermediate use levels—around twice weekly—corresponding to moderate temperatures but also influenced by rainfall, wind, and surface conditions (Shiino & Aikoh, 2014; Soini et al., 2025).

Similar patterns emerge in temperate-climate metropolitan environments. A study conducted in New York City found that playground utilization is highest during spring and summer, with a significant reduction in the winter months (Shiino & Aikoh, 2014; Silver et al., 2014; Soini et al., 2025; Wilkinson et al., 2017). These fluctuations are not only attributable to ambient climatic conditions but also to changes in caregiver perceptions of safety and comfort, as well as shifts in children's extracurricular schedules. In warmer months, playgrounds serve as multipurpose public spaces for physical activity, social interaction, and community engagement. Even in milder regions such as New Zealand and Australia, children and families tend to turn to indoor activities during the winter months; those who are accustomed to playing outside may continue to do so throughout the year (Ergler et al., 2013, 2016; Shooshtarian et al., 2017). Conversely, during winter, the physical environment often becomes less inviting—slippery surfaces, exposure to cold winds, and insufficient lighting discourage prolonged outdoor stays.

The combined findings from diverse climatic contexts suggest that seasonal usage patterns are shaped by an interplay of environmental, social, and infrastructural variables. Climatic conditions such as temperature, precipitation, and daylight duration directly influence physical comfort and safety, while socioecological factors—including neighborhood walkability, proximity to green spaces, and the availability of alternative indoor facilities—mediate the decision to engage in outdoor play (Bringolf-Isler et al., 2010; Egan & Pope, 2024; Gemmell et al., 2022; Lambert et al., 2019; Maddren et al., 2025; Visser & Aalst, 2021). Importantly, these patterns indicate that without deliberate design interventions and seasonal adaptation strategies, playgrounds risk underutilization for significant portions of the year. This underlines the need for year-round functionality as a central criterion in child-friendly urban resilience planning, ensuring that play remains an accessible and safe right across all seasons.

3.2. Seasonal Risk Perceptions and Behavioral Responses

Caregivers' perceptions of seasonal risks play a decisive role in determining whether and how children use playgrounds throughout the year. These perceptions are shaped by a combination of meteorological conditions, the physical characteristics of playground infrastructure, and socio-cultural attitudes toward outdoor play. Across diverse climatic contexts, four seasonal profiles emerge, each with distinct environmental hazards and corresponding behavioral adaptations.

3.2.1. Summer Risks

During summer months, elevated air temperatures and high ultraviolet radiation (UVR) levels constitute the primary environmental risks in playgrounds. Children, due to their thinner skin, lower sweat rates, and slower behavioral thermoregulation, are more susceptible to heat stress, dehydration, and burn injuries (Antoniadis et al., 2020; Pfautsch et al., 2022; Ryu & Lee, 2016). Surface temperatures of common playground materials—such as metal, rubber, and asphalt—can reach hazardous levels (≥60°C for metal, ≥77°C for plastic), posing acute burn risks upon contact (Cheng et al., 2025). In addition to thermal hazards, summer conditions may amplify biological risks, including mosquito and tick activity, especially near vegetated edges and stagnant water bodies. Caregivers often respond by restricting playtime to early morning or late afternoon hours, encouraging the use of protective clothing, or avoiding playgrounds without sufficient shade (Qi et al., 2022; Vanos et al., 2016). However, this adaptive behavior may inadvertently limit children's physical activity and social interaction during peak summer months.

3.2.2. Winter Risks

In cold climates, winter risk profiles are dominated by hypothermia, frostbite, and slip-and-fall injuries resulting from icy surfaces (Mcdaniel, 2021; Schimelpfenig & Jacobsen, 2022). Wind chill significantly exacerbates thermal discomfort, potentially lowering safe exposure times, particularly when children make skin contact with cold metal equipment.

Snow accumulation can obscure markings, reduce accessible routes, and create barriers for users with mobility impairments (Kuzulugil & Aytatlı, 2023; Shao et al., 2022). Additionally, hazards such as icicles falling from roofs or sudden snow slides from inclined surfaces threaten user safety. Freeze–thaw cycles can damage material integrity, causing microcracks in stone or concrete elements and joint failures in rubber surfacing. Caregivers often respond by avoiding outdoor play altogether during extreme cold, resulting in substantial reductions in winter playground utilization.

3.2.3. Spring Risks

Spring marks the transitional phase when winter-induced structural fatigue becomes visible. Freeze–thaw cycles may have led to pavement subsidence, joint separations, and surface irregularities that increase tripping hazards (Chamberlain et al., 2019). Concurrent snowmelt and seasonal rainfall can cause localized flooding and surface water accumulation, particularly in low-lying areas. Additionally, pollen loads peak during this season, triggering allergic reactions in sensitive children (Denton et al., 2025).

3.2.4. Autumn Risks

Autumn's primary risks are associated with slippery surfaces caused by the combination of rainfall and organic debris such as leaves, seed pods, or fruit husks (Tarcea et al., 2024). Accumulated debris can clog drainage systems, leading to shallow ponding and, with early frost events, the formation of hazardous "black ice." (Heydarian et al., 2021; Samaha & Gad-El-Hak, 2021) Reduced daylight hours can impair visibility and heighten perceptions of insecurity, particularly in under-lit playgrounds (Castillo-Martínez & Peña-García, 2021).

Overall, these seasonal risk profiles underscore the importance of integrating year-round hazard mitigation into playground design and operation. Beyond immediate physical safety, such measures influence caregiver trust and willingness to permit outdoor play, directly shaping children's opportunities for physical activity, socialization, and nature engagement.

3.3. Climatic and Microclimatic Indicators in Playground Safety

The safety of playgrounds in diverse climates is increasingly understood to depend on both macro-scale climatic conditions and microclimatic nuances that directly affect children's thermal comfort and physical risk exposure. At the macro scale, seasonal temperature ranges, precipitation patterns, and wind regimes determine the overall environmental stresses on playground materials and structures. For example, freeze–thaw cycles exacerbated by winter precipitation can induce icing on playground surfaces, while summer conditions can lead to elevated surface temperatures that pose burn hazards (Paolini et al., 2025; Park et al., 2022). These risks highlight the importance of incorporating durable materials and effective drainage systems capable of withstanding thermal cycling and preventing surface degradation.

At the micro-scale, factors such as surface temperatures diverging significantly from ambient air temperatures, localized UV exposure, and wind chill effects come into play. Evidence demonstrates that play equipment surfaces can reach temperatures high enough to cause burns in summer while, during winter, surfaces may cool to levels risking frostbite

(Paolini et al., 2025; Park et al., 2022) . In this context, microclimate analysis has shown that careful spatial design—such as strategic shade geometry, vegetative cover, and properly positioned windbreaks—can modulate these extreme conditions (Campo et al., 2020). For instance, incorporating vegetation and permeable surfaces can reduce the surface heat load by providing shade and promoting evaporative cooling, while also mitigating water pooling that might lead to hazardous icy patches in cooler seasons (Campo et al., 2020).

Moreover, effective playground safety strategies require combining site-specific microclimatic measurements (temperature logging, wind and radiation mapping) with macro-climatic data to establish a holistic evidence base for interventions (Campo et al., 2020; Paolini et al., 2025). Such an integrated approach facilitates the identification of high-risk areas where local overheating or overcooling might occur. Subsequently, designers and city planners can implement evidence-based solutions such as adaptive shading systems and material selections that counteract the adverse effects of wind chill and ultraviolet radiation. Localized interventions tailored to microclimatic conditions help ensure that playgrounds remain safe, accessible, and comfortable year-round despite extreme seasonal variations.

Environmental assessments also consider other dynamic variables, including allergen loads from certain vegetation species and the propensity for water pooling after rainfall. These factors can indirectly affect safety by altering children's physical activity patterns and exposure to secondary risks such as allergenic responses or slip hazards. By employing a multidisciplinary approach that encompasses both physical sciences and environmental engineering, urban planners can significantly enhance playground design. This approach improves immediate playground safety and builds long-term resilience against the multifaceted challenges posed by climate variability.

Furthermore, some studies argue that overly protective or one-dimensional child-friendly spaces may constrain children's right to free play and their social interaction (Biggs & Carr, 2015; Brown et al., 2019; Kaplan, 2024; Pérez-Del-Pulgar et al., 2024; Pitsikali & Parnell, 2019). In addition, the practical, economic, and cultural barriers to implementing seasonal strategies and inclusive design are discussed in the literatüre (Andal, 2022; Arvidsen et al., 2025; Jian et al., 2025; Q. Zhang et al., 2023).

In summary, the current body of research indicates that a comprehensive analysis of both climatic and microclimatic indicators is critical to optimizing playground safety in regions with diverse and extreme seasonal climates. Integrating macro-scale climatic data with fine-scale environmental measurements enables the development of adaptive design strategies—such as appropriately engineered shade structures, windbreaks, and effective drainage systems—that can mitigate thermal hazards and ensure safe play environments for children (Campo et al., 2020; Paolini et al., 2025; Park et al., 2022).

3.4. Erzurum Contextual Qualitative Field Observations

Erzurum's harsh continental climate is one of the key environmental parameters that limits open space use for most of the year and directly affects the seasonal accessibility of children's play areas. Qualitative observations were conducted in 158 play areas located in different neighborhoods in the center of Erzurum between May 2024 and June 2025.

These observations were systematically noted within the framework of themes such as the physical condition of the area, diversity of equipment, maintenance frequency, climatic adaptation measures, and user behavior. In Erzurum, where winter months are very long, it was observed that snow clearance was not performed in a significant portion of the play areas, and the freeze-thaw cycle caused joint opening and surface damage in the ground coverings. In windy locations, snow and ice accumulated around fixed playground equipment, narrowing access routes and making equipment surfaces slippery. Especially in open areas facing north, wind chill was observed to be a significant factor limiting children's play time to a few minutes. Due to the identified reasons, it has been observed that children's play areas in Erzurum are almost never used during the winter months. These field observations did not form part of the PRISMA screening and were used solely to contextualize the scoping synthesis; no personally identifiable data were collected."

Figure 1. Snow-covered public playground, Erzurum (23 March 2024).

During the summer months, the lack of shading elements has caused the contact temperatures of metal and dark-colored floor coverings to reach dangerous levels. Parents avoided bringing their children to the playground during midday hours, while areas with shade-providing trees were used more intensively. In many regions, it was observed that there were no natural or artificial shading solutions to reduce UV exposure.

During the spring and fall transition seasons, area usage varied depending on rainfall intensity and ground permeability. Inadequate drainage systems caused puddles and mud buildup after rainfall, creating accessibility issues, especially for wheelchair and stroller users.

These field observations indicate that seasonal strategies in cities with harsh climates like Erzurum must be addressed holistically not only during the design phase but also during maintenance and operation processes. Additionally, it has become clear that developing design solutions that are compatible with the climate–space–user triangle and tailored to the local context is critical for increasing the year-round usability of playgrounds.

4. Conclusion and Suggestions

This review underscores that seasonal variability is not merely a contextual backdrop for playground design but a decisive parameter influencing safety, accessibility, and long-term usability. Across climatic zones, seasonal transitions create distinct risk profiles—ranging from extreme surface heating in summer to frost-induced hazards in winter—each requiring targeted mitigation strategies. These risks are compounded by caregiver perceptions, which strongly shape children's outdoor play behaviors and, in turn, determine whether playgrounds remain active public assets year-round.

Current playground design practices often address seasonality through reactive maintenance measures rather than as an integrated design parameter. However, findings from this review suggest that a proactive, climate-sensitive approach can extend usability across all seasons, enhance user safety, and build public trust. Such an approach requires integrating macro-scale climatic data with site-specific microclimatic measurements to inform material selection, shading geometry, drainage strategies, and vegetation planning. The design process must also consider inclusivity, accessibility, and children's rights as non-negotiable components of climate resilience in urban play environments.

4.1. Recommendations for Seasonal Adaptation of Public Playgrounds

The following recommendations emerge from this synthesis:

4.1.1. Summer – Heat Stress, UV Exposure, and Insect Activity

- Adaptive Shading Systems: Install modular shade structures (tensile fabric canopies, retractable awnings) over high-exposure zones, prioritizing swings, slides, and seating areas.
- Vegetation-Based Shading: Integrate deciduous tree planting to provide dense summer shading while allowing winter solar gain.
- Cool Surface Materials: Use high-albedo, low-thermal-mass surfacing (e.g., light-colored EPDM, composite decking) to limit surface temperature rise.
- UV Protection Signage: Place clear visual indicators showing peak UV periods and shaded play recommendations.
- Hydration Infrastructure: Provide water fountains with child-height accessibility, ensuring compliance with hygiene standards.

- Vector Management: Eliminate standing water to reduce mosquito breeding; install low-level vegetation buffers between play zones and natural habitats to minimize tick exposure.

4.1.2. Winter – Snow, Ice, and Low Temperatures

- Snow Clearance and Anti-Icing Measures: Implement regular snow removal from play surfaces and pathways, using non-toxic de-icing agents to prevent slip hazards.
- Windbreak Installations: Erect semi-permeable windbreak panels (e.g., polycarbonate, mesh fencing) or vegetative barriers to reduce wind chill in exposed areas.
- Thermal Comfort Zones: Integrate enclosed or partially enclosed shelters adjacent to playgrounds for caregivers and children to rest in warmer conditions.
- Color Psychology for Cold Seasons: Paint surrounding walls or vertical elements in bright, warm colors to enhance visual stimulation and perceived warmth.
- Frost-Resistant Materials: Use elastomeric surfacing with high flexibility at sub-zero temperatures to avoid cracking.
- Lighting Enhancement: Ensure adequate illumination during shorter daylight hours to maintain perceived safety.

4.1.3. Spring – Rain, Flooding, and Allergens

- Drainage Optimization: Install permeable surfacing and subsurface drainage systems to prevent water pooling in high-use areas.
- Mud Management: Provide boardwalk-style elevated pathways over high-traffic muddy zones.

- Allergen Mitigation: Select hypoallergenic turfgrass species and position flowering shrubs away from main circulation paths.
- Post-Winter Inspection Protocols: Conduct structural audits after freeze–thaw cycles to repair cracks, gaps, or frost-heave damage.
- Emergency Shelter Points: Install small covered pavilions for sudden spring showers.

4.1.4. Autumn – Leaf Litter, Rain, and Reduced Daylight

- Leaf and Debris Management: Schedule frequent removal of organic matter from surfaces to prevent slip hazards.
- Gutter and Drain Maintenance: Regularly clear drainage inlets to avoid clogging and surface water accumulation.
- Anti-Slip Coatings: Apply textured surface treatments to ramps, bridges, and smooth play features before rainy season onset.
- Wind-Resistant Design: Secure movable play elements and ensure tree health to reduce branch-fall risk during autumn storms.
- Lighting Upgrades: Increase both functional and decorative lighting to improve safety and extend usability.
- Fungal Allergen Control: Treat organic play materials (wooden equipment, mulch) with safe antifungal coatings to prevent mold growth.

4.1.5. Cross-Seasonal and Year-Round Strategies

- Seasonal Play Zone Rotation: Design multi-use zones that can be reconfigured seasonally (e.g., sand or water play in summer, snow play in winter).
- Modular Equipment: Use interchangeable components that can be replaced or adapted based on weather conditions.

- Year-Round Maintenance Calendar: Establish preventive maintenance schedules synchronized with seasonal transitions.
- Community Engagement: Organize seasonal awareness campaigns for caregivers about weather-related risks and safe play practices.
- Climate-Responsive Policy Integration: Incorporate thermal comfort, wind safety, and drainage efficiency criteria into municipal playground design standards.

Ultimately, playgrounds must be conceived as adaptive systems capable of responding to seasonal dynamics without sacrificing safety or inclusivity. Embedding these strategies into municipal planning guidelines and playground standards can promote a shift from reactive to preventive management, ensuring that the right to play is protected as a year-round urban function. This approach not only benefits children's health and development but also contributes to broader goals of urban resilience, public health equity, and climate adaptation.

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Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article.

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From Vulnerability to Resilience: The Van Earthquake and Its Implications for Disaster-Informed Urban Planning

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1. Introduction

In an era of rapid urban expansion and increasing natural disaster frequency, the need to develop resilient cities is undeniable. Earthquakes, in particular, threaten densely populated areas, with the potential to cause widespread destruction and economic losses in the billions. For instance, the 1999 Marmara Earthquake resulted in approximately 17,000 fatalities and an estimated economic cost of 10–15 billion USD for Turkey (Erdik, 2000, Disaster and Emergency Management Presidency (AFAD) n.d.). Predicting or preventing the next major earthquake remains impossible.

Urban resilience plays a pivotal role in enhancing cities' capacity to cope with challenges arising from rapid urbanization and environmental change. Adapted from Holling's (1973) ecology-based resilience concept, it refers to a city's ability to anticipate, respond to, and recover from shocks and stresses (Meerow, Newell, & Stults, 2016, Ahern, 2011).

Recent major earthquakes in Turkey have underscored the critical need for urban resilience. The October 23, 2011 Van-Erciş and November 9, 2011 Van-Edremit earthquakes, in particular, highlighted the devastating impacts on urban areas. Data from the National Seismology Observation Network, operated by AFAD, indicate that the main shock on October 23 released energy equivalent to approximately 33.2 Hiroshima atomic bombs, and when aftershocks are included, the total energy released reached the equivalent of about 37 atomic bombs (Güney, 2012, AFAD 2012).

This article analyzes the Van earthquake within the framework of urban resilience. The resilience of physical and social systems is examined through five key criteria: robustness, redundancy, resourcefulness, adaptability, and rapidity. The analysis focuses on pre-earthquake measures, the planning process, and post-earthquake interventions.

In the planning process of Van, the elements defined as the 4Rs by Bruneau et al. (2003) were analyzed. This analysis was integrated with the Key Dimensions and Characteristics of Urban Resilience identified by Ribeiro & Gonçalves (2019).

2. Research Methodology

A systematic process was applied to conduct a comprehensive literature review on urban resilience. This process consisted of three stages: (i) searching online databases, (ii) analyzing data related to the Van earthquake, and (iii) examining spatial planning decisions in terms of urban resilience criteria. Academic databases were used to systematically select the articles reviewed in this study.

Database searches employed keywords such as "Urban resilience," "Resilient urban systems," "Resilient cities," "Resilience in cities," and "seismic resistance," along with related terms. For scientific articles, the review focused on the last 15 years (2010–2025), prioritizing relevance and selecting studies cited more than ten times. Technical documents were drawn from publications by relevant institutions on the Van earthquake, while spatial plans were obtained from the Ministry of Environment and Urbanization's website.

3. Urban Resilience and Its Conceptual Framework

The concept of resilience is widely applied across disciplines, from environmental studies to engineering, and from psychology to sociology and economics (Sharifi, & Yamagata, 2016). It generally encompasses both strength and flexibility. According to the Merriam-Webster Dictionary, “resilience” refers to (i) the ability of an object to return to its original size and shape after deformation under stress, and (ii) the capacity to recover and adapt in the face of adversity or change. In the context of earthquake disasters, Comfort (1999, p. 21, cited in Bruneau et al., 2003) defines resilience as “the capacity to adapt existing resources and skills to new conditions and operational demands,” emphasizing the need for both pre-event and post-event strategies, including risk reduction, loss prevention, impact minimization, and recovery.

Urban resilience extends this concept to the city scale, referring to a city’s capacity to withstand, adapt to, and recover from shocks while maintaining its essential functions and overall well-being (Ribeiro & Gonçalves, 2019; Cao, 2023). Importantly, resilience is not only about adaptation; historical evidence suggests that strategies that appear effective in the short term can, over the long term, increase systemic vulnerability, demonstrating the concept’s complexity and multidimensionality (Chelleri, 2012). The rise of the “Resilient Cities” framework reflects this complexity, particularly in the context of urban adaptation to climate change, and has stimulated global collaboration in fields such as risk management, sustainability, and urban governance.

Community-based seismic resilience emphasizes the role of social units—including organizations and communities—in reducing hazards, limiting disaster impacts, and recovering in ways that minimize social disruption. Effective resilience requires both robust infrastructure capable of functioning during and after earthquakes, and well-coordinated emergency response and recovery strategies to reduce fatalities, injuries, and economic losses (Bruneau et al., 2003).

Seismic resilience can be conceptualized through the four key attributes of the 4R framework—Robustness, Redundancy, Resourcefulness, and Rapidity—which collectively define urban resilience. **Robustness**, the capacity to maintain functionality under stress; **redundancy**, the ability to substitute functions in case of failure; **resourcefulness**, the capacity to identify problems, prioritize actions, and mobilize resources effectively; and **rapidity**, the ability to act promptly to limit losses and prevent future disruptions (Xie, 2023; Bruneau et al., 2003, Kapucu, Ge, Rott, & Isgandar, 2024) (Table 1).

Table 1. Key Components of Resilience;4R Framework (Bruneau et al., 2003)

Component	Description
Robustness	Ability to withstand stress without loss of function.
Redundancy	Capacity to substitute functions during failure.
Resourcefulness	Ability to identify problems, prioritize, and mobilize resources.
Rapidity	Ability to act promptly to limit losses and prevent future disruptions.

In addition, urban resilience can be examined across four interrelated dimensions: technical, organizational, social, and economic. The technical dimension captures the capacity of physical systems to maintain functionality under shocks, relying primarily on robustness and redundancy. The organizational dimension refers to the ability of institutions managing critical facilities and disaster tasks to coordinate, make decisions, and respond effectively, incorporating resourcefulness and rapidity. The social dimension reflects the degree of protection and support for communities and public administration units, emphasizing community-based resilience and post-disaster recovery. Finally, the economic dimension addresses the city's capacity to reduce both direct and indirect economic losses through risk management and loss mitigation strategies (Ribeiro & Gonçalves, 2019) (Table 2).

Table 2. Key Dimensions and Characteristics of Urban Resilience (Ribeiro & Gonçalves, 2019)

Dimension	Definition	Key Characteristics
Technical	Capacity of physical systems to function under shocks.	Robustness, Redundancy
Organizational	Capacity of organizations managing critical facilities and disaster tasks.	Resourcefulness, Rapidity, Decision-making ability
Social	Degree of protection for communities and public administration units.	Community-based resilience, Post-disaster recovery
Economic	Capacity to reduce direct and indirect economic losses.	Loss mitigation, Risk management

Taken together, these components and dimensions provide a comprehensive framework for understanding, assessing, and enhancing urban resilience, particularly in earthquake-prone and rapidly urbanizing contexts.

Ribeiro and Gonçalves (2019), building on Bruneau's criteria, evaluated resilience across five dimensions, including a natural dimension. Urban resilience is not limited to the four core components; it can also be assessed through these five dimensions: the natural dimension, which considers environmental factors and ecosystem resilience; the economic dimension, encompassing the sustainability of economic systems and their flexibility in the face of crises; the social dimension, reflecting communities' capacity to withstand crises through solidarity, social capital, and social networks; the physical dimension, addressing the resilience of infrastructure, buildings, and transportation systems; and the institutional dimension, covering governance, policy, planning mechanisms, and their role in crisis management. Within this framework, urban resilience is a multidimensional and dynamic concept aimed at producing holistic and sustainable solutions to the challenges cities face (Xie, 2023). It represents the ability of a city or urban community to withstand various risks, crises, and unexpected disruptions.

Several opportunities and challenges have been identified in the field of urban resilience. To capitalize on these opportunities and address the challenges, it is essential to integrate diverse experiences within and across cities and to foster collaboration among scientists, the public, and authorities. Such collaboration should aim to produce knowledge that is scientifically reliable, contextually relevant, socially robust, and practically applicable (Ribeiro & Gonçalves, 2019). Moreover, by generating clear operational definitions, measurable criteria, and concrete baseline data, conceptual ambiguities, local-level disconnects, and coordination gaps can be mitigated, while facilitating the integration of different types of knowledge (Table 3).

Table 3. Opportunities and Challenges in Urban Resilience (Ribeiro & Gonçalves, 2019)

Opportunities	Challenges
Integration of diverse experiences (within and across cities)	Conceptual ambiguity in different contexts
Collaboration among scientists, the public, and authorities	Lack of operational definitions
Production of knowledge that is applicable, contextually relevant, and socially robust	Local-level disconnects and coordination gaps
Development of clear criteria and concrete baseline data	Need for integration of different types of knowledge

Indeed, the urban resilience approach requires not only reducing disaster risks but also establishing social resilience mechanisms that enable effective response during crises and rapid recovery after disasters (Meerow et al., 2016). Consequently, resilience in urban areas aims not only to mitigate the impacts of potential disasters but also to strengthen communities through crisis experiences. This perspective, as illustrated by cases such as the Van earthquake, positions disaster risk management as a fundamental component of sustainable urban development (Cutter et al., 2008).

4. Characteristics and Spatial Vulnerabilities of the 2011 Van Earthquake

Van Province provides a relevant case study for applying these concepts. Historically, the region has experienced avalanches, landslides, earthquakes, rockfalls, floods, and rising lake levels (Ministry of Environment and Forestry, 2011). Among these, earthquakes are the most frequent and destructive, causing the greatest human and material losses. The province lies within first- and second-degree earthquake zones, with the city center in the second-degree zone, intersected by significant fault lines.

The region's fragile soil and settlements' limited resilience exacerbate seismic impacts. Earthquakes recur approximately every 30–35 years, and accumulated stress along fault lines, combined with loose soil and shallow groundwater, further increases damage potential. Additionally, interactions among multiple fault zones heighten regional vulnerability (Ministry of Environment, Urbanization and Climate Change, 2017- In 2021, "Climate Change" was added, making this the ministry's current official name). Strengthening disaster risk reduction and preparedness is therefore essential. The most destructive earthquakes in Van occurred in 1930, 1976, and 2011, each registering a magnitude of 7.2.

4.1. The 2011 Van Earthquake and Disaster Management Process

The 2011 Van Earthquake occurred on Sunday, October 23, at 13:40 local time, with its epicenter in Tabanlı Village, Central District, registering a magnitude of 7.2 (M). While post-disaster management efforts were ongoing, a second earthquake struck on Wednesday, November 9, at 21:20, with a magnitude of 5.6 (M) and its epicenter in the Edremit District. Following these events, an average of 180 aftershocks per day was reported over the subsequent month (Erdik, Kamer, Demircioğlu, & Şeşetyan, 2012)

The earthquakes resulted in 644 fatalities and 1,966 injuries. Damage assessments were conducted on 187,000 buildings, of which approximately 49,000 were identified as damaged. Among the assessed structures, 76.4% of residential buildings, 78.9% of workplaces, and 82.3% of barns were damaged. Overall, these assessments covered 77% of the total building stock, underscoring the vulnerability of local structures and their insufficient resilience to seismic events (METU, 2012; Yıldız Technical University, 2011).

Expert-led search and rescue operations began within the first thirty minutes following the earthquakes. Emergency needs—including temporary shelter, healthcare, and food support—were provided via road and air transport. Tent settlements were established to address multiple humanitarian requirements, including shelter, health services, education, psychological support, social spaces, sanitation, and security. These temporary settlements were later replaced by container-based housing complexes. The post-earthquake response provided critical lessons for enhancing regional resilience. Reconstruction efforts included the construction of permanent housing and the development of planned living areas. Site selection studies were conducted to identify safe locations for new housing, and comprehensive planning was completed to ensure secure living environments for earthquake survivors ((METU, 2012; AFAD, 2014). Overall, urban resilience in Van demonstrates that effective disaster risk management not only mitigates the impacts of earthquakes but also strengthens communities through crisis experiences, positioning resilience as a fundamental component of sustainable urban development (Meerow et al., 2016; Cutter et al., 2008).

4.2. Planning Studies in Van Province

Urban planning is an effective tool for disaster risk management, helping to prevent potential losses. In Van, planning efforts can be evaluated through the lenses of vulnerability and resilience. Prior to the 2011 Van earthquake, the 1996 zoning plan identified the city's population as 353,419. The urban fabric was dispersed, scattered, and sprawling, with a gross density of 53 people/ha and undeveloped areas in the city center (Van Büyükşehir Belediyesi 2016). Before the implementation of the 1996 plan, approximately 2,000 amendments were made, mainly increasing building heights, reducing green areas, and expanding residential zones, which disrupted the integrity of the plan (ÇŞB, 2013a). These changes intensified central urban density and strained infrastructure below planned standards (DAKA, 2014). Unregulated or unauthorized constructions, inconsistent building heights, and the unequal distribution of public facilities increased the city's vulnerability. Green areas were limited (2.15 m² per capita), and playgrounds were insufficient relative to population density. Overall, the 1996 plan was inadequate in providing public spaces, contributing to Van's disaster vulnerability (ÇŞB, 2013a).

4.3. 1/100,000 Muş-Bitlis-Van Environmental Master Plan (EMP)

The 1/100,000 scale Environmental Master Plan for the Muş-Bitlis-Van area, approved on April 1, 2011, aimed to prevent rural-to-urban migration, support balanced and sustainable regional development, control unplanned settlements, preserve ecological balance, promote agriculture and livestock, and protect natural and cultural assets (ÇŞB2019, April 5).

Residential areas for the projected 2035 population were proposed mainly on vacant urban plots and surrounding dry farmland. Northern areas were designated for industry and included the university. The plan also suggested specialized zones in the city center, such as fairgrounds, festival areas, technoparks, and storage/development areas for Van OSB (ÇŞB2019, April 5). Compliance with building regulations for disaster-prone areas, including the Earthquake-Resistant Buildings Regulation, was stipulated (Figure 1)

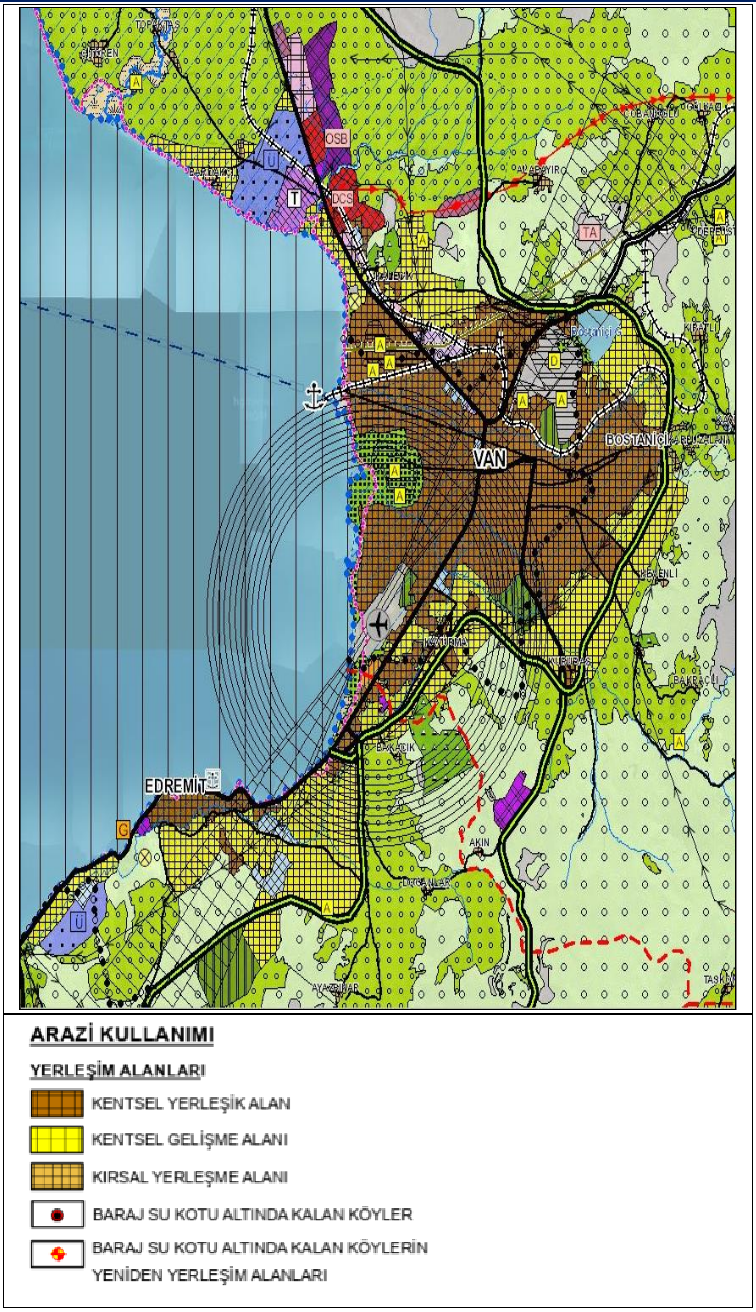

Figure 1. 1/100,000 Scale Environmental Plan (EP) of the Muş-Bitlis-Van Planning Region (www.csb.gov.tr)

4.4. 1/5,000 Scale Master Development Plan (MP)

The 1/5,000 MP was divided into three phases: Central, North, and South. The city developed between Erek Mountain and Lake Van, with the main road bisecting the city and commercial/public areas concentrated around it. Key facilities like the airport, industrial sites, university, and OSB were located in the north. The plan targeted a 2035 population of 700,000, with development directed toward southern and undeveloped areas to manage density. Bostaniçi and Edremit districts were planned with low- to medium-density areas to accommodate population growth safely. Transportation infrastructure lacked a comprehensive intra-city system, and parking shortages were identified as a major issue. Preferred commercial areas were positioned between the CBD and residential zones, with ground-floor commercial use along main axes.

Parks, squares, recreational areas, and green belts along rivers and energy lines were included. Social infrastructure was intended to be evenly distributed, and new housing developments adhered to detached zoning regulations, with population densities classified from sparse to high (Van Büyükşehir Belediyesi 2019).

4.5. 1/1,000 Scale Implementation Development Plan (UİP)

Under the 1/5,000 MP, the CBD was designated as the densest area, with building regulations B-5, B-6, and B-7 applied. Ground floors along main roads were allocated for commercial use (Van Büyükşehir Belediyesi 2019). Detached and semi-detached buildings were present in the city center, with density decreasing toward the periphery. Northern industrial zones lacked green buffers separating them from residential areas, increasing vulnerability. Although green areas were planned in the west, insufficient connectivity reduced overall urban resilience.

5. Evaluation of Van’s Planning Process Based on Disaster-Sensitive Spatial Planning Criteria

Van Province is located within first- and second-degree earthquake zones and is intersected by numerous fault lines. The faults in the region typically move every 30–35 years, often triggering adjacent faults to complete their recurrence cycles. These periodic fault movements, combined with the province’s seismic zone classification, result in a high overall earthquake risk. Consequently, the entire province was evaluated under the 1/100,000-scale Environmental Plan (ÇDP) as a risk-prone area. At finer scales, the 1/5,000-scale Development Plan (MP) and 1/1,000-scale Implementation Plan (UİP) treated the city center as a planning unit due to its high settlement density and mixed land uses(Van Büyükşehir Belediyesi 2019). Geological surveys and subsequent analyses supported directing new settlement areas from Van’s central district to the nearby Edremit District to reduce urban concentration—a decision considered a precaution against seismic risk. During the 2011 Van Earthquake, the Van Fault Zone in the north remained at a safe distance from populated areas, with agricultural lands separating the fault rupture from settlements. Important transportation routes, including railways and first-, second-, and third-degree highways, pass through this area. While no specific measures were taken for the fault zone itself, the absence of designated land use recommendations was viewed positively, reflecting partial mitigation of earthquake risk.

However, several planning deficiencies were noted. Settlement areas are not aligned parallel to fault lines, and the commercial center, concentrated around the Central Business District (CBD), lacks continuity with surrounding green spaces. No provisions exist for post-disaster activities in green areas. Although settlements are 20 meters away from fault lines, they are not separated by green buffers. Conversely, educational and social infrastructure are distributed evenly, and industrial zones are located outside the city center, preventing further urban concentration. Nevertheless, concentrating commercial use in a single center increases population density, and no recommendations exist for post-disaster functional uses in the city center.

In summary, earthquake mitigation measures were implemented in some areas but not others. Positively, energy transmission lines are located away from fault lines, and protective belts are proposed. Nevertheless, temporary housing and disaster support centers were not incorporated, limiting full compliance with resilience criteria. Alternative transportation systems within the city are lacking, though road alternatives exist, and overall accessibility to the province is maintained through external transport systems. The location of industrial zones outside the city center enhances resilience, and development in Edremit mitigates central concentration. Yet, insufficient planning for disaster-related land use and policies reveals partial alignment with resilience objectives.

Key observations include:

- Comprehensive zoning, phasing, and risk management studies for seismic hazards are limited. Some analyses and institutional consultations were conducted in line with regulations, but specialized studies for reducing earthquake damage are sparse. MP lacks provisions for settlement transformation, renewal, disaster management centers, emergency services/support centers, and temporary housing. Despite directing development toward Edremit, central urban density and commercial functions maintain vulnerability and limit preventive measures, indicating the need for overall urban resilience enhancement.

- Zoning according to disaster hazards and risks is partially sensitive, and construction conditions partially consider earthquake risk. Planning decisions in existing residential areas provide limited mitigation, while new development zones are better aligned with seismic risk reduction strategies. However, central urban and high-use areas are not designed according to risk-reduction strategies, increasing vulnerability and reducing resilience. The city macroform, concentrated around CBD with commercial, social, public, and residential uses, lacks separated and green-buffered housing areas, rendering it unsuitable for earthquake mitigation strategies.
- Social infrastructure is balanced, but hazardous uses within residential areas are not separated by green space, and post-disaster facilities are insufficient. Functional incompatibilities limit earthquake mitigation, increasing vulnerability and reducing resilience.
- The city center contains fuel stations within residential zones, increasing vulnerability. While accessibility exists, the lack of alternative transport systems exacerbates fragility, showing misalignment with earthquake mitigation strategies.
- Proposed green spaces meet regulatory standards but are insufficient in size and connectivity within the city center. Green

buffers to separate hazardous uses are lacking, limiting their effectiveness in reducing vulnerability and preventing earthquake damage.

- Post-disaster facility locations and area standards are partially met in MP, but no information is provided for specialized disaster facilities, reflecting weak alignment with earthquake mitigation strategies and continued vulnerability.
- Transportation systems are continuous, accessible, and include alternative routes, partially supporting earthquake mitigation strategies. However, lack of integration with green spaces, insufficient parking, absence of alternative transport modes, missing helicopter and heliport areas, and railways crossing settlements increase system vulnerability and reduce resilience.

The elements defined as the 4Rs by Bruneau et al. (2003) were analyzed within Van's planning process, as shown in Table 5. This analysis was combined with the Key Dimensions and Characteristics of Urban Resilience proposed by Ribeiro & Gonçalves (2019).

Table 5. Evaluation of the Planning Process According to Earthquake Risk

Planning Issues	Fundamental Dimensions and Characteristics of Urban Resilience			
	Technical Dimension	**Organizational Dimension**	**Social Dimension**	**Economic Dimension**
Planning Process & Risk Management	Low capacity of physical systems to maintain functionality under earthquakes or shocks	Average capacity of organizations managing critical facilities and performing disaster tasks	Average degree of protection of communities and public administration units from adverse impacts	Within the planning approach, the capacity to reduce direct and indirect economic losses is limited
4R	**1R**	**2R**	**3R**	**4R**
	▲	▲	▲	■
Residential Areas	Zoning, phasing, and risk management	No decisions on settlement transformation, disaster	Post-disaster social support mechanisms are not prepared	The capacity to reduce direct and indirect economic losses associated with post-

	are limited; some analyses exist based on regulations	management centers, or emergency service/shelter areas		earthquake casualties and damages is limited
4R	**1R**	**2R**	**3R**	**4R**
	▲	▲	●	■
Zoning and Building Conditions	Partially sensitive; new development areas are relatively more suitable	Critical facilities are not given a special place in the planning approach	City center and areas of intensive use increase vulnerability; not aligned with macroform strategies	In densely built-up urban areas, the capacity to reduce economic losses is highly limited
4R	**1R**	**2R**	**3R**	**4R**
	▲	▲	▲	▲
Social Facilities	Balanced distribution, but only positive in terms of standards	Distribution complies with planning regulations	Lack of post-disaster facility proposals	No clarity on how losses will be recovered
4R	**1R**	**2R**	**3R**	**4R**
	▲	●	●	▲
City Center (CBD and surroundings)	High-density risks not considered	High concentration; fuel stations located within settlements	No alternative transportation; vulnerability is high	Despite being the main component of the economy, the city center has no special planning decision
4R	**1R**	**2R**	**3R**	**4R**
	●	●	●	●
Green Area Uses	No sustainable systems in green areas	Complies with standards but insufficient in the center; not considered as post-earthquake gathering areas	No green belts or integrated networks to separate hazardous uses	The use of green areas does not aim to mitigate post-disaster losses
4R	**1R**	**2R**	**3R**	**4R**
	▲	▲	▲	▲
Post-Disaster Facilities	No disaster preparedness	Partially in line with standards	No special facilities/areas for risks	No dedicated budget
4R	**1R**	**2R**	**3R**	**4R**
	●	●	●	●
Transportation System	Transportation system built without considering post-disaster conditions	Continuous and accessible; alternative routes exist but not linked to disaster response	No green area integration; insufficient parking; lack of alternative transport modes and heliports	The transportation system is not designed for disaster-sensitive urban systems and may cause severe economic collapse
4R	**1R**	**2R**	**3R**	**4R**
	●	●	●	●

Note: **Main Components of Resilience (4R)** : 1. Robustness 2. Redundancy 3. Resourcefulness 4. Rapidity

Symbols used for 4R:

■ Fully aligned
▲ Partially aligned
● Low alignment

Source: Adapted from Erekinci (2019)

The UİP, in combination with strategies beyond MP, includes measures to mitigate earthquake damage. Development outside the city center follows detached planning, while the city center has mixed detached and contiguous zoning. Densest residential areas surround the city center, tapering outward. No vertical additions were made to existing buildings, and setbacks and engineering solutions comply with regulations. Roads have at least two lanes with no dead ends, supporting earthquake mitigation strategies.

However, residential blocks exceeding 75 m, fuel stations within housing areas, and absence of post-disaster facilities increase vulnerability and reduce resilience. Overall, the UİP's alignment with earthquake mitigation strategies is partially adequate but has notable deficiencies.

6.Conclusion and Recommendations

Turkey, due to its geographical location and geological structure, is highly prone to disasters, particularly earthquakes, and exhibits significant vulnerabilities. Disasters result not only in the loss of life and property but also in economic, social, physical, and psychological damages. Minimizing and mitigating these losses is critical for enhancing urban resilience at both regional and national levels and for ensuring sustainable development.

Urban planning serves as an effective tool for disaster risk management by identifying and reducing vulnerabilities, preventing potential damages, and strengthening resilience. Disaster-sensitive planning processes aim to enhance urban resilience to earthquakes and other hazards through comprehensive analyses, spatial planning decisions, plan annotations, and zoning regulations. This approach supports rapid and effective post-disaster recovery.

The crisis management process following the 2011 Van earthquake was largely successful. Inter-agency coordination was effectively maintained, search-and-rescue operations were conducted by expert teams, temporary shelters were provided through tent and container cities, and the construction of permanent housing commenced promptly, thereby improving the living standards of affected populations.

Despite these efforts, Van Province remains highly vulnerable due to a range of disaster risks, including earthquakes, landslides, avalanches, floods, and rising lake levels. Spatial planning strategies addressing landslides, avalanches, floods, and water-level increases have been developed, contributing to enhanced urban resilience. Nevertheless, planning measures aimed specifically at mitigating earthquake damages remain partially inadequate, increasing the city's vulnerability and negatively affecting its overall resilience.

While the implementation of disaster-sensitive regulations has been a positive step toward enhancing urban resilience, post-earthquake planning processes revealed shortcomings in several critical areas, including: designated post-disaster functions, green space systems, spatial distribution of land uses, settlement patterns, building typologies, the macroform of the urban center, distribution of hazardous functions, and the diversity of transportation networks. These deficiencies indicate that existing vulnerabilities have not been fully addressed, leaving urban resilience insufficient.

It is therefore imperative to update planning practices across Van Province to reduce vulnerabilities and strengthen resilience. Clearly identifying functions to be used during disasters will establish essential protective mechanisms against earthquake risks. Planning processes should be conducted by expert institutions, independently of political and economic pressures, to ensure a long-term resilience perspective. Furthermore, unnecessary or unregulated modifications to existing plans should be avoided. Establishing scientific advisory councils, similar to the Japanese model, can ensure that only necessary interventions are implemented, thereby reducing vulnerability. Active participation of local authorities and communities in disaster management will enhance social resilience. In this context, evacuation plans should be prepared, assembly areas for disaster use should be designated, and infrastructures to meet the basic needs of the population must be established.

Finally, raising public awareness and educating residents about disaster risks is essential for reducing vulnerabilities. Early warning systems, disaster-focused digital platforms, and rapid access to information are critical tools for strengthening urban resilience.

In conclusion, although post-2011 earthquake crisis management in Van was largely effective, planning for seismic risk mitigation remains partially inadequate. Disaster-sensitive regulations have positively contributed to resilience, yet gaps persist in post-disaster functional allocation, green space networks, settlement patterns, building typologies, and transportation diversity.

Recommendations for improving urban resilience in Van include:

- Updating all planning levels to explicitly integrate post-disaster functions.
- Conducting planning independently of political and economic pressures, under expert supervision.
- Establishing scientific advisory councils to approve only necessary plan modifications.
- Enhancing community participation in disaster management to strengthen social resilience.
- Preparing evacuation plans and infrastructure to meet the population’s basic needs during disasters.
- Implementing early warning systems, disaster-focused digital platforms, and rapid information access.

Effective integration of these measures will significantly reduce urban vulnerability and enhance resilience against future disasters.

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Natural Plant Species Cultivation Approach in the Perspective of Sustainable Urban Design

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1. Introduction

With its dynamic nature, evolving and advancing technology offers new opportunities compared to past periods, leading to increased migration from rural areas to cities and, consequently, to greater urbanization. The majority of the world's population resides in urban areas due to the various opportunities they offer, which in turn puts increasing pressure on urban environments. On a global scale, the concept of the modern city can be traced back most closely to the post-Industrial Revolution era, when the demand for labor was largely met by populations migrating from rural regions. This rapid urbanization, while creating comfortable and convenient living conditions and fulfilling human needs for survival, enjoyment, and development, has simultaneously led to significant disturbance and damage to the urban natural environment (Long, 2022). This necessitates a paradigm shift towards sustainable urban planning and design (Figure 1), prioritizing the integration of natural plant species cultivation to mitigate environmental degradation and enhance urban resilience (Zarei & Shahab, 2025) (Gobster, 2010).

Figure 1. Emergence process of urban resilience

In this context, sustainable planning and design approaches gain importance, encompassing measures such as waste control, quality of structural materials, pollution prevention, and the balance between built and green spaces. Furthermore, the selection of plant species for urban open and green spaces is directly linked to sustainability, favoring native vegetation that requires minimal irrigation, pruning, fertilization, or pest control due to its inherent adaptation to local soil and climatic conditions. This approach not only conserves natural resources but also fosters biodiversity, thereby contributing to the ecological health and aesthetic quality of urban environments.

Urban sustainability depends greatly on ensuring urban resilience, and the concept of urban resilience includes many sub-concepts and factors. Urban sustainability is but one of the many sub-concepts of urban resilience, but is an important aspect of urban resilience. The concept of urban sustainability in turn incorporates many other concepts, and this research highlights some of the reasons and benefits of using natural vegetation and growing species in natural vegetation for the ecological sustainability of cities.

1.1.The Impact of Unplanned Urban Growth

Unplanned urban growth often leads to the loss of valuable green spaces and critical limitations on sustainable development, calling for a cross-functional urban greening approach before it is too late (Arshad & Routray, 2019). This urban growth (primarily occurring in the Global South) only adds to the environmental crisis of habitat fragmentation, extraction of additional resources and the ongoing degradation of the natural environment, meaning that adding green infrastructure as an integrated environmental scheme is key for urban growth and climate adaptation (Sahle et al., 2025). The urgency is also escalated by predictions that urban population will form two-thirds of the global population by 2050 (Figure 2), anticipated much of the concentrated load factor will continue to be due to the additional pressure of climate change and urbanization, following demographic change in populations (Applegate & Tilt, 2023). This rapid urbanization can cause significant environmental degradation, including too high heat exposure due to the urban heat island (UHI) effect, which results in temperatures that are elevated well beyond that of surrounding rural areas where the impacts of urbanization similarly stress the pre-existing ecosystems and ultimately physical health (Yılmaz et al., 2025). The compounded effect of heat health-related issues and urban air pollution, water quality degradation, loss of biodiversity, and flooding risks provides a very clear and urgent case for integrated urban green infrastructure solutions and planning for urban land (Menon & Sharma, 2021) (Teotónio et al., 2020).

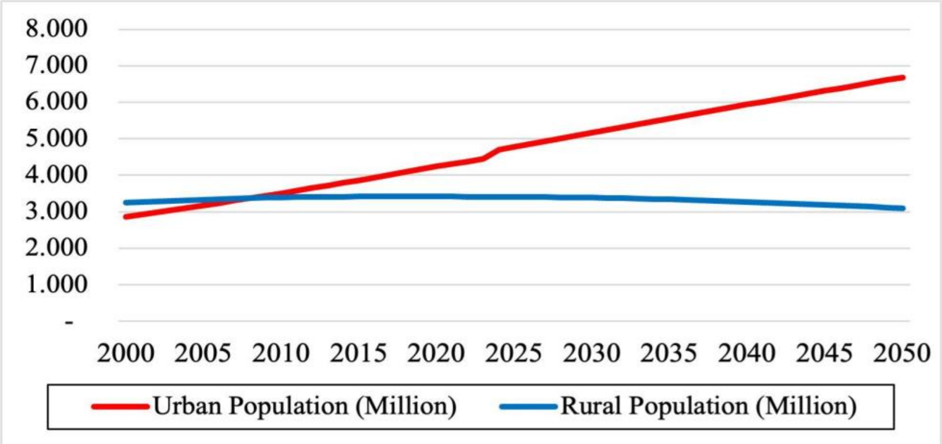

Figure 2. Indication of urban and rural growth by 2050
Source: United Nations, World Population Prospects 2022 (adapted by authors)

1.2.The Global Crisis: Resource Depletion and Pollution

Using non-native plant species that thrive outside of their local environment, especially need more water and high pest control which is a major driving force behind chemical waste that causes both soil and water pollution. The use of chemical pesticides contributes significantly to accelerating global warming, climate change, and depleting non-renewable natural. Unsustainable practices or approaches often negate any ecological benefits that are associated with urban greening and it clearly demonstrates our need to incorporate local species that provide support for local biodiversity and ecosystem services (Edeigba et al., 2024). On the other hand, smart use of native species will create a variety of ecological benefits that will lead to greater resilience to climate variability and allow for an opportunity to lessen the ecological footprint for urban care (Hensel, 2021). This means better land use planning to create and maintain urban green spaces, parks, urban gardens and roadside vegetation and demonstrate the value of mitigating airborne pollution and myriad ecosystem services (Ramaiah & Avtar, 2019). With suspected accelerating climate change and warming of urban areas under heat island effect as a result of loss of natural habitats and development sites leading to impermeable surfaces, our current urban planning process needs to include sustainable land use tools that focus on including nature-based solutions as they will have greater consequences on biodiversity loss, air quality, and overall urban ecology (Yan et al., 2024) (Ibrahim et al., 2020).

Population growth, industrialization, and urbanization have made urban morphology and energy composite notorious and have caused multiple environmental crises such as worsening air quality and an increase in average temperature within cities (Efe & Eyefia, 2014). This is a huge threat to human health and wellness and an urgent change towards green infrastructure must be made to reduce and limit the effects of urbanization on health and well-being (Liu et al., 2021). The loss of green spaces over time, because of urban expansion, is limiting biodiversity loss and urban centers should really promote integrated urban development that conserves and promotes natural habitats (Nshimiyimana et al., 2023). This also calls for more extensive usage of green infrastructure in urban planning including urban farms and urban forests to help mitigate environmental effects and promote a healthier urban ecosystem (Rallapalli et al., 2019).

1.3.Climate Change as a Consequence of Urban Expansion

Continued urban growth, primarily through sprawl, is one of the most critical factors to contribute climate change in cities. Urbanization increases impervious surfaces to increase the urban temperature, which severely impacts local hydrological cycles (Bai et al., 2017). This alteration can have multiple effects downstream, such as increased runoff, reduced groundwater recharge, UHI, and flood risk (Ajjur & Al-Ghamdi, 2022). Urbanization also raises energy consumption, as it increases cooling loads due to high urban temperatures, which also contributes to greenhouse gas emissions, resulting in further climate change (Ferrer et al., 2016). The combination of increasing energy demand due to air conditioning plus the energy to meet this need puts burdens on existing energy systems, which also increases carbon emissions, and challenges the sustainability of cities (Salamanca et al., 2013). The complex relationships between urban growth, climate change, and human health, wellbeing and livelihoods require an immediate transformation to sustainable and resilient urban planning, focused on green infrastructure and nature-based solutions for climate change adaptation and mitigation (Pandey & Ghosh, 2023) (Das et al., 2024) (Javidroozi et al., 2023). The transformation requires a reconceptualization of urban development, which relies on ecological concepts and focuses on climate resilience, to create new models of urban design to improve climate adaptation and climate change mitigation (Das et al., 2024). A resilience model incorporates urban green infrastructure as a key component of resilient socio-ecological systems, not just to improve aesthetics in the built environment, but to help society adapt to climate variability and improve urban livability (Vargas-Hernández & Zdunek-Wielgołaska, 2020) (Kabisch et al., 2021). Integrating nature-based solutions and green infrastructure into urban planning is essential to address the growing climate change pressures, promote urban resilience, and improve the quality of live for urban dwellers (Raparthi & Vedamuthu, 2022) (Choi et al., 2021).

1.4.Urban Heat Islands and the Role of Green Spaces

The urban heat island effect refers to the phenomenon where urban areas experience higher temperatures than their non-urban counterparts, primarily due to intensive energy use, reduced air quality, and associated impacts on human health (Irfeey et al., 2023) (Naserikia et al., 2019). Minimization strategies must be created, and how to achieve this is important. Green infrastructure is one important nature-based solution for addressing urban overheating and providing enhanced thermal comfort (Yuan, 2024) (Yılmaz et al., 2025). In reality, the urban heat island effect only occurs because many studies attribute component parts to it from anthropogenic heat sources and impermeable urban surface temperatures. In addition to agreements in the literature, it is known to increase temperatures of urban areas and compromise human beings, and more than ever, increasing urban planning and cities' actual response to hot conditions must be part of urban planning interventions (Nazarian et al., 2022). Urban green spaces, i.e., parks, urban forests, and green roofs, have significant potential for lessening the urban heat island effect, as green spaces provide shade, conduct evapotranspiration, and/or allow air to circulate (Kirschner et al., 2023). In particular, not only do green are partially absorb heat from urban areas, but they create a healthier urban microclimate to provide a bigger picture to urban sustainability (Song et al., 2024) (Oğuztürk et al., 2025). Specifically, green roofs can have substantial reductions of surfaces and ambient temperatures of up to 30 °C surface temperatures and thus lessen the urban heat island direct measures to mitigate and stormwater manage are superior (Zhang et al., 2024). Another method of how diverse green infrastructure is strategic is in the form of private dwelling gardens, or yards and patio, and flowerpots, which also can use some of the referred cooling effects of shading and evaporative cooling (Taleghani et al., 2019). Altogether, in addition to local effects, large urban parks and/or large green spaces are both subsequently, required to lessen urban heat island effects from a regional, agglomeration scale affecting nearby built environments (Wong et al., 2007) (Bosch et al., 2021). Because urban designers and planners must consider the high intensity, density to reduce urban heat islands (Aram et al., 2019). It understands together and the highest potential for reducing urban heat and contributing to improving urban microclimates means everything basic to improving the performance of increasing quality of urban life and so the term "urban became connected. Of all the areas of green blue grey infrastructures, registrarial, vegetation-based, water-based, and engineered green structures show a complete (overall) response to lessening overheating of urban areas and reduce energy in a positive way to be quality of the urban dweller's life is greater (Kumar et al., 2024). In the, design and development phases, integrating natural plant species in green infrastructures is crucial because natural plant species, made of existing plant species, are already suited and adapted to a more local climate. This qualitative response of species suitability and adaptation, for example, make green infrastructure systemic and sustainable systems for the city. Also, in the same dialogue, a perspective of how natural plant species provide maximum opportunity in a minimum area similar to space is precious for small urban environments.

1.5.Landscape Practices and Their Environmental Impact

Traditional landscape practices are heavily reliant on a high-input model of practice (heavy irrigation, chemicals (fertilizers and pesticides), and irrigation techniques, etc.) that causes water pollution, soil degradation, and loss of biodiversity when placed within the ecological context of urban settings. Traditional landscaping practices with little potential for ecological integrity are also increasing the heat island effect in urbanized areas by ignoring the benefits of planting native and climate/hydrology adapted plant species that require fewer resources (Mackey et al., 2011) (Virtudes, 2016). The exclusion of native species and resource-conserving plant species creates less resilient urban ecosystems that are not able to buffer against wide climatic differences or support native flora/fauna biodiversity (Shiu et al., 2022). The use of sustainable landscape practices that keep native and climate and hydrology adapted plants as part of the initial landscape design supports viable ecosystems by conserving water, reducing chemicals, and increasing urban biodiversity to create more resilient and ecologically sound urban practices. In addition to the adoption of sustainable landscape practices, policy and planning mechanisms should work together to encourage more sustainable practice adoption in urban areas and landscapes and create urban landscapes that are rich, impactful, and ecologically and economically sound (Gunawardena et al., 2017).

1.6.Principles of Sustainable Urban Design

Sustainable urban design seeks to integrate natural processes, and ecosystem functionalities into the built environment in order for our cities to become resilient, sustainable, and livable (González et al., 2023). It helps reduce its ecological impact, but encourages social equity and economic feasibility when communities achieve efficient land use, resource consumption, and benefit from green infrastructure. The intentional selection of species or vegetation that is climate- and soil-specific to the existing ecosystem is necessary to achieve sustainability because it significantly reduces maintenance requirements and embodies the most efficient resource use (Shahmoradi & Marvi, 2015). Additionally, by choosing appropriate species populations of the urban ecological character, and particularly, native plants, it provides an important opportunity to increase local biodiversity, improve ecosystem services, and re-enforce urban connection to the natural environment. Sustainable urban design promotes and prioritizes the needs of nature against the needs of humankind. Thus, an ideal sustainable urban design aims to mitigate the negative ecological impact of the built environment (in terms of water, soil, air and climate) (Thomson et al., 2022). Therefore, urban growth or development should contribute to neither the poisoning nor the degradation of ecological health. Urban cities must develop and uphold their biodiversity and be resilient enough to negotiate the actions of both human and non-human inhabitants. Sustainable urban design prescribes ways to deviate from traditional urban design models, including comprehensively adopting resistance practices (Yiu, 2025). At the heart of this paradigm is the understanding that the built environment must enhance, rather than diminish the natural environment, while planning doses must be economically sustainable and supported by a broad range of public consensus (Parra, 2002). The use of heavy agricultural equipment and other technologies, will need to be part of sustainable urban design practices that will mitigate endless, poor urban growth and truly allow to responsibly diversify and implement sustainable forms of urban design in cities. Urban agriculture is also not only praised for its contributions to urban sustainability in food procurement and maintaining landscapes (Arshad & Routray, 2019) but viewed as a vehicle for more equitable and sustainable public policy objectives addressing equitable access to good food and the environmental impact of the food chain (Saint-Gès et al., 2024). These technologies play an important role in resources optimization; trash reduction, impacts on the environment, and enhancing the resilience of urban ecosystems, directly link to sourcing natural plant species and management of green infrastructure (Shehata et al., 2022; Yuan et al., 2022).

In order for all urban dwellers to access natural resources that can be passed on to the next generations, while also keeping a proper balance between conserving and using those resources, viable planning and design approaches are gaining traction under the rubric of "combating climate change." Many actions are being implemented in the process of conserving and using the natural resource base of the earth, in areas such as inventorying and protecting existing resources, producing and utilizing renewable resources, and minimizing all waste outputs.

Sustainable design in urban public spaces is not only connected to sustainable development in diverse areas, such as using appropriate structural materials, avoiding materials that pollute, accounting for the ratio of buildings to existing open and green spaces, but also the plants under consideration in plants used/preferred plants in urban open and green spaces. Therefore, one of the main practices to provide sustainable futures and protect natural resources is if the choice/use of vegetative plants in their native ecosystems are as naturally behaving as possible and require no maintenance (eg. watering, pruning, fertilizing, and pesticides) and choose sweetly variable contextually plant species that demonstrate the highest level of adaptability to the natural soils and climates inherent to those native ecosystems.

2. Material and Method

This study was designed as a comprehensive review of literature focusing on the role of native plant species in sustainable urban design. To ensure transparency and replicability, a systematic procedure was followed in the collection, screening, and analysis of sources.

2.1. Literature Identification

Scientific publications were retrieved from major academic databases (*Web of Science, Scopus, Google Scholar*) covering the period between 2000 and 2025. Keywords such as *urban resilience, native plant species, xeriscaping, sustainable landscape design, water-efficient landscaping, climate-responsive urban planning,* and *automation in urban ecosystems* were used in various Boolean combinations. Additional relevant materials, including policy documents, municipal guidelines, and reports by international organizations, were considered to complement the academic literature.

2.2. Screening and Selection Criteria

All identified records were imported into reference management software, where duplicate entries were systematically removed. The initial screening was conducted on titles and abstracts, excluding studies that did not address sustainable urban design, native vegetation, or ecological and technological aspects of landscaping. Priority was given to peer-reviewed articles, book chapters, and conference proceedings with clear methodological contributions.

2.3. Eligibility Assessment

Full-text evaluation was applied to the remaining studies. Publications were excluded if they lacked methodological rigor, contained insufficient data on vegetation and design practices, or focused exclusively on ornamental plants without sustainability considerations.

2.4. Inclusion for Synthesis

The final set of studies was thematically categorized into clusters such as:

- Ecological benefits of native vegetation,
- Xeriscaping and water-efficient practices,
- Technological and smart system integration,
- Governance and planning frameworks for sustainable urban ecosystems.

2.5. Data Extraction and Thematic Analysis

For each included study, descriptive data (authors, year of publication, methodological approach, vegetation type, and ecological/technological contribution) were extracted. Thematic coding was used to identify recurrent strategies, design principles, and barriers in integrating native species into urban landscapes. This process allowed for comparative evaluation across different contexts without limiting the scope to a specific geographic region.

3. Findings and Discussion

Within the scope of sustainable and resilient urban landscape design, the preference and use of perennial plant species instead of annual and/or seasonal plant species, especially in urban open and green areas, ensures water-efficient landscape design while adhering to drought-tolerant landscape design principles.

The concept of xeric landscaping is based on the idea that only certain types of plants can survive during periods of drought. Accordingly, a landscaping approach appropriate to different climate characteristics must be determined. The primary objective of this approach is to minimize water consumption by using plants with low water requirements and to ensure the sustainability of natural water resources (Barış, 2007). Applications that are adapted to natural vegetation and have xeric landscaping characteristics are becoming increasingly competent today (Çorbacı et al., 2017; Çorbacı and Bayramoğlu 2021).

During the sustainable planning and design process, xeric landscaping will be implemented by selecting/using plant species found in natural vegetation, and existing water (clean water) resources will be protected.

Within the scope of water-efficient design, sustainable urban open and green spaces will be created by developing new methods and practices such as minimizing the use of clean water, increasing wastewater, and harvesting rainwater, thereby supporting the struggle with climate change.

3.2. The Importance of Native and Low-Maintenance Plant Species

The inclusion of native and low maintenance plants in urban landscapes is a core principle of sustainable urbanism, offering multiple environmental, economic and social benefits. Native plants are intrinsically suited to local climatic conditions, and require little irrigation, fertilization and pest management than plants introduced from other regions of the world. As a result, urban green spaces can significantly diminish their ecological footprint. (Russo et al., 2025). By using native plants, urban green spaces can conserve valuable resources, deepen local biodiversity, create habitats for native wildlife, and contribute to urban ecosystems that are more stable and resilient (Yiu, 2025). Native plants also contribute to the aesthetics of urban areas, demonstrating regional identity and enhancing the sociocultural value of public spaces (Al-Hagla & Al-Sulbi, 2025) (Stino, 2017). Choosing native plants also encourages stronger connections to the local ecosystem, develops community interest and interaction with ecological systems, and aids the overall sustainability goals of urban system development (Shareef & Altan, 2021). Additionally, the deep roots native plants tend to possess supports soil stabilization and permeability, supporting water management that minimizes negative urban runoff (Ulloa-Espíndola et al., 2022). In this manner, native plant establishment provides significant carbon-sequestration functions, which improves urban air and mitigates climate change through natural processes.

As a part of the landscape design process, the local characteristics of climate and soil requires consideration too. Particular attention should be paid to the use of natural plant species in the design. This is because natural plants require very little watering after the landscape application is completed, or they do not require additional watering beyond natural rainfall. In addition, they do not require additional fertilization and are more resistant to diseases and pests.

3.3. Water-Efficient and Climate-Responsive Landscaping

In particular, the large-scale consumption of water in open green spaces has necessitated the development of new landscape designs that use as little water as possible. In this regard, landscape design principles that differ from classic landscape design concepts such as "Water Efficient Landscaping," "Water-Wise," "Low Water," and "Natural Landscaping" have been developed (Barış, 2007). One of the first conceptual approaches developed with the formulation of these basic principles is "Xeriscape," which can be defined as a type of landscape design that aims to conserve water resources and the environment by using the least amount of water possible. This concept was first developed in 1981 by the Denver Water Department to promote water conservation in landscape design, combining the Greek word "xeros" (meaning 'dry') with the English word "landscape."

There are seven basic principles underlying xeric landscaping which are:

- Planning and designing that minimizes the amount of lawn space and requires the least amount of watering.
- Conducting soil analysis and improving soil conditions in accordance with the results,

- Selecting natural plant species that require minimal water and are drought-resistant,
- Designing lawn areas in a way that offers practical and economical solutions that facilitate application and maintenance work,
- Establishing an effective watering system,
- Mulching (covering the soil with materials that can create suitable temperature and moisture conditions around plant roots and preserve soil moisture, such as dry leaves, straw, etc.)
- Conducting appropriate and regular maintenance work (Barış, 2007).

According to the xeric landscaping strategy, natural and ecological factors are taken as a basis, maximum benefit is obtained from existing water resources while water consumption is minimized, and the balance of "conservation" in nature is maintained. Xeriscaping saves energy, time, and money while providing ecological benefits such as increasing the drought resistance of plants, providing habitats for fauna, contributing to the sustainability of natural resources, and creating spaces with high landscape character and quality—offering numerous ecological and economic benefits (Çorbacı and Ekren 2022).

In xeriscape applications, the use of large lawn areas and hydrophytic (aquatic) plants should be kept to a minimum, and plants with high drought tolerance should be preferred (Hersek and Korkut, 2021). This approach emphasizes the selection of drought-tolerant and climate-adapted vegetation, meticulously chosen to thrive within the specific hydroclimatic regimes of urban areas, thereby significantly reducing the demand for potable water in irrigation (Table 1). This practice, often termed xeriscaping or water-efficient landscaping, involves thoughtful plant grouping, efficient irrigation systems, and the utilization of mulches to optimize water retention and minimize evaporation. Such strategies are crucial for sustainable urban development, particularly in arid and semi-arid regions, where water scarcity is a pressing concern (Wang et al., 2020).

Furthermore, the incorporation of nature-based solutions such as green roofs, permeable pavements, and rain gardens increases retention and infiltration and transforms urban environments into more resilient "sponge cities" that can manage stormwater successfully, creating resilience against flooding (Rosenberger et al., 2021). These green infrastructure interventions address flooding, reduce urban heat by providing evapotranspiration during stormwater management, which can rehabilitate the urban heat island effect (Reinstaller et al., 2025) (Pace et al., 2025). In addition to hydrological benefits, the integrated systems described, may provide wider ecological services that deliver biodiversity services and potential aesthetic and recreational benefits for urban green space users (Sitzenfrei et al., 2020). Notably, this way of adaptive management links science and knowledge, supporting shifting to a resource-centric agenda, rather than simply considering rainwater as a risk hazard, which potential to regenerate urban ecosystems and increase the resilience of cities (Palazzo, 2018).

Table 1. Comparison of Key Characteristics of Native and Non-native Plant Species in Urban Landscapes

Criteria	Native Plants	Non-native / Imported Plants
Water Consumption	Low	High
Pest Control Need	Minimal	Frequent
Soil Compatibility	Naturally Adapted	Often incompatible
Biodiversity Contribution	High	Low
Maintenance Requirement	Low	High
Climate Adaptability	Excellent	Varies
Chemical Input (Fertilizers/Pesticides)	Low	High
Aesthetic Integration	Region-specific	Often ornamental but mismatched
Lifecycle Cost	Low	High
Carbon Sequestration Potential	High	Varies

3.4. Automation and Robotic Applications for Urban Green Spaces

The upkeep of urban green spaces requires ground maintenance activities such as pruning, irrigation, fertilization, pest control, and waste disposal, which all have significant environmental footprints with regard to energy use and greenhouse gas emissions. To identify efficiencies and reduce footprint impact is the utilization of automation and robotic technology. For example, automatic mowers are used for sustainability (Hubbard et al., 2021). Outlined designs for lawnmowers indicate the range of multi-functional and low noise alternatives for trimming bushes and grass (Liu, 2014). Water efficient cleaning devices for roadside green belts have been developed to enhance water utilization and energy efficiency (Lu et al., 2013). Urban agriculture is also emerging in cities to provide more food production in limited space (Dhakal et al., 2015), therefore, robots are being designed uniquely to monitor plants, facilitate precision-based irrigation methods, and provide economical designs for individual or urban farm level green spaces (Moraitis et al., 2022). Robotic systems are vital to improve urban farming by monitoring plants, improving resource use and sustainability (Kempelis et al., 2024).

The landscape plan that will be developed should take into account regional and microclimatic conditions, existing vegetation, topography, land use and most importantly, how to group plants where they require similar water amounts.

Watering will depend on the season, amount and length of light exposure, microclimate, type of plant, and soil. If an automatic control system is used for watering, it can be fully dependent on the season and setup based on the weather. Automatic systems must be turned off if there is rain, to save water (Deniz, 2009).

In areas with high evaporation rates, plants either go directly into dormancy or die immediately from drought by covering the upper layers of soil with their roots.

To prevent damage to plants or death due to overwatering instead of underwatering, the water requirements of existing plants should be well understood and the appropriate amount of water should be provided. When the optimum amount of water required by the plant is used, water savings will also be achieved.

3.5. Smart Systems and Sensor Technologies in Urban Greening

The advent of technologies such as the Internet of Things, computer vision, artificial intelligence, and machine learning is revolutionizing urban agricultural practices by improving efficiency, monitoring capabilities, and decision-making processes (Kempelis et al., 2024; Mahmud et al., 2023). Management systems incorporating IoT technologies are now being used to monitor and management environments, developing the logistics of supply of locally grown fresh produce, in controlled environments and indoor container farms (He et al., 2022). These systems allow for precision agriculture and incorporate sensors and automation to reduce reliance on labour while allowing for effective management in ornamental nursery crop production (Mahmud et al., 2023). The devices can provide real-time information of soil moisture, nutrient levels and plant health allowing them to manage their resources efficiently (Xing & Wang, 2024). Smart irrigation systems are also being developed to provide exacting nutrient concentrations which enable precise nutrient application which supports plants grow needs at varying stages (Sangeetha & Periyathambi, 2024). In vertical farms aeroponics systems and water recovery technologies represent some of the most advanced agronomic production systems using water very efficiently (Carotti et al., 2023).

3.6. Urban Agriculture and Controlled Cultivation Systems

In addition to nature-dominated approaches emphasizing native plants in the public realm, controlled cultivation systems (e.g., vertical farming and plant factories) provide a useful alternative system to address land constraints and rising food demand. These directed cultivation systems can be deployed at a building, block or district scale to increase production per land area and reduce supply chains within cities, enhancing food security and reducing emissions from transport in a congested urban fabric (Wang et al., 2023; Wood et al., 2020). Importantly, controlled cultivation systems are not replacing natural vegetation or non-built green space, rather they are coming in to fill certain provisioning holes while the city restores, increases, and ecologically upgrades blue-green infrastructure at the same time.

From a resource efficiency perspective, modern cultivation systems utilize recirculating hydroponics/aeroponics, close nutrient-loop delivery, and tight environmental control to minimize water losses and production inputs per kilogram of product (Erekath et al., 2024; Kabir et al., 2023; Morella et al., 2023). Sensor networks, IoT-enabled automated systems and machine-human intelligence decision support are adapting to minimize fertilization and canopy management, noting design recommendations for infiltrating built environments in a water-efficient way (He et al., 2022; Mahmud et al., 2023; Kempelis et al., 2024). Since energy demands can be considerable, it is best practice to couple these systems with on-site renewables, waste-heat recovery and demand-response operation, concurrently with design teams examining project life-cycle trade-offs on-site so that lift in water use efficiency is not be consumed by undue energy load impacts.

Controlling cultivation systems can be strategically integrated into urban plans in order to share space and resources with native plant public space to provide a more resilient multifunctional urban ecosystem. Actionable examples include: tying rooftop farms to green roofs to provide additional stormwater retention capacity, heat mitigation; selecting crops and cultivars suited to regional climate and market needs; retrieving nutrients from organic waste-sites; and, when appropriate indexing water use per kg, energy use per kg and biodiversity metrics into municipal procurements and zoning incentives (Oh & Lu, 2022). In this way, cultivation systems can be thought of as targeted solutions enabled by technology to complement nature-dominated designs in a way that cities can meet food and resource demands, while native vegetation remains the foundation for biodiversity, microclimate regulation, and cultural identity.

3.7. Toward a Resilient and Sustainable Urban Future

This section explores methods and practices of urban planning and design that recast and aim to develop a holistic approach to planning that can seamlessly integrate the cultivation of local flora with enhanced water management and climate adaptation practices (Snep et al., 2020) (Sharma et al., 2023). A holistic approach coherently implies there is a capacity for urban communities to increase resilience against the impacts of climate change, including both excessive heat and flooding, harnessing the concepts of ecology to create urban ecosystems that are self-sustaining (Avramidou & Manika, 2021). The notional resources necessitate a reversal from centralized, single-purpose infrastructure to decentralized, multi-functional green infrastructure where urban surfaces can simultaneously maximize ecological performance and deal with resource issues (Pille & Säumel 2021) (Croce, Inc. et al Ap. 2019). The success of these integrated approaches wholly depends on the continuous inventive use and universal uptake of agricultural equipment and smart technologies that will allow nature-based options to be implemented efficiently in the medium and long-term profitable methodologies (Ogwu & Kosoe, 2025). This comprehensive strategy acknowledges that, in light of the rising global urbanization levels and a certain degree of impermanence in climate, the urban water role needed to manage will require more than the traditional "grey" infrastructure alternatives, and embracing the provision of nature-based solutions will be capable of flooding controls, improved water quality and possibly climate resilience (Ahmed et al., 2022). Certainly, with extreme precipitation events likely to increase urban vulnerabilities and not wanting to experience the impacts of significant, and sometimes devastating pluvial floods, had conventional urban drainage systems provide much refuge (hyo-min et al., 2016) (Shevade et al., 2020). Naturally, we must recognize there are increasing calls for resiliant and sustainable urban drainage and what improvements can be made from green-grey infrastructure systems that aim to be flexible and adaptive to exciting climatic shifts (Fereshtehpour & Najafi, 2025; Kourtis et al., 2020). This recognizes the transformation and innovative approaches to urban water management and planning to co-consider, one urban water cycle that devotes equal treatment to the management of supply and demand, wastewater treatment for reuse and stormwater reuse, ensuring valuable human and natural elements become part of an urban water cycle as competitively valuable, securing sustainable and circular economies of water (Maftuhah et al., 2018) (Taouraout et al., 2020). This shift remains immensely important if we are to make urban environments sufficiently firm to withstand the onslaughts of environmental shocks and return to voluntary equilibrium, thus giving urban residents a deserving, healthy place to live (Beceiro et al., 2020) (Doulabian et al., 2023).

3.8. Water Efficient Landscape Design for Urban Sustainability

With increasing building density in cities, the amount of impermeable surfaces is also increasing, and the amount of open and green spaces is decreasing at the same rate. As part of the fight against climate change, one of the most important global issues, the formation of urban heat islands, air pollution, noise pollution, and similar issues caused by the increase in impervious surfaces in cities, intensive vehicle use, and the decrease in green areas, as well as the protection of existing resources, the control of resource use within the framework of a conservation-use balance, and the protection of biodiversity are among the issues included in the action plans.

Water, one of the most important resources that must be protected on a global scale, is also a key focus of water-efficient design, a method used to protect water resources and combat climate change. Water-efficient landscape design is finding its place in the design of urban open and green areas due to its features such as reducing water consumption, preserving biological diversity through the use of natural plant species, lowering facility and maintenance costs, contributing to the local economy, and enhancing visual landscape value through adaptive plant species.

4. Conclusion and Suggestions

The species in the natural vegetation of a region are those that are best suited to the natural landscape features of that region, such as climate conditions, rock structure, soil structure, slope, and wind, but there may also be species that directly require existing features. In this context, these species develop without the need for intervention or maintenance. Plants that grow, develop, branch out, leaf out, flower, and shed their leaves according to seasonal and climatic conditions offer a visual feast of different cycles throughout the year when the conditions and combinations appropriate to their location are provided. Plants that showcase the seasons and seasonal transitions through their leaves and flowers should be selected from the natural plant cover species to meet the recreational needs of people living in residential areas/urban dwellers in terms of their interaction with nature. Choosing native species for urban open and green spaces will bring many benefits. For example, creating large grassy areas in urban areas will increase water consumption and lead to maintenance requirements such as fertilization, planting, and mowing. However, natural species such as pimpernel, periwinkle, and rock samphire can be used to create extensive open and green spaces in cities without the need for pruning, watering, or fertilization. Therefore, the selection and use of natural species will provide both ecological and economic benefits.

In the planning and design processes of cities, many issues are addressed, such as land use, possible growth directions, and alternative transportation systems, through the accurate analysis of ecological data. Within this scope, studies are conducted that include the locations and quantities of urban open and green spaces. Areas such as refuges, parks, gardens, and recreational areas are defined as urban open and green spaces. In the urban design process, the basic principle of road side green belts in all planned new transportation systems and the selection of natural species for refuge plants will enable ecological gains in many areas, such as low maintenance costs, economic benefits, the non-use of clean water sources for irrigation, the prevention of groundwater pollution, and the prevention of urban heat island formation through the establishment of a permeable -impermeable surface balance, and preventing the formation of urban heat islands.

Selecting species that are naturally present in the vegetation cover as part of water-efficient landscape design or xeriscape design will reduce implementation costs, eliminate the need for additional chemical inputs as these are the most suitable and adapted species for the existing microclimate, prevent contamination of groundwater resources by eliminating the need for fertilizers and pesticides, Since these are plants with the lowest water requirements, water and energy consumption will be minimized, and maintenance will be required. The invasive characteristics of imported plants will be prevented, and the biodiversity of the existing vegetation will be preserved. During the design phase, it is essential to thoroughly analyze and evaluate the existing environmental conditions, such as climate, soil, topography, and vegetation, to the highest possible extent and ensure their protection.

Retention of existing vegetation cover and the incorporation of local, drought tolerant and water-wise plants in landscaping are crucial considerations. Lawn areas should be minimized and perennial ground-covering plants should be selected over annual flowering plants. Specific irrigation systems for the water needs of the plant, mulch for soil moisture retention, rainwater harvesting and onsite rainwater storage, and reuse of wastewater for landscaping irrigation are the key methods to effectively conserve water. It has become imperative for all sectors and professions to take precautions against increasing drought. The drought problem experienced in large cities during the dry winter season highlights the need for efficient water use and the protection of water basins and resources (Atik ve Karagüzel 2007). Agricultural engineers and landscape architects should come up with natüre-based ideas as interdisciplinary solutions within the context of urban resilience.

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All authors contributed equally to the article.

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Establishment of an Ecological Planning and Design Network for Disaster-Resilient Settlements

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1. Introduction

The increasing frequency and severity of natural disasters in the 21st century have made the vulnerability of cities and settlements more apparent. The concept of 'natural disaster' itself has been questioned, and it has been argued that disasters are largely the product of social and political processes (Wijkman & Timberlake, 1984). The frequency of disasters, economic losses, and the number of people affected have increased globally. This situation reveals that, despite improvements in disaster management capacity, social vulnerability has become more widespread (Feldbrügge & von Braun, 2002). These developments have not eliminated global inequality; rather, increasing vulnerabilities have created greater risks, particularly in developing countries (Alexander, 2006). Methodological studies on specific types of disasters, such as drought, point to the need to develop risk indicators and monitoring systems (AghaKouchak et al., 2015; Carrão, Naumann & Barbosa, 2018). Disaster risk assessment approaches have diversified over time, with comparative analyses conducted based on static-dynamic representations of hazard, exposure, and vulnerability components (Ward et al., 2020). Climate change, rapid urbanisation, ecosystem degradation, and inadequate planning practices are exacerbating the social impacts of disaster risks and complicating the achievement of sustainable development goals. However, significant inconsistencies have been observed among disaster risk indices, particularly in exposure indicators (Garschagen et al., 2021). This situation causes multifaceted impacts not only on the built environment but also on social, economic, and ecological systems. Long-term analyses show a downward trend in individual and material risk, but an increase in financial risk in the insurance sector (Boccard, 2021). Recent data reveal that the impact of disasters affects a wider segment of the population in countries with low levels of human development. In today's world, where traditional engineering solutions are insufficient in combating disasters, nature-based solutions (NbS) are emerging as a new paradigm. Therefore, the importance of NbS and justice-focused international intervention mechanisms is emphasised (Donatti et al., 2024).

NbS are integrated approaches that aim to reduce disaster risks by utilising ecosystem services, while also enhancing ecological sustainability and societal well-being. These solutions include applications such as green infrastructure, blue spaces, permeable surfaces, natural flood basins, and ecological corridors, and enhance resilience to disasters in both rural and urban areas. NbS are gaining increasing attention in disaster risk reduction (DRR) policies in terms of sustainability, co-benefits, and the integration of ecosystem services. Post-2000 literature shows that these solutions are being addressed more systematically in the context of DRR. Typologies proposed to develop effective and comprehensive NbS strategies in a spatial context take into account variables such as application approach, landscape unit, targeted hazard types, biome conditions, and techniques used (Nehren et al., 2023). However, the success of NbS is shaped not only by biophysical factors but also by social acceptance and perception. Factors influencing public perception include risk awareness, trust, place attachment, and social conflict, and within this framework, the PA-NbS theoretical model is proposed (Anderson & Renaud, 2021). It is emphasised that potential co-benefits and adverse effects of NbS applications should be assessed together at an early stage to ensure their sustainability (Ommer et al., 2022). User-centred structures in which the purpose, method, and components of the assessment process are carefully defined are also mentioned in the literature (Veerkamp et al., 2021). Global analyses show that the likelihood of NbS implementation is higher in countries with high needs and capacity. This highlights the need for natural capital management and policy coherence (Tyllianakis et al., 2022; Debele et al., 2023). While the benefits of NbS in terms of ecosystem services are highlighted in European examples, spatial mismatch and data gaps pose significant limitations (McVittie et al., 2018; Dubo et al., 2023). In contexts such as São Paulo and India, governance deficiencies, prioritisation of grey infrastructure, and lack of long-term strategy are noteworthy (Young et al., 2019; Ghosh et al., 2024).

The integration of nature-based solutions into disaster management is not only related to technical and environmental adequacy but also directly linked to spatial planning, policy-making, and local capacity. Global-scale analyses using large datasets show that NbS applications are concentrated in hydro-meteorological disasters (floods, landslides, avalanches) and that the most commonly used methods are green infrastructure, afforestation, and water conservation techniques (Debele et al., 2023). However, it has been observed that these applications are not always located in the areas most at risk, particularly in the Alps, where spatial mismatches between needs and applications have been identified (Dubo et al., 2023). Experiences from ecosystem-based adaptation (EbA) examples show that multi-scale applications have high potential, but data gaps, financial sustainability, and challenges in measuring co-benefits limit implementation success (McVittie et al., 2018). The São Paulo example shows that, despite decision-makers' positive perceptions of NbS, grey infrastructure continues to dominate implementation, and sectoral integration is lacking in governance (Young et al., 2019). Similarly, analyses conducted in the Indian context suggest that, despite recommendations for NbS applications in urban flood management based on international best practices such as Sponge City and Room for the River, these approaches remain limited due to deficiencies in legal infrastructure and comprehensive planning (Ghosh et al., 2024). All these findings show that, in order for NbS to be an effective tool in disaster management, comprehensive strategies are needed not only in ecological terms but also in governance, spatial and social dimensions.

In this context, this book chapter focuses on the integration of nature-based solutions and ecological principles into spatial planning processes for disaster risk reduction, adopting the creation of an ecological planning and design network for disaster-resilient settlements as its central axis of discussion. Within this framework, the EPD-Net (Filling The Gap: Development of Ecological Planning and Design Learning Network and an Adaptive Smart Training Module for Disaster Resilient and Sustainable Cities) project, supported by Erasmus+ and implemented with a multi-stakeholder structure, offers a comprehensive approach that includes digital, pedagogical, and managerial components aimed at enhancing disaster resilience capacity. The project aims to integrate ecological resilience-based content into higher education curricula in the fields of spatial planning and design, which are directly related to disaster management. Additionally, it promotes interdisciplinary knowledge production through AI-supported smart learning modules, multilingual educational materials, case analyses, and workshop applications. In contrast to disaster policies that are mostly shaped by technical engineering solutions in the literature, this project offers a unique contribution by addressing NbS approaches from the perspectives of local knowledge, social participation, and pedagogical transformation. Within the scope of this section, the components of this network structure, educational strategies, inter-actor collaboration, and policy-making capacity will be discussed.

2. Conceptual Framework

In creating disaster-resilient settlements, ecological planning and design concepts must be addressed within a multi-scale and multi-actor framework. In this section, the concept of 'ecological planning and design' is first explained, followed by an assessment of key components such as vulnerability, adaptation, and recovery under the heading of 'disaster resilience'. Additionally, within the framework of NbS and sustainability principles, the theoretical interplay and synergistic functioning of these concepts are discussed.

2.1. Definition of Ecological Planning and Design

Ecological planning and design is an interdisciplinary and multi-scale approach that aims to shape human settlements in interaction with natural systems, in line with long-term sustainability and resilience goals. This approach is based on the holistic assessment of biophysical, socio-cultural and managerial data. As Wang, Palazzo & Carper (2016) point out, this approach is based on viewing the relationship between humans and nature not as a dualistic opposition but as one of mutual dependence and ecological wisdom. The model developed by Steiner and Brooks (1981) structures ecological planning as a decision-making process consisting of seven stages: goal setting, inventory, suitability analysis, alternative development, implementation, management, and evaluation. This structure points to a systematic planning methodology that integrates computer-assisted analysis and interdisciplinary collaboration. Over time, this framework has expanded to include new thematic axes such as ecosystem services, green infrastructure, resilience, and biodiversity (Heymans et al., 2019).

In the current literature, ecological planning is being redefined to explain more complex urban dynamics using the social-ecological-technological systems (SETS) approach. McPhearson et al. (2022), within this framework, emphasise the interactive structures of nature, society and technology, arguing that urban planning decisions should be made through multi-layered systems. This understanding is supported by tools such as UPSUF, which develops decision support systems based on natural capital and urban ecosystem services (Puchol-Salort et al., 2021).

Ecological planning requires an approach that is not only environmentally protective but also sensitive to social justice, aesthetic integrity, and cultural values. Ignatieva, Stewart & Meurk (2011) emphasise that green spaces are not only habitats but also areas of social and cultural interaction, drawing attention to the multifunctional nature of ecological networks. In this sense, ecological planning is an effort to reintegrate the urban fabric with both natural and social values. On the other hand, Bibri (2022) addresses ecological planning within the framework of smart eco-cities supported by digital tools such as big data, spatial modelling, and urban metabolism. They argue that sustainable urban forms can be reconfigured through parameters such as density, greening, and low carbon footprint. Similarly, Semeraro et al. (2021) argue that nature-based solutions should be designed in site-specific ways based on human health, permeability, and social needs. In this context, the governance, financing, social equity, and technical capacity deficiencies highlighted by McPhearson et al. (2025) indicate that ecological planning must be addressed not only in physical terms but also in institutional and political dimensions. When all these approaches are brought together, ecological planning and design emerge as a planning paradigm shaped by multi-dimensional principles such as technological innovation, social participation, institutional collaboration, and cultural awareness, rather than merely the protection of natural processes.

2.2. Disaster Resilience: Vulnerability, Adaptation, Recovery

The concept of disaster resilience is not limited to physical robustness or infrastructural resilience. It refers to a multi-layered and dynamic structure that also includes social, institutional, economic and cultural dimensions. Resilience analyses a system's response to risk-prone components through three fundamental concepts: vulnerability (the likelihood of damage), adaptation (the capacity to respond to shocks), and recovery (the ability to rebuild after a disaster) (Table 1). Şen (2021) addresses this tripartite structure under the headings of 'absorption capacity,' 'adaptation,' and 'coping,' emphasising that resilience is a holistic system shaped by the interaction of social, technical, economic, and institutional factors. This approach also reflects the paradigm shift observed in disaster management literature. There has been a shift from strategies focused on reducing vulnerability to policies aimed at increasing resilience. The Hyogo and Sendai Frameworks and the Sustainable Development Goals (SDGs) have placed the construction of resilient societies at the centre of disaster risk reduction (Şen, 2021). In this context, resilience is seen not only as a defence mechanism but also as a means of sustainable development and social justice.

Table 1. Disaster Resilience Components.

Component	Definition
Vulnerability	The likelihood of suffering damage from a disaster; the level of social, economic and physical sensitivity. Adaptation
Adaptation	The capacity of a system to adapt to environmental and social changes before, during and after a disaster.
Recovery	The ability of the system to return to its functional state and/or rebuild in a more resilient manner after a disaster.

It is important to emphasise that resilience is not a static characteristic but a process-oriented capacity. Jiang, Ritchie & Verreynne (2021) address resilience in three stages: situational awareness, adaptation capacity, and transformation ability. This structure is defined by the steps of ‘sensing,’ ‘seizing,’ and ‘transforming’ and demonstrates that organisations can respond strategically to crises by restructuring their existing resources. Similarly, Parsons et al. (2021) used their Australian Disaster Resilience Index to show how social, economic, and institutional capacity are affected by spatial inequalities, noting that resilience is generally low in rural areas. The concept of resilience has evolved over time through three evolutionary stages: ‘bounce back,’ ‘build back better,’ and ‘bounce forward.’ Graveline and Germain (2022) analyse this evolution through the lens of social learning, community-based approaches, and social capital, framing resilience not merely as an outcome but as a strategic learning process. In this context, resilience is built not only through engineering-based measures but also through socio-political processes supported by participatory governance, institutional flexibility, and local knowledge systems. Zhang, Lv & Sarker (2024) examine resilience in the tourism sector, highlighting the impact of risk reduction, community participation, and sustainable planning on post-disaster recovery processes. This sector example demonstrates that resilience is not solely dependent on physical infrastructure but also on social and economic systems.

At the community level, reducing the impact of disasters on public health is one of the most visible outcomes of resilience capacity. Programmes such as COAST, COPEWELL and Ready CDC, analysed by Abrash Walton et al. (2021), have highlighted the importance of interventions aimed at strengthening indicators such as mental health, disaster preparedness and social capital in low-resource municipalities. These approaches point to the need for a multi-level resilience network that extends from individuals to institutions.

Overall, resilience to disasters is not merely a capacity to ‘bounce back,’ but rather a multi-actor, multi-level process of reconstruction that involves reducing vulnerabilities, developing adaptation mechanisms, and building transformative potential. To achieve success in this process, interdisciplinary knowledge production, inclusive decision-making mechanisms, and policies that prioritise contextual flexibility must be implemented simultaneously.

2.3. NbS and Sustainability Principles

NbS are defined as multi-dimensional and multi-stakeholder intervention strategies that aim to enhance both environmental sustainability and social well-being by strengthening ecosystem processes. NbS not only generate environmental benefits but are also structured in an integrated manner with sustainability principles in areas such as social justice, governance capacity, and systemic transformation. Particularly in urban contexts, these solutions gain meaning through structures that are responsive to local needs, inclusive, and based on collaborative learning. Kabisch, Frantzeskaki & Hansen (2022) propose a systematic framework linking nature-based solutions to sustainability through five core principles: (1) systemic understanding, (2) simultaneous benefits for humans and biodiversity, (3) long-term and inclusive solutions, (4) contextual appropriateness, and (5) learning-communication orientation. These principles define the necessary conditions for NbS applications to be sustainable not only at the technical level but also at the social and managerial levels. In this context, concepts such as justice, inclusivity, and co-production are linked to the normative foundations of sustainability.

Wijsman and Berbés-Blázquez (2022) link the success of NbS to principles of distributive, recognitive, and procedural justice, emphasising that technocratic approaches can lead to problems of social legitimacy. The authors propose five key inquiry headings to provide normative clarity, arguing that social sciences should be more actively integrated into NbS processes. This approach envisions participation not only at a formal but also at a functional level, and sustainability goals advancing on the basis of social acceptance. Global analyses conducted by Cook et al. (2025)

show that when NbS applications are evaluated within the context of socio-ecological-technological systems (SETS), there are significant knowledge and application gaps in areas such as governance, economic valuation, social justice, and community participation. The study highlights that effective and sustainable NbS applications require not only technical expertise but also a long-term, contextual, and transformative learning process. The role of these transformative learning processes in urban sustainability was examined by Wickenberg et al. (2022) through two different NbS applications in the city of Malmö. The study reveals that factors such as citizen participation, care ethics, experiential knowledge production, and the active role of change agents are key factors that enhance the sustainability capacity of NbS. The institutionalisation of learning, visionary strategies, and collaborative governance models are the drivers of this transformation. On the other hand, Dorst et al. (2021) analyse the structural barriers to NbS applications through the conceptual framework of 'urban infrastructure regimes.' Eight regime dimensions, including physical geography, economic incentive systems, information infrastructure, and political regulations, explain why NbS is still implemented on a limited scale and the obstacles to achieving sustainability goals. This analysis reveals that cultural transformation and systemic alignment are as necessary as technical capacity. When the overall approach is evaluated, the table below summarises the relationships between NbS and sustainability principles (Table 2).

Table 2. NbS and Sustainability Relationship.

NbS Principle	Sustainability Dimension
Systemic understanding	Comprehensive analysis of socio-ecological-technological systems
Focus on biodiversity and human well-being	Balancing ecosystem services and social well-being
Long-term and inclusive solutions	Producing solutions that can be transferred to future generations and inclusiveness
Contextual appropriateness	Planning that is sensitive to local needs and based on justice
Focus on learning and communication	Participatory governance, transformative learning and joint knowledge production

All these approaches demonstrate the need for multi-stakeholder, equitable, contextual and learning-oriented structures to ensure that nature-based solutions can be integrated into sustainability. The long-term success of NbS requires the simultaneous establishment of technical accuracy, social legitimacy, transformative learning processes, and institutional alignment. Therefore, NbS should not be viewed merely as an environmental intervention but as a multi-level and normatively grounded tool for sustainability.

3. Interdisciplinary Transformation in Disaster-Focused Ecological Planning Education: The EPD-Net Approach

The integration of ecological planning and design into disaster management processes has become one of the fundamental tools for building sustainable and resilient cities. However, limited education and professional development opportunities in this field have created significant gaps in practitioners' disaster-focused planning skills. The EPD-Net project was developed to address this gap. It aims to offer a new ecological-based learning approach in disaster management through an interdisciplinary collaboration network and an artificial intelligence-supported smart education module. The project supports the restructuring of planning and design disciplines in the context of disasters by integrating green skills, digital competencies, and resilience capacity. This section will discuss the conceptual rationale, target audience, and partnership model of the EPD-Net project, as well as its transformative contributions to disaster-focused ecological planning education.

3.1. Theoretical Rationale and Conceptual Foundations of the Project

As the frequency and impact of climate-related disasters increase, cities' capacity to respond to these risks is being addressed not only through engineering solutions but also within a socio-ecological framework. NbS, ecosystem services and sustainable spatial planning approaches are at the forefront of building disaster-resilient settlements. However, these concepts have been integrated into the curricula of disciplines such as planning, landscape design, and disaster management only to a limited extent. This deficiency hinders the development of multi-sectoral and multi-actor solution capacities in disaster management practices and creates a structural gap in areas such as green skills, digital literacy, and social resilience.

The EPD-Net project is designed to address this gap by aiming to disseminate an ecologically focused planning approach through an interdisciplinary educational infrastructure. The project's theoretical framework is built on three main pillars: (1) creating resilient urban systems through nature-based solutions, (2) integrating the integrity of socio-ecological-technological systems (SETS) into decision-making processes, (3) establishing a multilingual learning system focused on green and digital skills in line with the European Qualifications Framework (EQF) (Figure 1). Thus, the project contributes to building comprehensive capacity not only for post-disaster recovery processes but also for preventive planning and risk reduction.

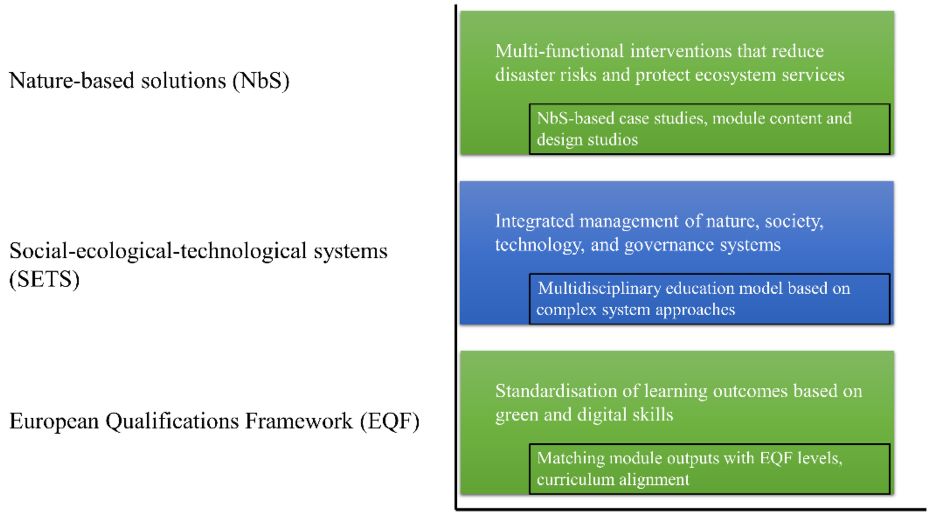

Figure 1. Theoretical Foundations of the EPD-Net Project

At the conceptual level, EPD-Net's approach to resilience is based on reducing vulnerabilities, strengthening adaptation processes, and increasing the potential for transformation. The ecological planning approach, on the other hand, requires a multidimensional way of thinking that considers not only physical planning but also social justice, cultural belonging, participatory governance, and biological diversity. EPD-Net aims to bridge the gap between knowledge production and professional practice by incorporating this way of thinking into learning processes. In this regard, the project offers a transformative learning infrastructure for a more equitable, sustainable, and resilient future in the fields of education, disaster management, and urban planning.

3.2. Project Objectives, Scope, and Target Groups

The EPD-Net project was developed in response to structural gaps identified in disaster-focused ecological planning and design education. Current education systems do not sufficiently address critical issues such as disaster risk reduction, nature-based solutions, and socio-ecological resilience in planning and design disciplines. In particular, the increasing number of hydro-meteorological disasters in Europe and its surroundings clearly highlight the need for professionals working in these fields to have up-to-date, comprehensive, and technical knowledge. In this context, the project aims to develop an AI-supported smart education module that integrates ecological principles into disaster management processes and, through this module, to comprehensively impart green skills, digital competencies, and resilience capacity (Figure 2).

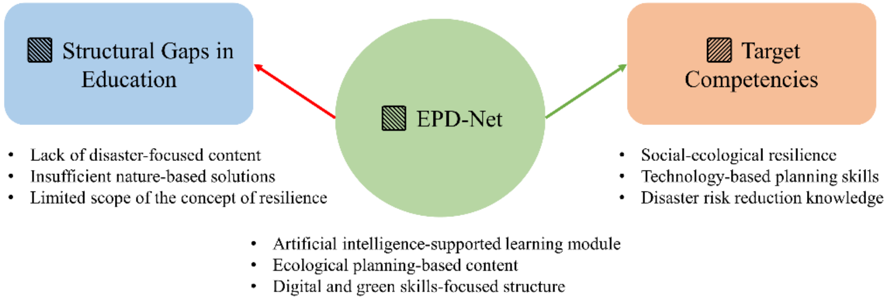

Figure 2. Educational Rationale and Contributions of the EPD-Net Project

In this context, the primary target audience of the project consists of urban planners, landscape architects, architects, public authorities, and disaster management professionals who play an active role in the planning of urban and rural spaces. To enable these groups to play a more effective role in pre-disaster risk assessment, disaster response, and post-disaster recovery processes, there is a need for a restructured educational infrastructure in the areas of sustainable spatial planning, ecological sensitivity, and technological literacy. The secondary target group of the project is academic institutions, research centres, and professional training organisations. These stakeholders will utilise the project outputs to generate new research areas, pedagogical models, and policy recommendations (Table 3).

Table 3. EPD-Net Target Groups and Contributions.

Target Group	Need/Gap	EPD-Net Contribution
Planning and design professionals	Lack of disaster-focused ecological planning skills	Skill development through digital modules and case-based applications
Disaster management experts	Weakness in integrated and interdisciplinary response capacity	Nature-based education content for pre- and post-disaster processes
Public authorities and local governments	Limited knowledge of spatial resilience and nature-based solutions	Data-based decision support systems in urban strategy development
Academic institutions and research centres	Need for pedagogical and content-based transformation	Production of new research areas and educational materials
Vocational training institutions	Lack of EQF-compliant modular training content	Integration of module outputs into curricula

In this context, EPD-Net aims to strengthen equal opportunities in education by developing a learning infrastructure that is applicable not only within Europe but also in global regions exposed to disaster risks. The smart modules and learning network to be developed within this scope will be implemented in a structure that is compatible with the EQF, multilingual, and multi-stakeholder, and will enhance both institutional capacity and social resilience by disseminating educational outcomes. The project aims to pioneer an education-based paradigm shift towards the construction of disaster-resilient, sustainable, and equitable settlements.

3.3. International Partnership and Cooperation Structure

Developing a comprehensive and effective intervention in disaster-focused ecological planning education is only possible through a multi-stakeholder and multidisciplinary cooperation structure. In this context, the EPD-Net project has been designed with a broad-based international consortium structure representing academia, the private sector, professional organisations and civil society. The consortium consists of various institutional profiles, including higher education institutions (HEI), vocational education providers (VET), research institutes (RI), software and artificial intelligence companies (SME & LE), professional associations (PC), non-governmental organisations (NGO) and international network structures (Table 4).

Table 4. EPD-Net Project Partners and Areas of Contribution.

Partner Institution Type	Areas of Contribution
Higher Education Institutions (HEI)	Academic content development, definition of learning outcomes
Vocational Education Providers (VET)	EQF-compliant modular education design and implementation
Research Institutes (RI)	Data analysis, resilience research, evaluation
Software & Technology Companies (SME/LE)	Artificial intelligence module, digital platform design
Professional Organisations (PC)	Policy-level contribution, professional dissemination
Non-Governmental Organisations (NGO)	Community-based learning, social inclusion
International Networks	European-scale dissemination and visibility

In addition to geographical diversity, disciplinary diversity has also been taken into account in the partnership structure. Partners from different fields of expertise, such as planning, landscape architecture, disaster management, geographic information systems, digital teaching design, and professional qualification systems, participate equally in the knowledge production and content development processes (Figure 3). The coordinator of the consortium is Eskişehir Technical University. The implementation processes are organised under a three-tier governance structure: the Executive Committee, which makes strategic decisions; the Project Coordinator, who ensures the coordination of processes; and the work package leaders, who are responsible for each work package. A consensus-based governance principle has been adopted for decision-making processes, and communication, planning, and evaluation mechanisms have been structured to operate at regular intervals.

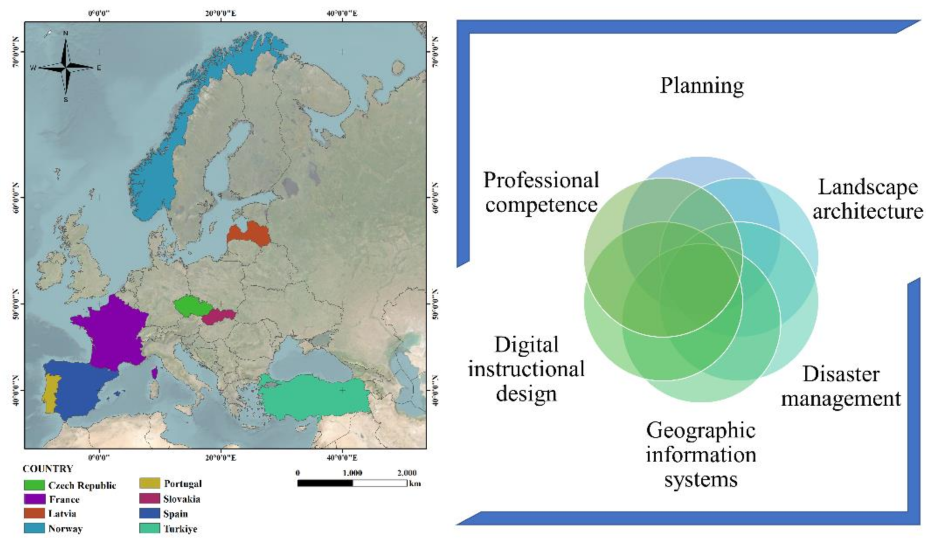

Figure 3. Geographical diversity and disciplinary differences in the partnership structure

This structure plays a strategic role not only in the development of project outputs but also in the dissemination, sustainability, and policy interaction phases. The presence of various professional organisations facilitates access to professional networks. In addition, technology companies contribute to the development of digital infrastructure. Higher education institutions play a leading role in the production of academic content and modules, while VET providers and professional associations integrate these outputs into education systems. In this way, EPD-Net is not just a project, but a collaborative, multi-level, and sustainable learning ecosystem.

4. Discussion and Evaluation

The dissemination of ecological planning and nature-based solution approaches in the context of disaster management through education brings about not only individual knowledge and skill development, but also institutional transformation and effective interventions at the policy level. The EPD-Net project addresses these multi-layered objectives within an interdisciplinary learning network, offering a new resilience-focused education paradigm. This section evaluates the relationship between the project's theoretical foundations and its practical outcomes, presenting a comprehensive discussion on the place of ecological planning in education, network-based operations in institutional capacity building, and compatibility with the EQF.

4.1 The Role of Ecological Planning in Education

Ecological planning and design offer a multidimensional approach that serves to organise the physical environment, reduce social inequalities, prevent disaster risks, and develop sustainable lifestyles (Wang, Palazzo

& Carper, 2016; Heymans et al., 2019). However, in many countries, this multi-layered content is still not sufficiently represented in higher education programmes. Although Steiner and Brooks' (1981) classic model proposed the integration of biophysical data into planning, today's urban crises, technological transformation, disaster risk, and social justice require the integration of these new axes into the model (McPhearson et al., 2022; Puchol-Salort et al., 2021).

The EPD-Net project has developed a pedagogical intervention aimed at integrating disaster-focused ecological planning into the academic curriculum, centring on this transformation. The AI-supported learning module designed within the scope of the project is structured with interdisciplinary content, case analysis, and workshop-based learning approaches. Thus, the theoretical foundation of ecological planning is supported by practical skills. This structure aligns with the objectives of researchers such as Bibri (2022) and Semeraro et al. (2021), who advocate for bridging the gaps between digital transformation, ecosystem services, and social needs.

4.2 The Role of Network Structures in Developing Institutional Capacities

Disaster-focused ecological planning requires institutional learning and interaction beyond individual expertise. Parsons et al. (2021) and Abrash Walton et al. (2021) have demonstrated that disaster resilience can be most effectively developed through local-scale, inter-institutional network structures. In this context, EPD-Net brings together partners from different countries and institutions to build an interdisciplinary and cross-sectoral learning ecosystem.

The consortium structure includes higher education institutions, vocational training providers, technology companies, and professional organisations. This structure supports content production as well as dissemination and sustainability. This interaction model directly aligns with the principles of transformative learning, multi-stakeholder governance, and knowledge sharing proposed by Cook et al. (2025) and Wickenberg et al. (2022). The development of institutional capacities provides a critical foundation for new-generation education models that integrate technology and pedagogy.

4.3 Alignment with the European Qualifications Framework (EQF)

One of EPD-Net's strongest points is that the project outputs are structured in line with the EQF. The EQF is a system that makes it possible to clearly define learning outcomes and recognise them across countries (Symeonidis & Blomqvist 2025). Within this framework, the project aims to integrate not only with the EQF but also with frameworks such as ESCO, ECVET, DigComp, and EntreComp. This approach ensures that learning outcomes are compatible with the European labour market, measurable, and transferable.

In the literature, competency-based education models are seen as a key element for professional transformation in the fields of disaster management and ecological planning (Zhang et al., 2024). EPD-Net defines both individual and institutional capacity within this framework, thereby proposing a system that can be disseminated across Europe and beyond by structuring resilience-focused planning skills according to EQF levels. The project targets EQF levels 5-6-7, representing a multi-layered learning system that encompasses undergraduate and postgraduate education as well as professional development.

5. Conclusions and Policy Recommendations

The increase in the frequency and impact of disasters necessitates a rethinking of spatial planning approaches based not only on engineering solutions but also on ecological principles, social justice, and multi-stakeholder governance models. The success of this transformation is directly linked to policy documents and the training of human resources capable of implementing these policies. At this point, the EPD-Net project integrates nature-based solutions and ecological planning principles with disaster management. It also aims to increase resilience capacity at both the individual and institutional levels by offering an interdisciplinary learning ecosystem. The AI-supported learning module designed within the scope of the project contributes to content production, equitable access to education, co-production, and digitalisation processes with its EQF-compliant content structure and multilingual, multi-actor network design.

It is necessary to integrate education systems with disaster risk reduction and sustainable development goals and to make ecological planning and resilience-based content more visible in higher education curricula. In this context, nature-based solutions, climate adaptation, green infrastructure strategies, and a socio-ecological systems perspective should be addressed simultaneously in applied disciplines such as planning, landscape architecture, disaster management, and geographic information systems. Additionally, by adopting EQF-compliant modular structures, it will be possible to develop recognisable and transferable qualifications across Europe, enhance the transparency of learning outcomes, and support professional mobility. As emphasised in the literature, not only technical skills but also horizontal skills such as transformative learning, governance literacy and social participation capacity play a decisive role in building resilient societies.

In this context, policymakers at the national and local levels need to place disaster-focused ecological planning at the centre of urban strategy documents, education and professional development policies. The interdisciplinary, digital, and participatory learning model developed by EPD-Net is considered a scalable and replicable tool that can serve this purpose. The learning module and open-access resources offered by the project have a flexible structure that can be used not only in universities but also by vocational education providers, local governments, and professional associations. In a broader context, the construction of disaster-resilient, sustainable, and equitable cities is only possible through a fundamental paradigm shift in education systems, and EPD-Net is positioned as an important policy tool in this transformation process.

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The article complies with national and international research and publication ethics.

Ethics Committee approval was not required for the study.

In this study, artificial intelligence was used solely for the purpose of enhancing the language and clarity of the manuscript; it did not play any role in the analysis, interpretation, or generation of the results.

Author Contribution and Conflict of Interest Declaration Information

1st Author 50%, 2nd Author 25%, 3rd Author 25% contributed.

There is no conflict of interest.

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From Crisis Response to Strategic Resilience: A Capacity-Based Transformation of Türkiye's Development Planning Towards the 2053 Vision

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1. Introduction

Development is a complex, long-term, and multidimensional process that extends far beyond the pursuit of economic growth. It encompasses the sustained enhancement, adaptation, and integration of economic, social, institutional, and environmental systems. Within this comprehensive understanding, resilience emerges as a critical foundation for ensuring development continuity and social welfare. Resilience refers not merely to the ability to withstand shocks but to a society's strategic capacity to absorb disruptions, adapt to evolving conditions, and transform structurally when necessary - thereby maintaining and strengthening core functions over time. In today’s interconnected, rapidly changing, and risk-prone global landscape, this capacity is indispensable.

Countries across the world are increasingly facing a complex array of risks -economic downturns, geopolitical instability, pandemics, technological disruptions, climate change, and natural disasters- all of which threaten to undermine development gains and long-term policy objectives. As these challenges grow in both frequency and intensity, traditional reactive approaches to development planning are no longer sufficient. Instead, proactive, integrated, and forward-looking strategies that embed resilience into the core of national policy are urgently needed. These strategies must be capable of anticipating systemic risks, enhancing institutional flexibility, and fostering inclusive, adaptive governance.

Türkiye, due to its unique geographic position, dynamic socio-economic structure, and exposure to diverse risks, stands at the forefront of this global shift toward resilience-oriented planning. From frequent earthquakes and economic volatility to demographic transitions and regional political tensions, the country must navigate a wide array of acute shocks and long-term stressors. In the past, Türkiye's development efforts often relied on short-term absorptive strategies to cope with crises. However, as the global risk environment becomes increasingly volatile, a transition toward a more robust and future-proof development paradigm has become imperative.

In this context, the Twelfth Development Plan (2024–2028) represents a pivotal juncture in Türkiye's development trajectory. While continuing to employ absorptive strategies to stabilize the system during crises, the plan also begins to emphasize the importance of building adaptive capacity—developing institutions that can learn, adjust, and evolve in response to change. Although transformative capacity is still in its early stages, this period must lay the groundwork for deeper structural reforms that will be advanced in subsequent planning cycles. The Twelfth Plan is therefore more than a continuation of prior efforts—it is a bridge that connects short-term crisis response with long-term resilience, innovation, and sustainability.

To operationalize resilience, this study adopts a framework based on three interrelated capacities: absorptive capacity, which enables systems to manage immediate shocks; adaptive capacity, which promotes learning and adjustment in response to change; and transformative capacity, which supports systemic reform and innovation for long-term sustainability. These dimensions, when strategically balanced across development phases, offer a pathway for managing current risks while preparing for future transitions. This phased model supports the gradual evolution from reactive policy responses to proactive and transformative national development planning.

Ultimately, this paper provides both a conceptual foundation and a strategic roadmap for embedding resilience into Türkiye's long-term development agenda. Anchored in the twin transitions of the green economy and digital transformation, and aligned with international frameworks such as the UN Sustainable Development Goals (SDGs) and the Paris Agreement, Türkiye's resilience strategy can enable the country not only to safeguard its development gains, but also to emerge as a global leader in future-proof, inclusive, and sustainable development. By integrating resilience capacities into every phase of planning—from the Twelfth Development Plan to the 2053 Vision—Türkiye can build a more stable, adaptive, and transformative society in the face of uncertainty.

2. Theoretical Background: The Evolution of the Concept of Resilience

The concept of resilience, derived from the Latin word resilire—meaning "to bounce back" or "to recoil"—has undergone significant evolution across various academic disciplines. Initially employed in the 19th century in engineering and shipbuilding to describe a material's ability to withstand pressure and return to its original form (Tredgold, 1818; Mallett, 1862, as cited in McAslan, 2010), resilience began to emerge as a broader analytical framework in the natural and social sciences throughout the 20th century. Its adoption expanded particularly within ecology, psychology, and sociology, where it came to describe the ability of ecosystems, individuals, or communities to respond effectively to shocks and stresses (Alexander, 2013).

In its early conceptualizations—especially in ecological theory—resilience was associated with a system's ability to return to a pre-disturbance equilibrium (O'Brien & Leichenko, 2000; Zobel & Khansa, 2014). Holling (1973) defined this as "engineering resilience," emphasizing recovery and the preservation of system stability. However, as the complexity and interconnectivity of global risks increased, scholars moved beyond this narrow understanding. Contemporary resilience thinking now embraces the capacity of systems not only to absorb disturbances but also to adapt and transform in the face of ongoing change (Olsson et al., 2015).

This shift toward a more dynamic and integrated interpretation of resilience has been reflected in key international policy frameworks. The United Nations' 2030 Agenda for Sustainable Development and the Paris Agreement on Climate Change position resilience as a central pillar for sustainable development, explicitly linking it to climate adaptation, institutional capacity-building, and social inclusion (United Nations, 2015a, 2015b). Despite its increasing prominence, however, operationalizing resilience remains challenging due to its context-specific and multi-dimensional nature (Pelling, 2010; Miller et al., 2010; Olsson et al., 2015). As a result, resilience continues to intersect with, and occasionally blur into, related concepts such as risk, vulnerability, adaptability, sustainability, and equity.

In socio-ecological systems, resilience is now commonly analyzed through three interconnected and interdependent capacities: absorptive, adaptive, and transformative. Absorptive capacity refers to the ability of a system to endure shocks while maintaining core structures and functions. Adaptive capacity denotes the ability of a system to learn from experience, reorganize its functions, and adjust incrementally in response to changing conditions. Transformative capacity, the most systemic of the three, refers to the capacity to initiate deep, structural changes that address the root causes of vulnerability and promote long-term sustainability (Folke et al., 2002; Lumbroso et al., 2017). These capacities are not isolated; they interact and reinforce one another over time, forming a continuum of resilience capabilities.

The relationship between resilience and development is both complex and at times contradictory. While development is aimed at improving human well-being, economic conditions, and institutional efficiency, resilience ensures that these gains are not eroded by sudden or chronic disturbances. Nonetheless, tensions can arise—particularly when short-term development priorities, such as rapid economic growth, undermine longer-term resilience goals like environmental integrity or social cohesion. Scholars like Constas et al. (2014) and Jones & Tanner (2017) stress that resilience should be viewed not simply as a product of development but as an essential enabler of it—a foundational capacity that allows development trajectories to be sustained and adapted in uncertain and dynamic contexts.

Measuring resilience is another significant challenge in both academic and policy circles. Given its multi-faceted character, scholars and institutions have developed a variety of frameworks to assess and track resilience across contexts. For instance, the Food and Agriculture Organization (FAO) has introduced tools such as the Resilience Index Measurement and Analysis (RIMA) and the Targeting Approach for Resilience Outcome (TANGO), which seek to quantify resilience using a combination of qualitative and quantitative indicators across economic, social, and environmental dimensions (FAO, 2016; Henly-Shepard & Sagara, 2018). These frameworks aim not only to assess resilience levels but also to identify entry points for targeted interventions.

In summary, the evolution of the resilience concept reflects a significant broadening from a narrowly defined engineering notion to a comprehensive analytical framework that captures the complexity and dynamism of socio-ecological systems. Today, resilience encompasses the capacity to absorb shocks, adjust incrementally, and transform structurally in pursuit of sustainable and equitable development. As such, it must be understood not as a fixed outcome, but as a continuous, strategic process that supports long-term development and system robustness in the face of uncertainty.

3. Methodology

This study employs a qualitative document analysis methodology to investigate how resilience is conceptualized and integrated into Türkiye's Twelfth Development Plan (2024–2028). The primary aim is to assess the strategic articulation of resilience across economic, social, institutional, and environmental domains, and to generate forward-looking insights that can inform resilience-centered planning for future development periods, particularly in light of the country's 2053 Vision.

Document analysis offers a systematic framework for extracting patterns, themes, and strategic orientations from policy texts. It is particularly effective in examining how conceptual priorities such as resilience are embedded in official narratives and goal structures (Yıldırım & Şimşek, 2018; Öz & Karabay, 2022). In this context, the method is used not only to trace the presence of resilience-related terminology but also to interpret the coherence and depth of policy integration. The approach is well-suited for identifying strategic gaps, thematic consistencies, and the extent to which resilience planning aligns with broader national and international development agendas, including the Sustainable Development Goals and climate adaptation frameworks.

Central to this analysis is the evaluation of three interconnected resilience capacities: absorptive, adaptive, and transformative. These capacities represent distinct yet complementary mechanisms by which systems respond to and evolve from risk. Absorptive capacity refers to the ability to buffer external shocks without substantial loss of function; adaptive capacity involves the capacity to reorganize and adjust to changing circumstances; and transformative capacity captures the potential for deep structural change when existing systems and paradigms prove insufficient (Folke et al., 2002; Lumbroso et al., 2017). The study assesses how these dimensions are reflected in the Twelfth Development Plan's strategic goals, with the aim of determining their relative emphasis and integration.

To carry out this evaluation, the strategic objectives outlined in the Development Plan were systematically mapped against resilience characteristics established in leading global frameworks. Specifically, the classification draws on the City Resilience Index developed by the Rockefeller Foundation (2015) and the OECD's urban resilience indicators (Figueiredo et al., 2018). A conceptual mapping process was used to align keywords from the Development Plan with resilience capacities. These keywords were grouped into thematic clusters and classified under umbrella categories representing economic, social, institutional, and environmental dimensions of resilience.

In the visual mapping shown in Figure 1, the resilience attributes identified by the Rockefeller Foundation (purple boxes) are matched with related terms from Türkiye's Twelfth Development Plan (yellow boxes). These terms were chosen based on their conceptual similarity to the resilience attributes. While some closely align, others were included because they express similar ideas or intentions within the context of the Plan, even if they do not fully correspond to the original definitions. The purpose of this visualization is to offer a clear and structured way to explore how the language used in the Plan reflects different aspects of resilience.

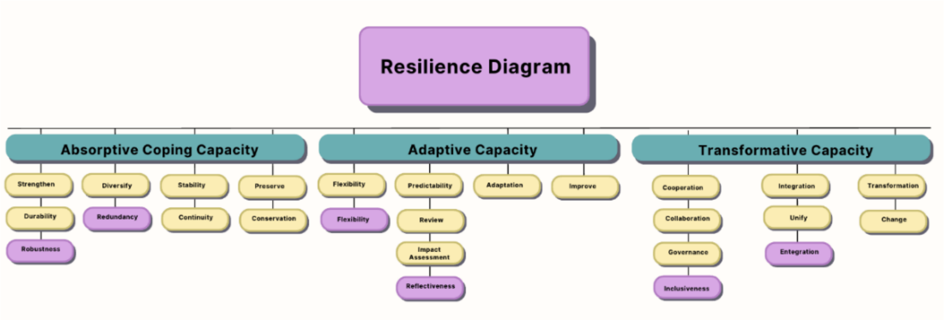

Figure 1. Mapping Resilience Characteristics to Strategic Goals

Despite the methodological rigor of the study, certain limitations should be acknowledged. First, the analysis is limited to the "objectives and goals" section of the Development Plan, deliberately excluding operational strategies, sectoral implementation mechanisms, and performance indicators. This narrowed scope helps to maintain focus on the strategic intent rather than on administrative execution. Second, compound expressions such as "urban transformation" were only included when they clearly aligned with the definitions of absorptive, adaptive, or transformative capacity. Additionally, due to the semantic complexity of the Turkish language and the nuanced nature of policy discourse, particular attention was given to ensure that terms were interpreted within their appropriate resilience-related contexts.

The document analysis was conducted in four stages. The first stage involved a preliminary review of the full Development Plan to identify overarching priorities and resilience-relevant themes. In the second stage, keywords related to resilience were extracted and categorized according to the four main domains. The third stage focused on mapping these themes to the three resilience capacities. Finally, the fourth stage entailed the interpretation of the results and the formulation of strategic recommendations, with the aim of guiding future development planning toward a more resilience-centered approach.

Through this structured and multi-phase analysis, the study not only reveals the current status of resilience integration in Türkiye's strategic planning but also offers a conceptual foundation for strengthening resilience across future development cycles. In doing so, it contributes to a long-term transformation agenda that is both aligned with Türkiye's 2053 Vision and responsive to the complex economic, environmental, and institutional realities of the 21st century.

4. Evaluation of Resilience Dimensions and Capacities in Türkiye's Twelfth Development Plan

Türkiye's Twelfth Development Plan (2024–2028) presents a strategic framework designed to address the complex interplay of economic, social, institutional, and environmental challenges. The Plan is shaped not only by long-term development priorities but also by a series of recent domestic and global disruptions, most notably the COVID-19 pandemic (2020), Türkiye's ratification of the Paris Agreement (2021), the Russia-Ukraine War (2022), and the devastating Kahramanmaraş earthquakes (2023). These events have elevated resilience from a secondary policy concern to a foundational element of national planning. Structured around five strategic axes—stable growth and a strong economy; competitive production through green and digital transformation; a qualified, healthy society rooted in strong families; disaster-resilient settlements and a sustainable environment; and democratic governance grounded in justice—the Plan aims to systematically integrate resilience into all policy dimensions, aligning national development with long-term sustainability.

This section assesses the extent to which resilience is embedded within the Plan, categorized into four main domains: economic, institutional, social, and environmental. These domains are evaluated through the three core resilience capacities: absorptive, adaptive, and transformative. Economic resilience is one of the most explicitly articulated dimensions in the Plan. Its absorptive capacity is reflected in strategies aimed at minimizing the immediate impacts of economic shocks through macroeconomic stabilization, sectoral diversification, and support for entrepreneurship and innovation. Initiatives promoting labor specialization and the expansion of tourism into new markets illustrate efforts to reduce vulnerability to external shocks. However, despite these proactive measures, the Plan offers limited articulation of social protection mechanisms and shock-resilient infrastructure—both critical components for buffering socioeconomic vulnerabilities during crises.

Regarding adaptive capacity, the Plan seeks to facilitate structural change through green and digital transitions, an improved investment environment, and labor market flexibility. Yet, this approach tends to emphasize institutional "improvement" rather than systemic adaptability. Strategies to foster innovation and diversification remain underdeveloped, and mechanisms to enhance policy predictability are largely absent, thereby weakening the economy's ability to respond to evolving global conditions. The transformative economic capacity is partially addressed through long-term objectives such as digital transformation, vocational education reform, and enhanced sectoral competitiveness. Nevertheless, the limited integration across sectors and lack of policy coherence pose risks to the transformative potential the Plan aims to achieve.

Institutional resilience is framed primarily within the context of democratic governance and effective public administration. The Plan defines absorptive institutional capacity through reforms focusing on transparency, accountability, and crisis preparedness—such as risk-based planning, flexible governance in urban contexts, and increased institutional awareness. While these elements are valuable, the absence of strong legal protections, fiscal sustainability, and institutional continuity during crises suggests an incomplete approach to absorptive resilience, especially when viewed through the lens of adaptive capacity. While valuable, the absence of a strong emphasis on legal protections and institutional continuity during crises suggests an incomplete approach to absorptive resilience. Adaptive institutional strategies are more clearly defined, with efforts to harmonize national legislation with European Union norms, enhance regulatory predictability, and modernize public administration. However, critical aspects such as inter-agency coordination, stakeholder engagement, and bureaucratic flexibility remain insufficiently addressed, limiting institutional adaptability. Transformative institutional capacity is approached via initiatives aimed at integrating green and digital governance, strengthening international cooperation, and building institutional capacity at multiple levels. Despite these ambitions, the Plan lacks clarity on how to institutionalize civic participation, improve transparency across governance layers, or achieve inter-institutional coherence—gaps that are especially significant given the central role of democratic legitimacy and inclusive governance for institutional resilience.

In the social domain, the Plan recognizes that sustainable development depends not only on economic strength but also on cohesive and inclusive social structures. Social absorptive capacity is addressed through investments in health, education, and social protection systems, with particular attention to vulnerable groups such as children, families, and the elderly. In particular, strengthening education systems is not only essential for immediate recovery and support during crises, but also contributes to social resilience and long-term human development. Adaptive social capacity is supported through efforts to reduce income inequality, expand access to quality education, and promote lifelong learning. Programs targeting youth and the elderly, alongside improvements in university research infrastructure, reflect an awareness of demographic trends. Nevertheless, strategic planning remains limited in emergency social services, demographic adaptation, and well-being metrics, which are crucial for long-term social adaptability. Transformative social capacity is partially addressed through participatory policymaking, regional cooperation, and equal opportunity initiatives. Structural challenges such as regional disparities and social fragmentation are insufficiently targeted, and the absence of integrated strategies for family policy, social inclusion, and geographic equity suggests that the Plan underutilizes the transformative potential of social resilience.

Environmental resilience holds a central position in the Plan, especially under the axis of "resilient living spaces and sustainable environment." Absorptive capacity is supported by disaster risk management strategies, infrastructure resilience, and ecosystem protection. However, the lack of comprehensive, sector-wide emergency response mechanisms limits the full realization of environmental absorptive capacity. Adaptive strategies include decarbonization efforts, renewable energy expansion, and climate-resilient urban planning. Despite these important initiatives, sectoral blind spots—particularly in agriculture and water management—raise concerns given Türkiye's vulnerability to climate-induced disasters such as drought and flooding. Transformative environmental capacity is partially addressed through the promotion of green innovation, circular economy models, and sustainable agricultural practices. Yet, the Plan falls short of providing an integrated, multisectoral framework that aligns energy, transport, industry, and food systems around a cohesive environmental resilience agenda. Without such coordination, efforts risk fragmentation and diminished impact.

Overall, the Twelfth Development Plan demonstrates a clear commitment to embedding resilience within Türkiye's development trajectory, adopting the language of absorptive, adaptive, and transformative capacities across economic, institutional, social, and environmental domains. Nonetheless, this integration remains uneven in terms of conceptual clarity and strategic depth. Absorptive capacity is prioritized, often through mechanisms designed for short-term risk management, whereas adaptive and transformative capacities—critical for anticipating systemic shifts and enabling structural reform—receive relatively limited attention. This imbalance is especially evident in economic and environmental domains, where long-term resilience requires more than reactive policy tools. Furthermore, the Plan's strategies often operate in silos, with limited interconnectivity across policy areas. The absence of systemic integration, particularly in aligning governance, social equity, and environmental sustainability, restricts the Plan's capacity to address compound and cascading risks effectively. In sum, while the Twelfth Development Plan marks an important step toward resilience-oriented planning, more comprehensive and interconnected strategies are necessary to realize its full potential. Strengthening adaptive and transformative capacities—especially through inclusive governance, cross-sectoral integration, and long-term risk foresight—will be essential for advancing Türkiye's resilience within the broader scope of its 2053 Vision.

5. Strengthening Türkiye's Development Strategy Through Resilience: Towards the 2053 Vision

In an increasingly uncertain global context marked by climate change, geopolitical volatility, and growing social inequalities, resilience must be a foundational pillar of Türkiye's development strategy. Resilience encompasses a nation's capacity to absorb shocks, adapt to evolving circumstances, and implement long-term transformative solutions across economic, institutional, social, and environmental dimensions. The upcoming Thirteenth Development Plan represents a pivotal phase in advancing Türkiye’s 2053 Vision, building upon the groundwork laid by the Twelfth Development Plan.

The Twelfth Plan predominantly emphasized absorptive capacity, focusing on crisis management and short-term stabilization measures during periods of economic and social upheaval. While this approach was effective in addressing immediate disruptions, it insufficiently engaged with adaptive and transformative strategies that are critical for ensuring sustainability and systemic change over the long term.

Within the economic domain, the Twelfth Plan’s emphasis on structural transformation—highlighted by green and digital innovation and efforts to boost sectoral competitiveness—was notable. However, strategies aimed at enhancing absorptive and adaptive capacities, which facilitate immediate shock absorption and flexible adjustment, were relatively underdeveloped. The Thirteenth Plan should address these gaps by incorporating mechanisms such as market stabilization tools, early warning systems, and flexible policy instruments alongside continued support for green and digital transitions. Prioritizing economic diversification, innovation, and predictability will foster a resilient and future-ready economy capable of managing shocks while sustaining growth.

Institutionally, resilience efforts during the Twelfth Plan focused on strengthening legal frameworks and enhancing institutional capacity. Nonetheless, repeated legal reforms often lacked effective implementation, thereby limiting substantive progress. To overcome these challenges, the Thirteenth Plan must critically evaluate the impact of existing regulations before introducing new reforms, avoiding redundancy and enhancing governance efficiency. Strengthening adaptive capacities through improved policy predictability, accountability, and flexible governance structures is vital. Furthermore, embedding digital governance tools can bolster institutional coherence and responsiveness. Establishing a dedicated emergency management axis will help align crisis preparedness with long-term governance objectives.

In terms of social resilience, the Twelfth Plan addressed key human development priorities such as education, healthcare, and welfare, thereby reinforcing absorptive capacity. However, it fell short in tackling income inequality and integrating the social dimensions of disaster resilience, including emergency service accessibility and communication infrastructure. The Thirteenth Plan should systematically incorporate income distribution and inequality indicators across absorptive, adaptive, and transformative strategies. Additionally, integrating social aspects of disaster preparedness is essential to protect vulnerable populations and enhance societal resilience. Existing social development initiatives should be maintained and expanded with greater flexibility, integrating demographic planning alongside green and digital innovations to foster inclusivity and sustainability.

Environmental resilience was the least developed area within the Twelfth Plan. Although climate adaptation, sustainable urban planning, and ecosystem protection were acknowledged, they were insufficiently operationalized across all resilience capacities. The Thirteenth Plan must place stronger emphasis on comprehensive environmental risk management, including provisions for emergency shelters, climate-resilient infrastructure, and circular economy models. Incorporating robust environmental indicators will be crucial to achieving Türkiye's sustainability targets as outlined in the 2053 Vision.

A key limitation of the Twelfth Plan was its disproportionate focus on absorptive capacity at the expense of adaptive and transformative approaches. Future development plans should address this imbalance by embedding four guiding principles throughout their design: protection (to prevent regression during crises), flexibility (to enable evolution amid changing conditions), stability (to ensure continuity), and systemic integration (to foster coherence across sectors and institutions). This holistic approach will strengthen Türkiye's capacity not only to withstand shocks but also to adapt and thrive sustainably over the long term.

5.1. A Balanced Approach to Resilience: Strengthening Capacities for Sustainable Development

Türkiye's development trajectory reflects a continuous effort to address a broad spectrum of economic, social, and environmental challenges. Its development policies increasingly emphasize resilience, focusing on both crisis preparedness and long-term sustainability. Achieving success in these policies depends on maintaining an effective balance among absorptive, adaptive, and transformative capacities. These three capacities perform complementary functions at various stages of development strategies, and understanding their interplay is essential for evaluating Türkiye's overall development effectiveness.

Absorptive capacity plays a critical role in managing immediate crises, especially during periods of economic or social instability. Historically, Türkiye's development plans have prioritized temporary solutions to urgent crises, activating absorptive mechanisms that provide rapid relief during acute disruptions. While absorptive capacity effectively mitigates short-term impacts, it falls short in addressing deeper, long-term challenges, as it focuses mainly on crisis management rather than structural transformation. Periods marked by intense economic and social crises illustrate this reliance on absorptive strategies, where urgent, temporary fixes stabilized fragile systems. However, absorptive capacity alone cannot sustain long-term resilience or systemic change.

In contrast, adaptive capacity emphasizes proactive, strategic responses to long-term sustainability challenges. It enables systems to adjust and reorganize in response to shifting conditions, promoting flexibility, learning, and anticipatory capacity. This capacity has gained importance in Türkiye's development planning, particularly in response to rapid changes in environmental, social, and economic contexts. Developing adaptive capacity requires strengthening institutional frameworks and fostering continuous learning processes that build resilience against future risks. Integrating adaptive capacity into development strategies ensures that Türkiye can respond effectively to evolving challenges, moving beyond reactive crisis management toward strategic adaptation.

The deepest level of change is represented by transformative capacity, which entails fundamental shifts that reshape existing development paradigms. It fosters innovative, sustainable solutions that challenge the status quo and drive systemic change. Future development plans for Türkiye must emphasize transformative capacity to address structural issues that neither absorptive nor adaptive measures can fully resolve. By prioritizing transformative capacity, Türkiye can accelerate its transition to resilient, sustainable economic, social, and environmental systems. This capacity will be pivotal in implementing profound changes that secure long-term development goals.

Türkiye's development policies increasingly recognize the critical importance of resilience capacities in navigating complex and evolving challenges. This study presents a conceptual framework that models potential transitions in absorptive, adaptive, and transformative capacities as strategic pillars of Türkiye's national development planning. Table 1 illustrates these capacity shifts proposed by the study, depicting how resilience capacities could be prioritized and rebalanced across Türkiye's future development plans. It is important to emphasize that the capacities and transitions shown do not represent an existing or historical state, but rather reflect the strategic evolution recommended by this research to support Türkiye's 2053 Vision.

Table 1. Study-Projected Evolution of Resilience Capacity Weights in Türkiye's Development Plans

Development Plan (DP)	Resilience Capacity		Resilience Capacity		Resilience Capacity	
	Absorptive	Key Policies	Adaptive	Key Policies	Transformative	Key Policies
Twelfth DP	High	Rapid crisis response, emergency relief, short-term stabilization	Low	Limited flexibility, reactive institutional adjustments	Moderate	Initiation of structural reforms, preliminary green/digital initiatives
Thirteenth DP	High	Strengthened emergency management systems, macroeconom	Moderate	Early warning systems, contingency planning, flexible governance	Low	Foundations for green and digital transformation

		ic stabilization				
Fourteenth DP	Moderate	Targeted stabilization tools, sectoral shock absorbers	High	Proactive risk management, institutional learning, scenario planning	Moderate	Sustainability-driven reforms, sector integration
Fifteenth DP	Moderate	Crisis management support, maintenance of core infrastructure	High	Embedding adaptive governance, long-term flexibility in policies	Moderate	Initiation of systemic structural transformation
Sixteenth DP	Moderate	Operational continuity during transition	High	Systemic risk anticipation, multi-sector coordination	High	Comprehensive systemic reforms, innovation-led sustainability
Seventeenth DP	Low	Baseline crisis response to residual shocks	Moderate	Integration of adaptive policies into mainstream governance	High	Full institutionalization of sustainable, resilient systems

Table 1 provides a detailed and comprehensive depiction of the evolving resilience capacities embedded within Türkiye's sequential Development Plans. This framework illustrates a progressive recalibration of absorptive, adaptive, and transformative capacities at each planning stage, reflecting the nation's shifting strategic priorities as it transitions from immediate crisis management toward sustained systemic transformation and long-term sustainability.

During the Twelfth Development Plan (2024–2028), absorptive capacity was prioritized to stabilize the economy and society in the face of immediate shocks. Policies primarily concentrated on rapid crisis response, emergency relief measures, and short-term macroeconomic stabilization. In contrast, adaptive capacity remained limited, predominantly reactive, with minimal institutional learning mechanisms, while transformative capacity was moderate, signaled by initial green and digital initiatives. This stage underscores the necessary prominence of absorptive capacity in early crisis contexts but simultaneously highlights its insufficiency for fostering enduring resilience.

The Thirteenth Development Plan (2029–2033) sustains a high emphasis on absorptive capacity but progressively integrates adaptive strategies, such as enhanced early warning systems and more flexible governance models. Transformative capacity, though still limited, begins to lay essential groundwork through expanded green and digital transitions. This plan serves as a critical strategic bridge, balancing the urgency of crisis management with the deliberate incorporation of adaptive and transformative elements, thereby facilitating a phased and resilient progression toward sustainable development.

A significant paradigm shift occurs during the Fourteenth (2034–2038) and Fifteenth (2039–2043) Development Plans, where adaptive capacity assumes a central role. Policy frameworks evolve to prioritize proactive risk management, institutional learning, and scenario-based planning. Adaptive governance becomes institutionalized, bolstering flexibility and responsiveness to emerging challenges. Absorptive capacity is maintained at moderate levels to ensure continued crisis mitigation, while transformative capacity experiences moderate growth, driven by sustainability-focused reforms and innovative economic initiatives aimed at deeper systemic change.

The Sixteenth (2044–2048) and Seventeenth (2049–2053) Development Plans represent the culmination of this strategic evolution, positioning transformative capacity as the dominant driver of resilience. These phases emphasize comprehensive systemic reforms across economic, social, environmental, and institutional dimensions. Innovation, circular economy practices, and the institutionalization of sustainable development become fundamental pillars. Concurrently, adaptive capacity remains vital for ensuring ongoing learning and responsiveness, while absorptive capacity sustains essential baseline functions during transitional phases.

This expanded model highlights the critical importance of a phased, balanced approach to sequencing resilience capacities within Türkiye's development strategy. By deliberately transitioning from absorptive to adaptive and ultimately transformative capacities, Türkiye can establish a robust resilience architecture capable of effectively managing acute shocks and chronic stressors, adapting to evolving risks, and driving profound systemic change. The strategic layering and reinforcement of these capacities through targeted policies at each phase are essential to achieving the ambitious objectives of Türkiye's 2053 Vision, fostering a flexible, sustainable, and future-ready society.

Importantly, rather than creating entirely new resilience frameworks, future development plans should build upon the existing strategic foundation to ensure continuity and enhance policy effectiveness. The Twelfth Development Plan structured its policies around five principal axes—stable growth, competitive production, human and social development, resilient living spaces, and democratic governance—anchored by green and digital transformation goals. While this provides a solid base, refinement is necessary to correct imbalances and promote more even development across all resilience capacities.

Moving forward, development plans should explicitly signal a more balanced approach: sustaining high absorptive capacity to manage immediate risks, elevating adaptive capacity to moderate levels to increase systemic flexibility and responsiveness, and maintaining transformative capacity at a foundational yet deliberate level to enable gradual structural shifts. Subsequent plans should continue to increase adaptive capacity emphasis, marking a strategic pivot toward flexible, learning-oriented governance and transformation-ready policies, while preserving absorptive functions at moderate levels and fostering transformative capacity to encourage ongoing structural reform. Finally, the later plans should prioritize transformative capacity, facilitating deep systemic changes and shifting focus from crisis management toward durable resilience and sustainability.

This analytical framework reinforces the essential role that resilience capacities play in shaping Türkiye's development trajectory. As the country advances toward its 2053 Vision, the purposeful enhancement of adaptive and transformative capacities will be indispensable for addressing complex, interconnected future challenges. Embedding greater flexibility and systemic integration into resilience strategies will further strengthen Türkiye's capability to respond effectively and sustainably to emerging uncertainties and crises.

5.2. A Phased Approach to Resilience: The Role of Future Development Plans

Türkiye's long-term development strategy, aligned with the 2053 Vision, requires a phased and dynamic approach to resilience planning. Each five-year Development Plan should represent a progressive stage in the country's transition from immediate crisis response toward deep systemic transformation. This evolution depends on a gradual shift in the balance between absorptive, adaptive, and transformative capacities, ensuring that Türkiye incrementally builds a more resilient, sustainable, and future-ready structure.

The Thirteenth Development Plan (2029–2033) should primarily focus on enhancing absorptive capacity, which is essential for managing acute and immediate crises through rapid interventions and emergency preparedness. Building upon the foundations laid by the Twelfth Plan, this phase must prioritize rapid response mechanisms, emergency management systems, and temporary stabilization tools designed to prevent systemic collapse. While absorptive capacity provides critical short-term relief, it alone is insufficient for achieving long-term transformation. Therefore, the Thirteenth Plan should also lay the groundwork for system strengthening, diversify institutional mechanisms, and develop contingency and early warning plans. During this phase, adaptive capacity should be supported through limited and flexible strategies, whereas transformative capacity remains a lower priority but is recognized as foundational for subsequent phases. Moreover, to address a significant shortcoming of the previous plan—its overemphasis on absorptive capacity at the expense of adaptive and transformative strategies—the Thirteenth Plan must embed four key resilience features: protection to prevent regression during crises; flexibility to allow evolution amid changing conditions; stability to ensure continuity in systems and policies; and systemic integration to foster coherence across sectors and institutions. Anchored in green and digital transformation goals, the Thirteenth Plan serves as a crucial bridge between short-term crisis management and the long-term sustainability objectives outlined in Türkiye's 2053 Vision. By refining and extending existing strategies with a forward-looking, resilience-centered focus, Türkiye can position itself as a global leader in resilience-based development.

The Fourteenth Development Plan (2034–2038) should mark a clear shift toward the development of adaptive capacity. This phase emphasizes flexible governance structures, proactive risk management, and institutional learning and knowledge integration. While absorptive mechanisms established during the Thirteenth Plan remain necessary for crisis response, they take on a secondary role. The enhanced adaptive capacity will enable anticipation and adjustment to evolving risks, integration of resilience into routine decision-making processes, improved stakeholder coordination, and strategic planning informed by risk assessments and scenario analyses. Although transformative capacity remains relatively low during this period, it plants the seeds for future systemic transformation.

By the time of the Fifteenth Development Plan (2039–2043), adaptive capacity should be fully consolidated as the central pillar of resilience strategy. Governance systems will have institutionalized learning from past crises, embedded adaptive mechanisms, and strengthened long-term flexibility. Concurrently, transformative capacity will begin gaining importance by initiating structured reforms aligned with sustainability goals. Absorptive capacity will continue to be relevant, albeit in a more supportive role focused on residual crisis management. This plan marks a critical transition where resilience evolves from reactive management toward anticipatory and strategic transformation.

From the Sixteenth and Seventeenth Development Plans (2044–2053 and beyond) onward, transformative capacity should take precedence in Türkiye’s resilience efforts. This stage will involve comprehensive systemic reforms, innovation in governance, economy, and environmental management, as well as cross-sectoral and inter-institutional collaboration. Adaptive capacity will continue to support ongoing learning and systemic integration, while absorptive capacity will ensure operational continuity during these transitions. The Seventeenth Plan will culminate this trajectory by completing major structural reforms that institutionalize permanent resilience. At this advanced stage, transformative capacity will anchor the development model, adaptive capacity will maintain the flexibility to respond to evolving challenges, and absorptive capacity will facilitate reflection and learning from past disruptions. The integration of all three capacities will be essential to achieving Türkiye’s sustainable development goals and embedding resilience permanently within national policymaking.

This phased approach ensures strategic continuity while progressively strengthening Türkiye’s capacity to respond, adapt, and transform in the face of emerging challenges. By aligning each Development Plan with a dominant resilience capacity, Türkiye can effectively navigate uncertainties and foster an inclusive, future-proof society.

In the planning process, Türkiye’s development strategies should initially emphasize absorptive capacity, given its higher importance in the early stages, to ensure rapid crisis intervention and infrastructure resilience. However, in the long term, adaptive capacity, which enhances the ability to adjust to environmental and societal changes, will become a critical component for achieving sustainable development goals. On the other hand, transformative capacity—with the integration of digitalization, the green economy, and innovative economic models—should come to the forefront, especially in long-term development processes (see Figurec 1).

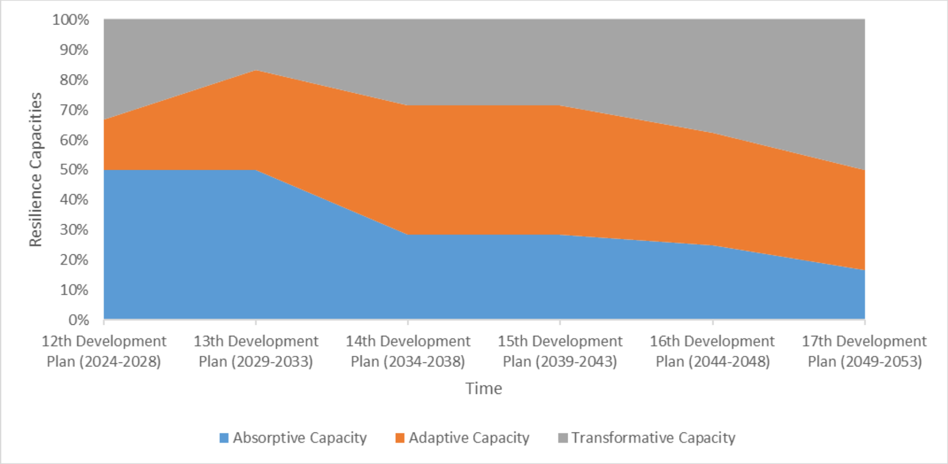

Figure 1. Resilience Capacities Across Development Plans

Initially, development strategies should emphasize absorptive capacity to guarantee rapid crisis intervention and infrastructure resilience. However, over time, adaptive capacity—enhancing the ability to adjust to environmental and societal changes—will become critical for achieving sustainable development goals. Finally, transformative capacity, supported by digitalization, the green economy, and innovative economic models, should drive deep systemic change in the long term.

Türkiye's development trajectory must move beyond mere crisis intervention to embrace long-term adaptation and transformation. While absorptive capacity remains vital in early phases, it cannot sustain resilience amid ongoing challenges such as urbanization, climate change, and global economic fluctuations. Strengthening adaptive and transformative capacities is therefore essential to realize the 2053 Vision. The Thirteenth Development Plan must act as a bridge between immediate crisis management and systemic transformation, enhancing resilience across all dimensions. Through strategic continuity, innovation, and inclusivity—rooted in green and digital transformation—Türkiye is well positioned to address short-term challenges and achieve its ambitious sustainability goals, emerging as a global leader in resilience-centered development.

6. Conclusion

The realization of Türkiye's 2053 Vision fundamentally depends on embedding resilience as the cornerstone of its national development strategy. In an era marked by unprecedented global volatility, climate crises, rapid technological changes, and deepening social inequalities, Türkiye's future hinges on its ability to not only withstand shocks but to adapt and fundamentally transform its systems. The findings of this study highlight that a phased, capacity-focused approach to resilience is indispensable—one that strategically balances absorptive, adaptive, and transformative capacities across successive development plans.

The analysis reveals that the Twelfth Development Plan's predominant focus on absorptive capacity, centered on immediate crisis management and short-term stabilization, while effective for urgent response, proved inadequate for driving systemic and sustainable change. This overreliance limited Türkiye's capability to address structural vulnerabilities or pursue long-term reforms, exposing a critical gap in resilience strategy.

Importantly, the Thirteenth Development Plan (2029–2033) must act as a strategic turning point—maintaining strong absorptive mechanisms while decisively embedding adaptive capacity and laying the groundwork for transformative resilience. The plan's success hinges on strengthening rapid response systems, institutional contingency planning, and macroeconomic stabilization, alongside incrementally building adaptive governance, early warning, and learning systems. While transformative efforts remain nascent, their integration, especially through green and digital transitions and economic diversification, is essential to catalyze future structural reforms.

The transition between the Fourteenth and Fifteenth Development Plans (2034–2043) is identified as a critical window for consolidating adaptive capacity. During this period, Türkiye must evolve its institutions into dynamic, learning organizations capable of managing long-term risks and embedding resilience into all policy layers. Adaptive strategies—including scenario planning, flexible regulation, and stakeholder engagement—should take precedence, preparing the ground for targeted transformative initiatives focused on sustainability and inclusion.

The study projects that from the Sixteenth Development Plan onward (2044–2053 and beyond), transformative capacity must emerge as the dominant force driving Türkiye's resilience strategy. This phase will be characterized by deep systemic reforms across economic, social, environmental, and institutional domains, fueled by innovation and sustainable practices. Adaptive capacity will continue supporting this transformation through ongoing learning and flexibility, while absorptive capacity ensures essential stability. This marks a paradigm shift from reactive crisis management toward proactive, systemic transformation, essential for realizing the 2053 Vision.

These findings collectively underscore a clear, actionable roadmap for Türkiye's resilience journey: gradual yet deliberate progression from crisis absorption, through adaptation, to transformative change. This phased approach not only strengthens Türkiye's ability to handle immediate shocks but also equips it to navigate complexity, uncertainty, and systemic risks over the long term.

From an economic perspective, the integration of digitalization, innovation, and green transformation emerges as a decisive factor for enhancing competitiveness and reducing exposure to global shocks. Socially, the findings emphasize the necessity of inclusive policies and protection for vulnerable groups to foster social cohesion and resilience. Environmentally, the analysis calls for robust climate adaptation, circular economy models, and sustainable urban planning as cornerstones of a resilient development path.

Moreover, the critical role of digital governance tools, data-driven decision-making, and cross-sectoral coordination is highlighted as indispensable for effective implementation. These enablers will improve institutional responsiveness, accountability, and public trust—pillars without which resilience cannot be institutionalized or sustained.

In sum, this study concludes that Türkiye's long-term success rests on its ability to shift from reactive crisis response to a proactive, resilience-based development model. By deliberately strengthening absorptive, adaptive, and transformative capacities through strategically sequenced development plans, Türkiye can build a robust, sustainable, and inclusive future. Rooted in the principles of protection, flexibility, stability, and systemic integration—and powered by green and digital innovation—

Türkiye is poised not just to meet but to lead in resilience-driven development. The 2053 Vision thus stands as a dynamic process of continuous evolution, anchored in resilience and shared prosperity.

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The article complies with national and international research and publication ethics.

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Urban Resilience Through Public Interior Adaptability

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1. Introduction

Cities have long faced complex crises such as disasters, epidemics, wars, and mass migrations, which threaten not only infrastructure but also social cohesion. These crises strain essential systems and erode social bonds, security, and quality of life—especially for vulnerable groups. To reduce such impacts, safe and supportive shelters are essential. In this context, public interior spaces like libraries and cultural centers gain new importance as adaptable environments that support social interaction and enhance urban resilience during crises.

Urban resilience—defined as a city's ability to withstand unexpected disasters or prolonged stressors—must be a fundamental consideration in the design and planning of these facilities. This study is structured as a qualitative investigation into the adaptability of public interior spaces within the framework of urban resilience. The research process consists of three main stages (Figure 1):

1. Development of the theoretical and conceptual framework:

In the first stage, a comprehensive literature review was conducted on the concepts of urban resilience, functional transformation of public interiors, and socio-spatial flexibility. National and international academic sources addressing the spatial implications of crises such as disasters, pandemics, and migration were examined.

2. Analysis of applied case studies:

In the second stage, case studies were analyzed to investigate how public interior spaces in various cities were adapted during crisis periods. These included examples of public buildings (e.g., libraries, cultural centers, municipal buildings) temporarily repurposed as shelters, health units, or coordination centers. Additionally, examples of ready-to-deploy design prototypes were reviewed.

3. Inductive identification of design principles and strategies:

Based on the findings from the case studies, key design principles and strategies for public interior spaces were identified through an inductive approach. These strategies were structured around core concepts such as flexibility, accessibility, multifunctionality, sustainability, and inclusivity. Thus, a bidirectional relationship was established between theoretical knowledge and practical application.

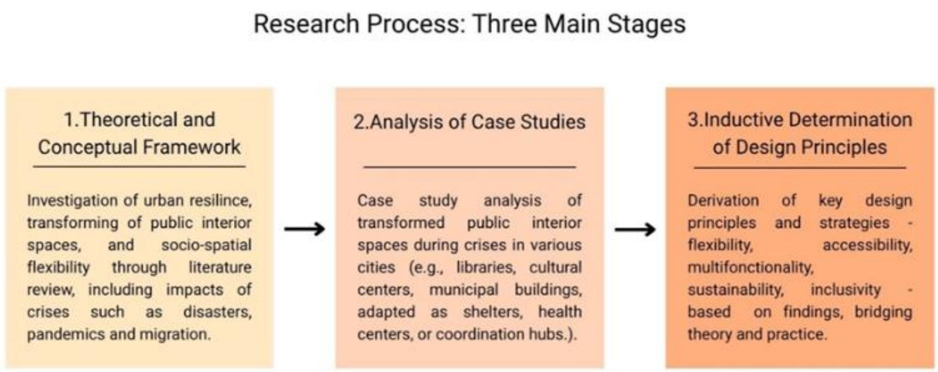


Figure 1. Research Methodology.

2. Urban Resilience Concept

Resilience, first introduced by Holling (1973) in the context of ecological systems, refers to a system's ability to absorb disturbances and maintain internal functions despite changes in variables and conditions. It is considered an inherent property determining whether a system continues or collapses (Ribeiro & Gonçalves, 2019).

The goal of resilience is to reduce the impacts of disruptions by enabling systems to resist, adapt, and return to equilibrium (Ribeiro & Gonçalves, 2019).

Urban resilience is the capacity of cities and their socio-ecological and socio-technical systems to sustain or quickly regain core functions during crises, adapt to changing conditions, and transform structures that hinder adaptability (Meerow, Newell, & Stults, 2016). It is based on four pillars: resisting, recovering, adapting, and transforming. Core components of urban resilience:

1- Robust Infrastructure: Resilient cities require well-designed, regularly maintained infrastructure systems that can continue functioning during shocks. These include resilient transport networks, reliable energy grids, effective water and sanitation services, and strong communication infrastructures.

2- Diversity and Inclusive Communities: Resilient urban societies foster diversity and promote inclusion by enhancing public participation and reducing social inequalities. Strong social networks and solidarity mechanisms are essential for collective action and mutual support during crises.

3- Effective Governance and Institutional Capacity: Urban resilience is closely tied to proactive governance structures. Critical elements include risk-informed urban planning, robust policy frameworks, and horizontal and vertical coordination among public institutions. The inclusion of diverse stakeholders in decision-making processes is also vital for resilient governance.

4- Adaptability and Flexibility: Resilient cities can adjust to changing conditions and respond flexibly. This involves embracing innovative technologies, applying sustainable urban planning principles, and periodically updating strategies to assess emerging risks.

5- Comprehensive Risk Management: Urban resilience requires integrated strategies to address multiple risk factors such as natural disasters, climate change, and socio-economic vulnerabilities. Early warning systems, land-use planning, green infrastructure practices, and preparedness and response plans are essential tools.

6- Resource Efficiency and Environmental Sustainability: Resilient cities prioritize the efficient use of natural resources to achieve environmental sustainability. Key efforts include promoting renewable energy, developing sustainable transportation systems, enhancing water and waste management, and expanding green spaces.

7- Knowledge-Based Approaches and Innovation: Strengthening urban resilience depends on generating and disseminating knowledge and fostering innovation. Investments in research and development, collaboration with academic institutions and experts, data-driven planning, and evidence-based decision-making are all critical.

In adopting the principles of urban resilience, cities not only enhance their capacity to withstand shocks and stresses but also improve the quality of life for their inhabitants. Moreover, they contribute to the creation of sustainable, inclusive, and livable urban environments for future generations.

3. The Concept of Public Interior Spaces

Publicness is defined by its openness and accessibility to all. Whether enclosed or open, public spaces refer to environments designated for general use, with accessibility being the key criterion (Gürallar, 2009, p. 52–55).

Public interior spaces are spatially bounded environments experienced as part of the public domain, including interiors of civic buildings and institutions (Poot et al, 2016, p. 54). These encompass areas for social interaction, mobility, leisure, commerce, and cultural engagement—both inside and outside buildings. According to Adıgüzel Özbek (2020, p. 100), urban interiors serve as umbrella spaces where people gather temporarily, shaped through collective action and transformation. These are mobile, evolving environments rather than predefined, static ones.

Citing Giunta (2009, p. 52–61), Özbek further describes urban interiors as systems composed of bodies, objects, and space. Bodies (individuals and communities) form the social dimension, requiring spatial settings to support interaction. Objects gain meaning through use and context, creating a symbolic and functional symbiosis. Urban interiors, therefore, are flexible, open-ended systems that allow for adaptation and transformation.

4. The Relationship Between Public Interior Spaces and Urban Resilience

Crises such as natural disasters, pandemics, and forced migration have redefined the roles of public interior spaces. Interior architecture now plays not only an aesthetic but also a strategic and societal role. Traditionally single-purpose buildings like libraries or cultural centers are increasingly inadequate. Instead, multifunctionality and temporary reprogramming are essential for resilience.

This shift necessitates flexible spatial design, where buildings support alternative emergency uses beyond their daily functions. To explore this, the study examined global cases that emerged under real crises—pandemics, earthquakes, refugee movements, and war—highlighting public buildings repurposed for socially driven functions.

Cases prioritized architectural or interior design interventions and included conversions into hospitals, screening centers, shelters, storage, and coordination hubs. The study focused particularly on healthcare and shelter uses. In addition, award-winning design prototypes developed for emergency scenarios were reviewed, offering innovative, scalable references for future crisis-responsive spatial planning.

4.1. Examples of Public Spaces Repurposed as Hospitals

During global health crises such as the COVID-19 pandemic, many public buildings were rapidly converted into temporary healthcare facilities to manage patient overflow and ease pressure on hospitals. This section explores key examples where civic structures were adapted as field hospitals, focusing on spatial strategies and design interventions employed.

4.1.1. Fangcang Shelter Hospitals – Wuhan, China

Fangcang shelter hospitals were temporary medical facilities established during the COVID-19 pandemic by repurposing public venues such as stadiums and sports halls. Designed to house over 1,000 beds, they provided isolation and basic care for patients with mild to moderate symptoms.

Their key functions included isolation, triage, basic treatment, continuous monitoring, and rapid referral to full-service hospitals when needed. Beyond healthcare, they offered food, shelter, and opportunities for social interaction, reflecting a holistic approach to patient well-being (Shang et al. 2020, p. 976). Fangcang hospitals highlight how large-scale public interiors can be swiftly transformed into efficient, human-centered care environments in times of crisis.

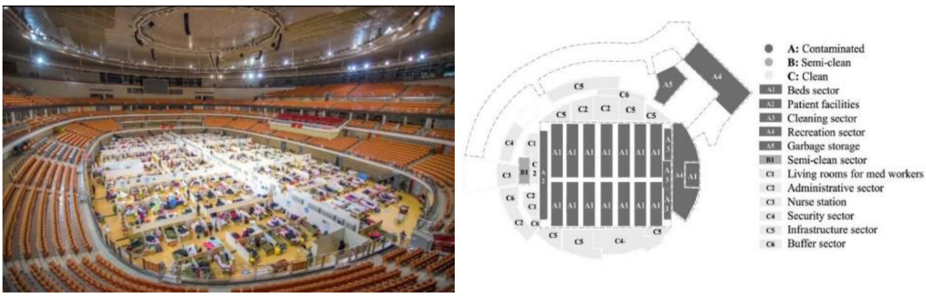


Figure 2. Functional Diagram of Fangcang Hospital-Hongshan Stadium (Fang et al., 2020) and Jiangxia Hospital (Jie et al., 2020, p.3).

Similarly, Jiangxia Fangcang Hospital was designed with a modular layout addressing clinical and logistical needs. According to Jie et al. (2020, p.3), zones were allocated for patient intake, isolation, staff operations, sanitation, supplies, and psychological care—ensuring efficient workflow, minimizing contamination, and enabling scalable capacity. These cases illustrate how large public interiors can be swiftly repurposed into functional, human-centered emergency facilities through integrated spatial planning (Figure 2). To transform public buildings into Fangcang-style hospitals, specific architectural and infrastructural criteria must be met (Fang et al., 2022, p.3):

1-Road accessibility: Proximity to arterial roads ensures logistics and emergency access.

2-Safe location: Away from water sources and densely populated areas to reduce risk.

3-Adequate space: Sufficient indoor and outdoor areas for wards, support, and circulation.

4-Infrastructure readiness: Reliable electricity, plumbing, mechanical ventilation; backup power, sufficient outlets, and appropriate lighting must be in place.

5-Flexible furnishings: Easily removable or adjustable interior elements.

6-Fire safety: Compliance with fire codes, with at least two emergency exits.

7-Controlled airflow: Clean-to-contaminated airflow; use of air purifiers; central AC discouraged.

8- Separate sanitation: Distinct toilets for staff and patients, proper waste management.

9-Water systems: Centralized supply with sterilization; separate drinking stations for staff and patients.

10-Zoning and layout: Divided into contaminated, semi-contaminated, and clean zones with dual circulation routes; movable non-combustible partitions at least 1.8m high.

Minimal intervention to the existing structure is key for rapid conversion, making full use of existing infrastructure (Marinelli, 2020, p. 49). Future architectural planning for large public buildings—such as stadiums or convention centers—should integrate adaptability, convertibility, and scalability, including provisions for ventilation and sanitation systems.

4.1.2. Conversion of the Javits Center into a Field Hospital – New York, USA

During the first wave of COVID-19 in 2020, New York City's 1.7 million m^2 Jacob K. Javits Convention Center was swiftly repurposed into a temporary care facility. Led by the U.S. Army Corps of Engineers with FEMA and state support, the center initially housed 250 beds, expanding to nearly 2,900 for non-COVID patients (Crothall Helped Transform the Javits Center into a Temporary Hospital, n.d.).

Large exhibition halls were converted into patient pods using temporary partitions, curtain doors, and open ceilings. The facility included a 48-bed ICU, radiology, lab, and clinical service areas. Although not individually ventilated, airflow was reversed to maintain negative pressure and limit airborne transmission. Ventilation was further enhanced by maximizing outdoor air exchange (Thompson et al., 2023, p. 268–276). While ultimately underutilized, the Javits Center highlighted how large public interiors can be rapidly transformed into scalable healthcare infrastructure, underlining the importance of adaptability and flexible architectural planning (Figure 3 and 4).

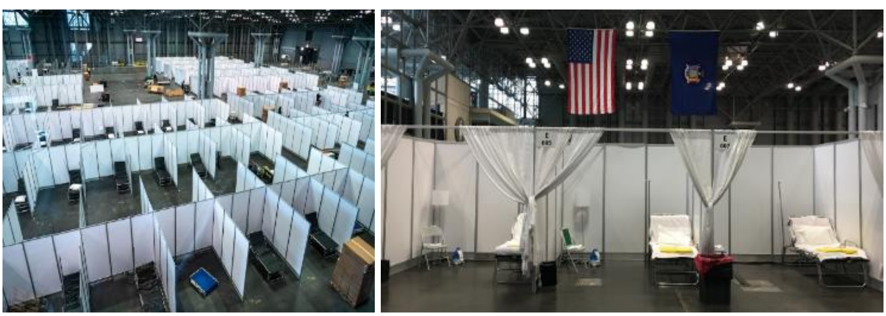


Figure 3. Conversion of the Javits Center into a Temporary Hospital, New York City (Lopez, 2020).

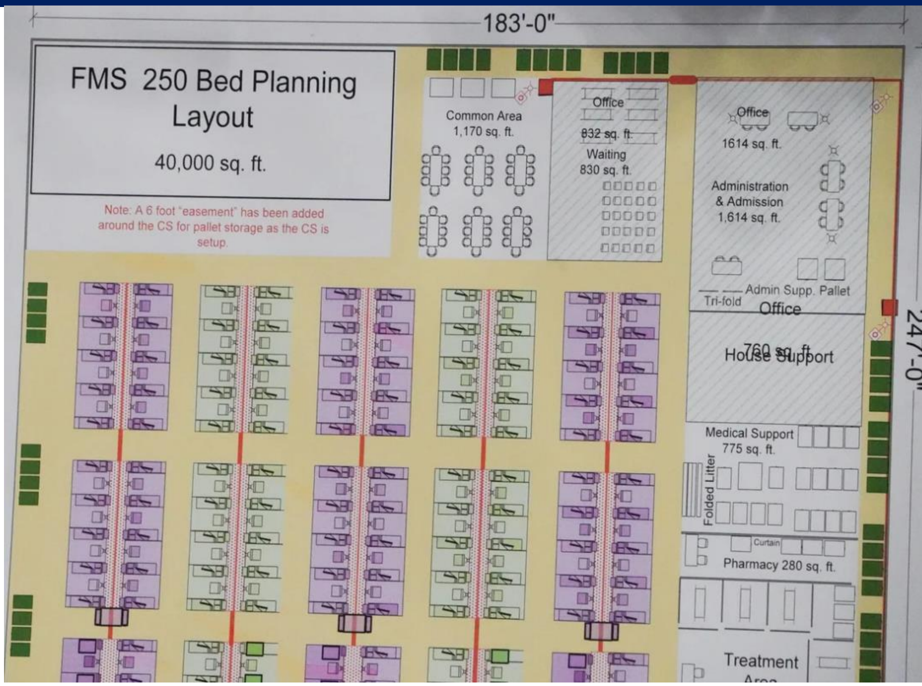


Figure 4. Functional Scheme of the Javits Center Field Hospital, (New York City's Javits Center Transforming into Field Hospital, n.d.).

4.1.3. Conversion of the ExCeL Exhibition Centre into NHS Nightingale Hospital – London, UK

During the COVID-19 pandemic, London's ExCeL Exhibition Centre was rapidly converted into a 4,000-bed temporary hospital due to its expansive, open-plan layout. In just nine days, 87,328 m² of exhibition space was reconfigured into a medical facility with approximately 80 wards, each containing 42 beds (Figures 5 and 6). The contractor followed the principle that "the less that has to be built or procured, the faster the process can happen" (Coronavirus: How NHS Nightingale Was Built in Just Nine Days, 2020; Ravenscroft, 2020).

Key priorities during the transformation included construction speed, reliable power supply, efficient medical gas distribution, and modular design. Lightweight aluminum profiles were used for rapid, demountable partitions; electrical infrastructure was upgraded; and temporary generators and oxygen tanks were installed at patient beds. Following its success, similar NHS Nightingale Hospitals were established in Birmingham, Manchester, and Harrogate.

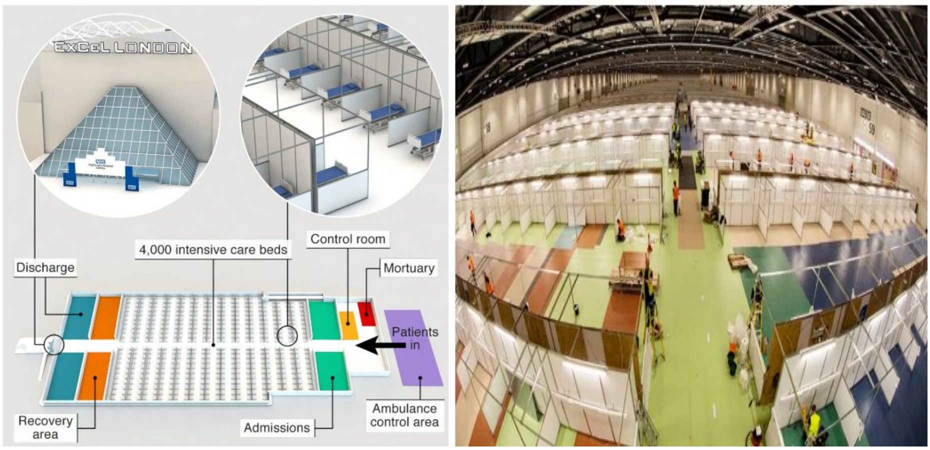


Figure 5. Functional Layout and Interior View of the NHS Nightingale Hospital at the ExCeL Exhibition Centre, London (Ravenscroft, 2020).

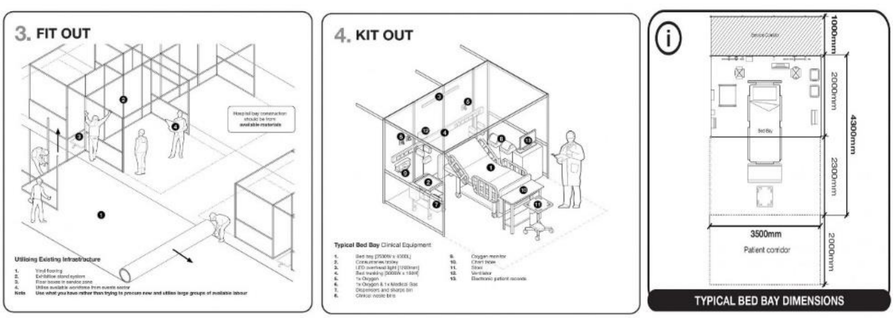


Figure 6. Design Drawings of the NHS Nightingale Hospital at the ExCeL Centre (Ravenscroft, 2020).

4.1.4. Sakarya Stadium: A Field Hospital and Airbridge Hub during the 1999 Earthquake – Türkiye

Stadiums are highly suitable locations for establishing field hospitals and accommodating medical teams, as they offer large, unobstructed open areas. Additionally, they are strategically positioned to serve as airbridge hubs, enabling the rapid evacuation of the injured to nearby functional hospitals via military and civilian helicopters.

During the 1999 Marmara Earthquake, stadiums in Sakarya, Yalova, and Kocaeli were effectively used for these purposes and played a key role in emergency response operations (Figure 7). However, in the 2023 earthquakes in Türkiye, this advantage was significantly diminished. The delayed deployment of military helicopters, combined with AFAD's prioritization of stadiums primarily for shelter purposes, led to a loss of the operational flexibility and strategic value that such spaces had previously provided.

Figure 7. Left: Sakarya Stadium Used as a Field Hospital After the 1999 Gölcük Earthquake; Right: Kahramanmaraş Stadium Used as a Shelter Following the February 6, 2023 Earthquakes in Türkiye (Sofuoğlu, 2024).

4.2. Examples of Public Spaces Used as Shelter and Aid Distribution Centers

During crises, public buildings like stadiums, convention centers, schools, and municipal halls are often repurposed as emergency shelters or coordination hubs. Originally intended for public gatherings, these adaptable interiors play a vital role in providing temporary housing, essential services, and humanitarian aid. The following examples demonstrate how such spaces support communities during disasters.

4.2.1. Istanbul TÜYAP Fair and Congress Center: A Post-Disaster Volunteer Construction Hub

Following the devastating earthquakes of February 6, 2023, in Türkiye, volunteers in Istanbul gathered at venues such as the TÜYAP Fair and Congress Center to construct modular, transportable shelters for earthquake survivors. These 15–20 m^2 units, fully equipped with basic amenities, were built by teams of architects, carpenters, and other skilled professionals, and subsequently transported to the disaster-affected regions.

Referred to as "portable disaster houses," these tiny homes were designed to meet survival standards under all conditions. They featured four-season insulation, ensuring year-round habitability and thermal comfort. This initiative exemplifies how public interiors can be mobilized as production spaces during emergencies, serving not only as temporary shelter zones but also as platforms for generating resilient architectural solutions (Figure 8).

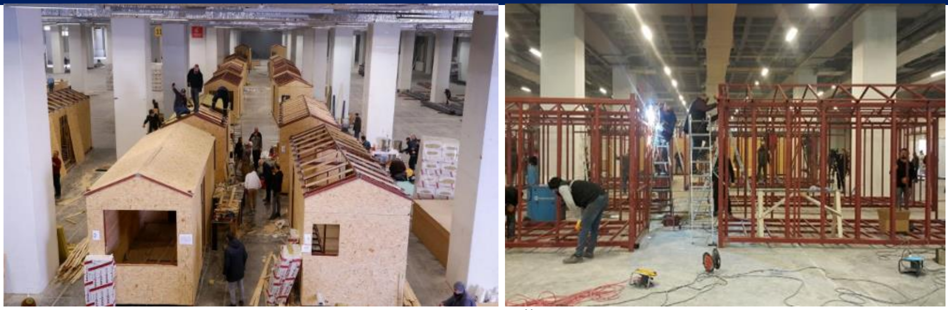


Figure 8. Transformation of Istanbul TÜYAP Fair and Congress Center into a Shelter Construction Workshop (Kahraman, 2023; Volunteers Produce Portable Homes for Türkiye's Quake Victims, 2023).

4.2.2. Colorado Springs: Isolation Shelter for Homeless Individuals with COVID-19

During the COVID-19 pandemic, public buildings such as convention centers, schools, gymnasiums, and libraries across the United States were repurposed as temporary shelters and isolation facilities for homeless populations. In Colorado Springs, the City Auditorium, located in the downtown area, was temporarily converted into an isolation shelter for homeless individuals showing COVID-19 symptoms. The facility provided safe accommodation for 70 adults and 130 infants.

The 70-bed shelter included portable restrooms with showers, recreational areas, daily meals, and, most importantly, a secure and protected environment where homeless men and women could safely quarantine during the pandemic. This case demonstrates the critical role of adaptable public interiors in inclusive public health strategies during crisis conditions (Figure 9).

Figure 9. Colorado Springs: Isolation Shelter for Homeless Individuals with COVID-19 (Colorado Springs 'Isolation Center', n.d.).

4.2.3. Shigeru Ban's Paper Partition System: Temporary Shelter Solution for Refugees and Disaster Victims

In response to the humanitarian crisis caused by the war in Ukraine, architect Shigeru Ban, in collaboration with civil society organizations, implemented his Paper Partition System (PPS)—a modular, rapidly deployable unit designed to provide privacy in emergency shelters. These partitions, made of cardboard tubes and fabric, were deployed across multiple locations including Poland, Ukraine, and France.

The PPS consists of a frame built from eight cardboard tubes with large holes at each end, connected by smaller tubes to form a stable structure. Each 2.3 × 2 meter module is enclosed with fabric to create visual privacy. The system's design is inspired by traditional Japanese shoji screens, yet Ban's choice of paper instead of wood makes it lightweight, portable, and cost-effective. Notably, the assembly time for a single unit is reported to be just 90 seconds, and no tools are required (Totaro, 2022).

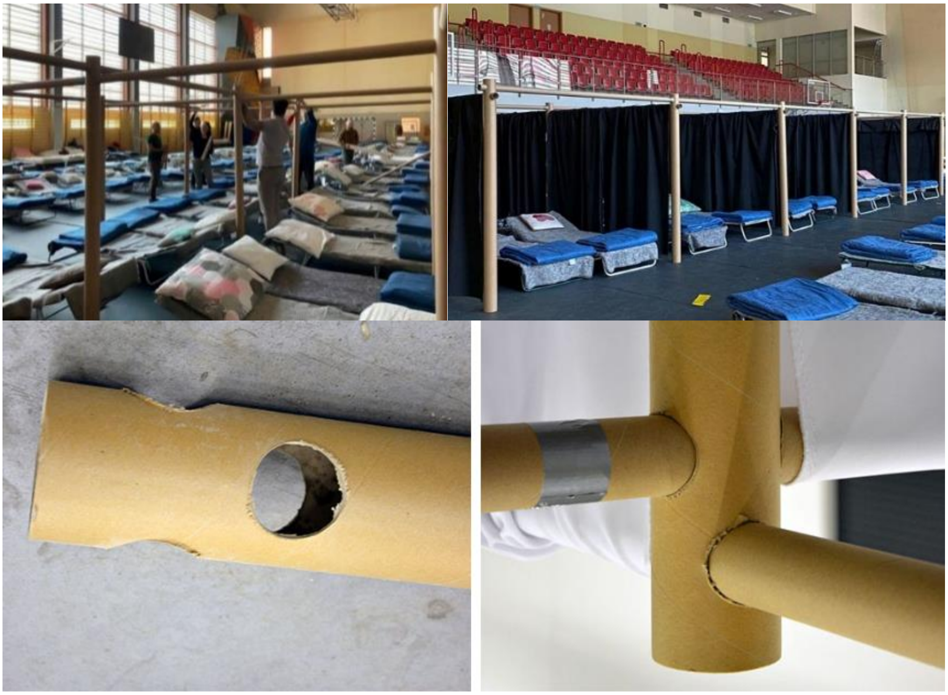


Figure 10. Refugee Shelter Modules Designed by Shigeru Ban (Ukraine Refugee Assistance / Paper Partition System, 2022).

Suitable for short- and medium-term use, the Paper Partition System (PPS) is portable, reusable, and recyclable, embodying sustainable, adaptable design principles (Figure 10). It was also implemented in the Mersin Yenişehir Sports Hall to house survivors of the Kahramanmaraş Earthquake (Figure 11). Previously, it had been successfully used in evacuation centers after the 1995 Kobe, 2011 Great East Japan, 2016 Kumamoto, and 2018 Hokkaido earthquakes—demonstrating its flexibility and effectiveness in diverse disaster contexts.

Figure 11. Mersin Yenişehir Sports Hall, Türkiye – Deployment of Paper Partition System for Earthquake Survivors (Bah, 2023).

Shigeru Ban's Paper Partition System (PPS) follows key design principles (Ban et al., 2014):

Sustainability – Use of recyclable materials to minimize environmental impact.

Simplicity – Easy assembly by anyone, regardless of skill level.

Human dignity – Designed to support both physical and psychological needs.

Temporary but dignified living – Provides privacy, order, and personal space in emergency settings.

4.2.4. Astrodome Stadium, Texas: Emergency Shelter Following Hurricane Katrina

Following Hurricane Katrina in 2005, the Houston Astrodome was repurposed as an emergency shelter for about 25,000 evacuees from New

Orleans, offering food, medical care, and temporary housing. However, issues such as poor sanitation, ventilation, and noise soon arose. To mitigate these, new water lines were installed, along with 400+ portable toilets and showers. Noise from background sounds and morale-boosting music created additional discomfort for many. Communication was facilitated through a public message board, mobile phone booths, and ATMs. Other public structures, including military barracks and shopping malls, were similarly adapted during the crisis (Houston's Helping Hand, 2010; Urban Edge, 2015) (Figures 12, 13, and 14).

Figure 12. Astrodome Stadium as a Shelter for Hurricane Katrina Evacuees (Astrodome Welcomes Thousands of Hurricane Katrina Evacuees, n.d.).

Figure 13. Mobile Shower Units and Wash Stations at the Astrodome Stadium (Houston's Helping Hand: Remembering Katrina, 2010).

Figure 14. Mobile Phone Booths and ATMs Installed at the Astrodome Shelter (Welcomes Thousands of Hurricane Katrina Evacuees, n.d.; Houston's Helping Hand: Remembering Katrina, 2010).

4.2.5. 2020 Elazığ Earthquake: Adaptive Use of Schools and Sports Halls as Emergency Shelters

Following the 6.8 magnitude earthquake that struck Elazığ, Türkiye, on January 24, 2020, approximately 40,000 people whose homes were either destroyed, severely damaged, or who were too afraid to return to their residences, were accommodated in dormitories, guesthouses, and apart-hotels (Figure 15 and 16). According to the Ministry of Interior, more than 15,000 people took shelter in school buildings and sports halls, while over

5,000 tents were set up to house those rendered homeless by the disaster (Williams, 2020). This multi-tiered shelter strategy highlights the importance of a diversified approach to post-disaster accommodation, utilizing both existing public interiors and temporary structures to meet urgent housing needs.

Figure 15. Post-Earthquake Shelter in Dormitories, Guesthouses, and Youth Centers in Elazığ (Şen, 2023).

Figure 16. Earthquake Survivors Sheltering in a Sports Hall in Elazığ (Depremden Etkilenen Vatandaşlar Spor Salonuna Sığındı, 2020).

According to the Turkish Ministry of National Education (MoNE), since the first day of the Elazığ earthquake, 54,661 survivors were accommodated in schools and MoNE-owned facilities throughout the city. Additionally, 767 people were housed in four dormitories and one training hotel in Elazığ (Elazığ Merkezli Depremde Zarar Gören Ailelerimizin Çocuklarına Eğitim Bursu Desteği, n.d.). However, it has been observed that these spaces were not specifically designed or adapted for post-disaster needs; rather, existing facilities were repurposed using available infrastructure, without any special spatial or ergonomic interventions tailored to the conditions and well-being of the displaced individuals.

4.2.6. Use of Adana Fair and Exhibition Center as a Shelter Following the February 6 Earthquake

After the February 6, 2023 earthquakes centered in Kahramanmaraş, the Adana Fair and Exhibition Center was repurposed as a temporary shelter for displaced residents. Basic needs such as food and water were provided, but the facility lacked adequate hygiene infrastructure—most notably, access to showers. The absence of spatial organization and privacy led survivors to create makeshift personal areas using cardboard boxes and chairs (Figure 17). This case highlights the importance of integrating both essential services and dignified spatial solutions in emergency shelter design.

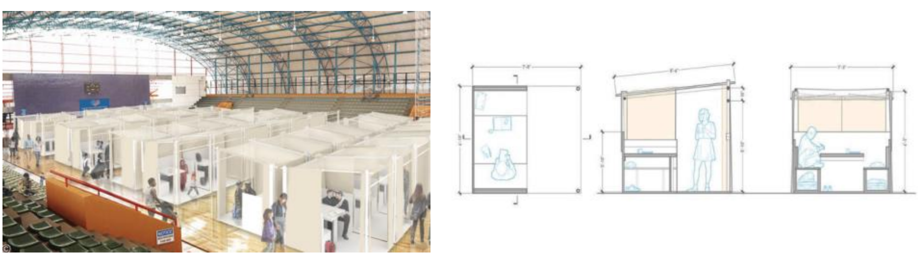
Figure 17. Transformation of Adana Fair and Exhibition Center into a Shelter (Fuar Alanı, Yaşam Alanına Dönüştürüldü; 7 Bin Kişi Geceyi Geçiriyor, 2023).

5. Design Examples

During disasters and emergencies, governments often adapt public buildings to meet urgent needs. The examples above illustrate real-life interventions carried out under extreme conditions, often quickly and used for long durations. Acknowledging the value of such adaptable spaces, designers have proposed various shelter solutions—some conceptual, others developed as prototypes. Studying these initiatives is essential to understanding spatial responses to crises and shaping future emergency design strategies.

5.1. Shelter Squared

In 2017, architects Jeremy Carman and Jayson Champlain designed modular emergency shelters for use in public interiors after disasters. Made from affordable, recyclable, and waterproof materials, each 4.5 m^2 unit includes a sleeping area, lockable storage, and seating, with fabric partitions providing privacy. Easily stackable and assembled in under 15 minutes with Velcro fasteners, the units can be self-installed and configured side-by-side to create a sense of community. Designed for gymnasiums and similar spaces, the shelters offer a practical, human-centered solution for dignified, temporary housing (Figure 18).



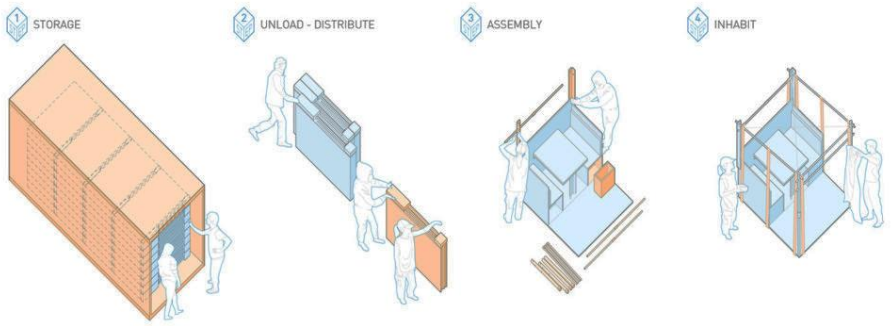


Figure 18. Emergency Shelter Units Designed by Architects Jeremy Carman and Jayson Champlain (Shelter Squared, n.d.).

5.2. Dome-Based Emergency Shelter Structures

In 2019, the architecture firm Perkins & Will designed a modular shelter unit aimed at providing privacy and dignity for displaced individuals in both indoor and outdoor environments. Each unit occupies approximately 4 square meters and includes: A twin bed with under-bed storage, a lockable wardrobe, a power outlet and integrated lighting, an optional fabric canopy for enhanced privacy.

The design is adaptable to multiple layout configurations and can be integrated into existing community structures. Engineered for portability, the unit is collapsible, easy to store, and reusable, making it a dignified and practical housing solution for individuals affected by disasters or displacement. The unit's human-centered approach addresses not only physical shelter needs but also psychosocial well-being by offering personal space in communal settings (Figure 19).

Figure 19. Dome (Tafur, n.d.).

5.3. 3D Puzzle Emergency Shelter

In the 3D Puzzle Emergency Shelter system, the structure is constructed from plywood components that have been laser-cut into 40 unique interlocking forms. These parts are assembled entirely through a slot-fit method, requiring no fasteners, adhesives, or specialized tools. The outer surface can be covered with a protective plastic membrane as needed, enhancing weather resistance. This shelter provides a variety of spatial zones within crowded post-disaster environments, including private retreats for individuals, semi-private spaces for small groups, and dedicated play areas for children. The modular nature of the design enables quick deployment and adaptability to different spatial layouts and user needs. It is particularly valuable in communal emergency shelters where maintaining a sense of personal space and dignity is essential (Figure 20).

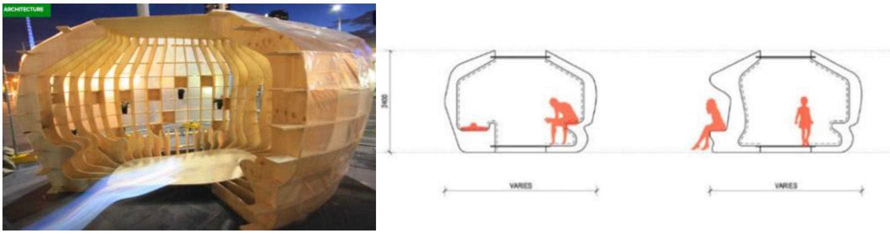


Figure 20. 3D Puzzle Emergency Shelter (3D Puzzle Emergency Shelter, 2013).

5.4. Tentative / Designnobis

Tentative, designed by Hakan Gürsu, is a compact, post-disaster shelter prototype using a snap-fit system for fast, easy assembly and maintenance. Made from lightweight modular panels, it folds into a 30 cm flat-pack form for efficient transport—allowing 24 units per semi-trailer. Each unit, suitable for a small family, offers privacy through its compact shape and can be clustered to form small communities. The design features a weather-resistant aluminum or composite frame, thermal insulation with perlite, and a multifunctional roof for rainwater collection, ventilation, and daylight. Elevated flooring improves insulation, using recycled materials. Tentative has won Red Dot and Green Dot awards and has been prototyped for various climates, offering a dignified, mobile shelter solution (Figure 21).

Figure 21. Tentative (Tentative, 2015; Moreira, 2021).

5.5. Origami ZIP, Origami-Inspired Flat Pack Emergency Shelter

Origami ZIP Shelter is a foldable, flat-pack emergency shelter designed for rapid disaster response. Named for its zipper-like mechanism, it unfolds easily using origami-inspired geometry and Velcro or zip closures—no tools required. Made from lightweight, waterproof textiles or plastic/fabric composites, it is durable yet flexible. Though not for long-term use, it's ideal for immediate relief, offering private pods, interior partitions, or shaded outdoor areas. Curtains or second dividers can enhance privacy. Foldable to backpack size, the shelter supports fast transport and easy deployment (Figure 22).

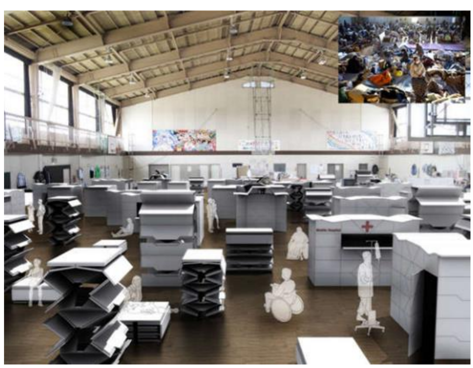


Figure 22. Origami ZIP (Origami-Inspired Flat Pack Emergency Shelter, n.d.).

5.6. Disaster Relief Prefab Folding Pod

Designed by Hariri & Hariri Architecture, the Disaster Relief-Folding Pod is a prefabricated capsule composed of modular, hinged, and foldable panels. It offers private spaces that ensure user privacy when deployed in public areas, both outdoors and indoors. Thanks to its flat-pack structure, the capsule can be easily transported and transformed into a 46-square-meter living space. The exterior cladding is made of Equitone (Linea), a fiber cement-based material known for its resistance to physical impacts and extreme temperatures, with a lifespan exceeding 50 years. Notably, the installation of the capsules requires no tools, enhancing their adaptability and rapid deployment in emergency or temporary scenarios (Figure23).

Figure 23. Disaster Relief Prefab Folding Pod (Khan, 2021; Hemsworth, 2022).

6.Findings

Based on the analysis of national and international cases, this study outlines how public interior spaces have been repurposed in crisis contexts and highlights adaptable design strategies. The key findings are:

1-Multi-Functionality of Public Buildings: Facilities like sports halls, libraries, and exhibition centers were successfully transformed into hospitals, shelters, or aid hubs during crises. However, many were not originally designed for flexibility, complicating these adaptations.

2-Need for Emergency-Ready Design: Public buildings should be designed to accommodate alternative uses during emergencies. This involves open spatial organization, accessibility, modularity, and robust infrastructure.

3-Role of Physical and Technical Features: Transformation success depends on technical systems—such as ventilation, power supply, zoning, and fire safety. Models like Fangcang hospitals clearly defined spatial and functional requirements.

4-Strategic Role of Interior Architecture: Interior design contributes to social resilience by offering adaptable, human-centered, and dignity-respecting spatial solutions—particularly in shelter scenarios.

5-Importance of Design Prototypes: Concepts like Shelter Squared, Origami ZIP, and Tentative provide scalable, modular, and deployable emergency solutions. These models offer valuable guidance for future building design.

6- Application in Turkey Without Design Integration: In Turkey's 2020 and 2023 earthquakes, public buildings were used as shelters but lacked adequate interior design input—resulting in issues like poor privacy and spatial organization. Future buildings should embed multifunctional planning from the outset.

7-Neglect of User Participation: Top-down approaches often disregard users' real needs. Case studies showed stress, disorientation, and inadequate layouts. Interior architecture must apply participatory, user-focused tools—such as profiling, behavior scenarios, and experience mapping—more systematically in crisis design.

7. Conclusion and Recommendations

This study investigates how public interior spaces can be designed to enhance urban resilience through greater flexibility and adaptability during crises. The analysis of national and international case studies demonstrates that public buildings—such as exhibition centers, libraries, and gymnasiums—often take on new roles during emergencies, serving not only as shelters but also as hubs for social recovery. These examples highlight the need for a multidimensional approach to architectural design. Findings show that interior design functions as a strategic tool in crisis contexts, supporting psychological well-being, privacy, and spatial organization. However, despite its potential, interior design remains underutilized—particularly in Turkey. Another key insight is the importance of integrating emergency scenarios into the architectural design process from the outset. Excluding user experiences from design decisions further reduces the livability and effectiveness of crisis-responsive spaces.

In summary, the adaptability of public interiors represents a critical convergence of design expertise and social responsibility. Future public buildings must be designed not only for current needs but also to accommodate alternative uses in times of crisis. This approach is essential for building sustainable and resilient cities (Figure 24).

Recommendations (Figure 24):

1-Design Strategies: Public buildings should be planned for multifunctional use (e.g., a cultural center that can also serve as a shelter).

Modular partitions, portable equipment, and mobile systems should be incorporated, with attention to ventilation, privacy, infrastructure, and sanitation based on potential crisis needs.

2-Education: Architecture and interior design curricula should include crisis-responsive spatial design. Students should engage in scenario-based projects to develop practical skills.

3-Policy and Governance: Municipalities and public agencies should pre-assess public buildings for emergency use and develop adaptive transformation guides. Designers should be part of crisis management teams.

4-Prototyping and Support:

Prototypes like Shelter² and Tentative should be adapted to local conditions and tested in public facilities. Institutions such as TÜBİTAK and KOSGEB should fund crisis-oriented design initiatives.

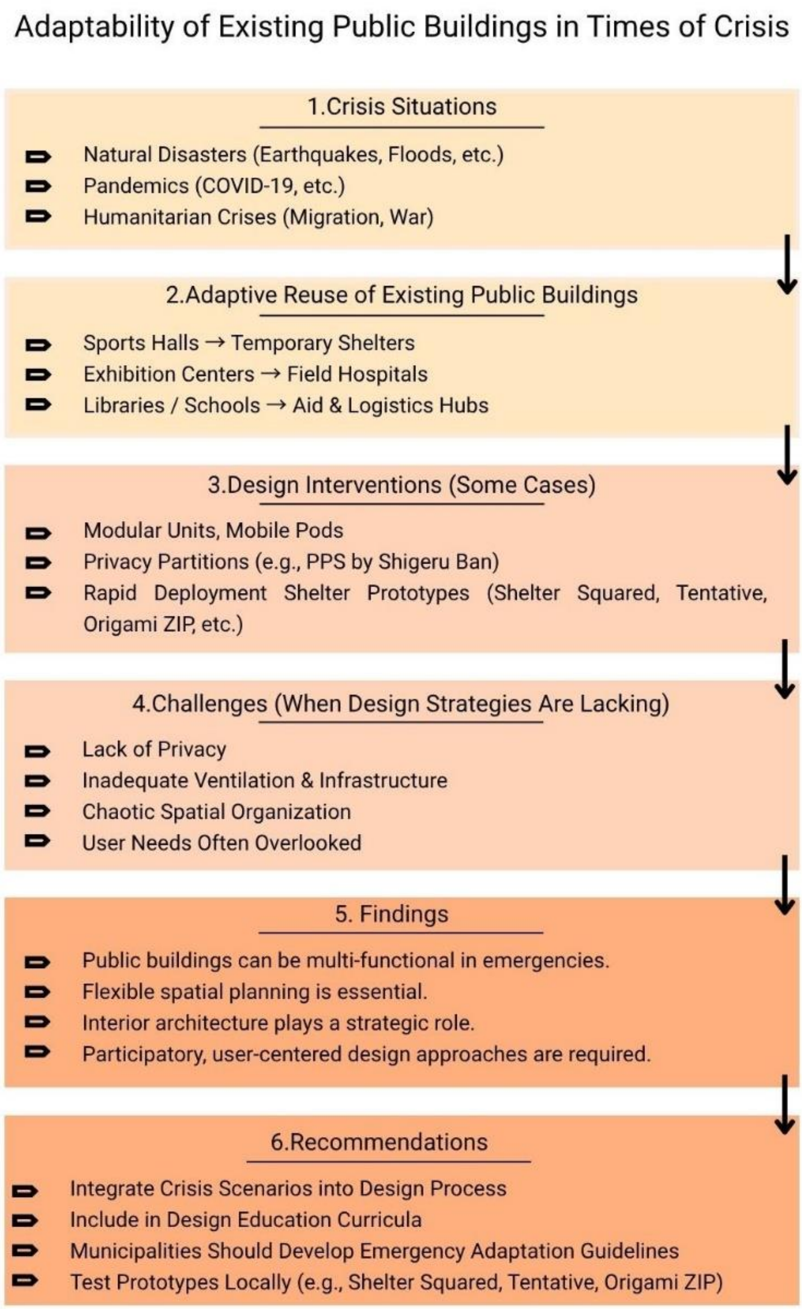


Figure 24. Adaptability of Existing Public Buildings in Times of Crisis.

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Author Contribution and Conflict of Interest Declaration Information

1st Author % 50, 2nd Author %50 contributed. There is no conflict of interest.

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Urban Resilience through Agroecological Urbanism: Transition Pathways across Societal, Ecological, and Institutional Dimensions in Beykoz, Istanbul

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1. Introduction

In recent years, the accelerating climate crisis, food insecurity, biodiversity loss and growing societal vulnerabilities have made it necessary to fundamentally rethink cities—both in their physical structure and governance systems. In this context, *urban resilience* offers a critical conceptual foundation, particularly from a planning perspective. However, it is often reduced to ensuring the continuity of technical infrastructure systems or is viewed too narrowly in terms of disaster management approaches (Meerow et al., 2016). Nevertheless, urban resilience should not solely be understood as the capacity to respond to crises, but equally as the ability to transform the structural inequalities that produce those crises in the first place (Vale, 2014; Ziervogel et al., 2017).

At this point, *agroecological urbanism* is a holistic approach that broadens the scope of debates on urban resilience by offering a transformative conceptual framework centred on the principles of social justice, ecosystem restoration and food sovereignty. Agroecology is a mode of production grounded in local knowledge systems and signifies the reconstruction of a nature-aligned, solidarity-based, and participatory way of life at the urban scale (Anderson et al., 2021; Tornaghi & Dehaene, 2019). This approach reinterprets resilience as not solely a 'response capacity,' but as an opportunity for transformation. This reorients urban planning towards greater justice, inclusivity, and sustainability (Ernstson et al., 2010; Colding & Barthel, 2013).

Integrating agroecological urbanism and urban resilience is particularly significant for reorganising urban food systems, promoting nature-based solutions and including vulnerable communities in decision-making processes. This approach provides a framework that prioritises technical, cultural, and political resilience in the face of crises (Fraser & Stringer, 2009; Colding & Barthel, 2013). As such, planning becomes a tool not exclusively for repairing existing systems, but more importantly for enabling alternative ways of living.

Building on this perspective, the present study draws on the scientific research project titled "*A New Generation Sustainability Strategy in Spatial Planning: Agroecological Urbanism,*" which was conducted at Mimar Sinan Fine Arts University in cooperation with the Municipality of Beykoz. As part of this collaboration, a participatory workshop was held in October 2024 which provided the main empirical basis for the research. Guided by a qualitative design, thematic analysis was employed to analyse the workshop discussions. The resulting insights were categorised into three dimensions—societal, ecological, and institutional—forming a framework to explore the dynamics of the agroecological transition within a multi-dimensional and intersectional context.

The research is structured around the following key questions:

- How does agroecological urbanism offer a transformative framework for building urban resilience?
- How do vulnerabilities emerging across societal, ecological, and institutional dimensions shape or constrain resilience strategies?
- In what ways can the experience of Beykoz serve as a model for developing strategies for agroecological urbanism at the metropolitan scale?

In response to these questions, the study puts forward a hybrid conceptual approach that combines agroecological urbanism and urban resilience, aiming to contribute to the development of more just, resilient, and sustainable urban policies at both local and metropolitan levels.

2. A Holistic Perspective on Urban Resilience: Agroecological Urbanism

Agroecological urbanism is a multi-layered approach to urban planning that has emerged in response to escalating ecological crises, increasing food insecurity, urban poverty, and exclusionary practices. It seeks to reimagine urban life as one that is aligned with nature, just and resilient, by integrating the environmental and societal principles of agroecology with critical urban theory in a holistic manner. As a relatively new conceptual foundation within urban planning, it challenges conventional paradigms by promoting principles of spatial justice, participatory governance, and ecosystem-based planning.

Agroecological approaches offer a structural framework for resilience, aiming to enhance cities' capacity to withstand multiple shocks caused by the climate crisis, entrenched urban inequality and ecosystem degradation. In this respect, they align with the concept of urban resilience at thematic, operational, and practical levels. Through the localisation of food systems, restoring ecosystem services, and expanding community-based practices, agroecological urbanism can develop transformative, rather than reactive, resilience strategies. By doing so, it offers an urban vision that addresses not solely the crises themselves, but equally the structural inequalities that cause them.

2.1. The Societal Ground of Agroecological Urbanism: Food Sovereignty and Social Justice

The literature on agroecological urbanism considers the spatial and institutional reorganisation of food systems to be an effective means of addressing urban inequalities and fostering societal resilience. Food sovereignty, in this context, is understood not simply through production processes, but more importantly through principles of public participation and democratic access (Patil et al., 2018; Resler & Hagolani-Albov, 2020; Simón-Rojo, 2021). From this perspective, food systems are more than physical sites of production; they are arenas of societal struggle where spatial injustices can be confronted and transformed (Tornaghi, 2017).

Agroecological spaces are understood as sites of food production and as platforms for cultivating community solidarity and enabling self-organisation. As a result, these spaces can become localised centres of self-sufficiency. Simón-Rojo's (2021) study of low-income neighbourhoods in Madrid shows that agroecological production areas encourage societal empowerment, and Resler and Hagolani-Albov (2020) demonstrate that such spaces promote food democracy. These social justice–oriented perspectives are closely linked to the social and societal dimensions of urban resilience. During times of extraordinary disruption, such as food crises, natural disasters or pandemics, the collapse of centralised food systems makes the resilience of local and community-based systems more vital (Altieri et al., 2015). From a rights-based planning perspective, agroecological spaces can be considered sites of 'societal resilience.'

Such practices introduce a new dimension to debates on urban resilience by proposing models that move beyond centralised, homogeneous solutions. Instead, they respond to diverse local needs and empower vulnerable groups. Agroecological systems based on food sovereignty are particularly important for supporting these groups, given that food insecurity disproportionately affects women, migrants, and those on low incomes. Drawing on the notion of 'urban vulnerability' emphasised by Xiu et al. (2011), recognising that analysing and assessing vulnerability provides a new basis for urban planning, particularly in large cities, highlights the need to prioritise vulnerable groups in planning processes. At this critical juncture, agroecological approaches offer urban resilience models that address multiple forms of vulnerability while integrating them with the pursuit of social justice.

Nevertheless, as food sovereignty encompasses more than just production, the spatial configuration of food systems and their integration into the wider urban landscape are equally important. Research focusing on integrating food systems into urban planning shows that agroecological planning can be applied not solely in rural areas, but equally at metropolitan scales. Marull et al. (2023) emphasise the importance of ecosystem services and rural–urban solidarity in peri-urban agricultural land planning, while Zhang et al. (2013) and Zaki et al. (2023) highlight the usefulness of GIS-based multi-criteria decision-making tools in assessing the spatial suitability of urban agricultural zones. These tools are particularly effective in ensuring the equitable and strategic spatial positioning of urban agricultural areas. Together, these studies reveal the vital role that scientifically sound spatial analysis can play in resilient urban planning.

However, local food production alone is insufficient for achieving food sovereignty; the distribution, accessibility and public integration of that production are equally important. To this end, the relationship between food production and ecosystem services must be made more visible (Sirowy & Ruggeri, 2024). Indicators such as carbon balance, oxygen generation and soil quality can inform data-driven assessments of the location of food production areas, facilitating the development of environments that promote health and productivity (Derkzen et al., 2017). In this regard, urban gardens have been shown to serve as sites of food production and contribute to stormwater management, soil permeability, and the mitigation of urban heat island effects (Corrêa et al., 2022). This approach highlights the importance of addressing agroecological systems holistically to rebuild resilient cities at ecological and public health levels. It is therefore essential to recognise agroecological spaces as foundational infrastructures for environmental health, psychological well-being, and even post-disaster recovery, in addition to sources of nourishment.

2.2. The Ecological Ground of Agroecological Urbanism: Nature-Based Resilience and Ecosystem Restoration

Nature-based solutions are strategies that enhance cities' resilience by responding to and anticipating crises, in addition to adapting structurally to cumulative environmental pressures. Agroecological urbanism is a powerful tool in this regard as it improves ecosystem services and redefines the relationship between local communities and the natural environment. In this context, ecosystem restoration is merely the first step; the ultimate goal is to re-establish a way of living that integrates nature within urban settings. By linking ecosystem restoration to social inclusion, knowledge production and local practices, agroecological urbanism provides a practical and non-normative foundation for nature-based resilience. For example, Sylvester et al. (2020) demonstrate in their study of the ecological prioritisation of degraded agricultural land in Colombia how ecosystem restoration can be incorporated into planning processes. This involves more than just physical repair; it also provides a spatial framework that enables public participation. Similarly, Zhou et al. (2011) emphasise that green space planning should consider not solely visual green elements, but equally ecological carrying capacity and environmental thresholds. Their work demonstrates how computational ecological suitability models can facilitate the scientific integration of nature-based solutions into spatial planning.

For this reason, agroecological urbanism does not solely seek to achieve nature-based resilience through the expansion of green spaces. Rather, it considers this objective alongside the reconstruction of cultural ties and the promotion of local production models. Tornaghi and Dehaene (2019) argue that such transitions constitute ‘prefigurative urban practices’ involving environmental interventions that shape new urban imaginaries. The case study of Bengaluru, examined by Patil et al. (2018), shows that agroecological practices deliver environmental benefits and reinforce local knowledge systems, socio-cultural memory and networks of solidarity.

Green infrastructure plays a highly strategic role within urban systems, generating biophysical benefits alongside economic, social, and psychological gains. These multi-functional landscapes enhance access to nature, thereby contributing to the realisation of the right to the city for vulnerable groups (Morris et al., 2022). Metropolitan-scale landscape planning models, for instance, highlight the contribution of agriculture to urban sustainability and the socio-ecological functions of large-scale green infrastructure (Marull et al., 2023). Technical models that demonstrate the measurability and integrability of such benefits into planning processes allow nature-based resilience to be strategically incorporated into urban systems (Zhang et al., 2017; Luan et al., 2021). At the same time, these models position urban ecological infrastructures as functional tools, encompassing aesthetic and visual green elements, climate resilience, and socio-economic stability. Indicators such as carbon sequestration, oxygen generation, soil moisture regulation, and microclimate control provide scientific insights into how urban landscapes can be reimagined. Integrating these indicators with agroecological approaches makes nature-based resilience measurable, actionable, and co-developable in collaboration with local communities.

In this context, nature-based resilience constitutes an approach that transforms the epistemology of planning itself, rather than being a singular strategy. Agroecological urbanism unites the spatial, administrative and cultural infrastructures of this transformation, enabling cities to evolve into multi-functional, multi-scalar, and multi-actor systems that can withstand uncertainty.

2.3. The Institutional Ground of Agroecological Urbanism: Planning Tools and Governance Models

Agroecological urbanism is a multi-level approach that addresses not solely the physical environment and production systems, but equally how these systems are planned and governed, guided by a holistic perspective. The planning tools and governance models employed within this framework are critical in understanding how urban resilience can be built and institutionalised at the local level. In turn, the institutionalisation of urban resilience depends less on technical instruments than on governance mechanisms that are participatory, transparent and based on local knowledge.

The effective use of planning tools depends largely on the quality of decision-making structures, or the forms of governance. Rather than relying on conventional top-down, hierarchical governance models, agroecological urbanism employs multi-scalar and multi-actor approaches to governance. Studies have shown that the success of agroecological initiatives is closely tied to collaborative efforts between municipalities, cooperatives, civil society organisations and neighbourhood-based groups (Resler & Hagolani-Albov, 2020; Simón-Rojo, 2021). This highlights the fact that institutional resilience advances through pluralistic and inclusive governance.

Weidner et al. (2019) emphasise the importance of integrating knowledge sharing related to food systems, participatory decision-making processes and equitable governance structures throughout the planning process in agroecological urbanism. In this regard, they argue that governance mechanisms play a transformative role in shaping the relationship between urban agriculture and urban justice. The authors also highlight the importance of what they refer to as *reflexive governance* for the successful implementation of agroecological transitions at an urban level.

In acknowledging the need to consider both vulnerable groups and spatial vulnerabilities in the planning process (Cutter et al., 2003; Xiu et al., 2011), the agroecological urbanism approach provides a more democratic, preventive and equitable planning framework. Rather than addressing these vulnerabilities through social assistance programmes, it uses participatory planning tools. At the same time, it plays a strategic role in building comprehensive resilience against multiple shocks, ranging from disaster risks to the climate crisis.

Studies have shown that urban agroecological practices contribute to gains in biodiversity and the development of *biocultural resilience* (Vidal Merino et al., 2021; Villavicencio-Valdez et al., 2023). In this context, it is emphasised that planning and governance processes must engage with both formal structures and cultural, traditional, and local knowledge systems.

In this regard, González de Molina and Petersen (2019) conceptualise agroecology as both a sustainability strategy and a strategic framework for economic restructuring and social justice advancement. One of the key indicators of success in governance models is therefore the production and sharing of knowledge. The tools outlined in studies exploring the use of open data infrastructures and participatory monitoring systems in agroecological planning serve to democratise these processes (FAO & The World Bank, 2020). The Ecopolitana plan, developed in Italy, provides a comprehensive example of the integration of agroecological principles with urban design, multi-functional land use and governance-oriented sustainability (Del Fabbro Machado et al., 2022).

As previously noted, multi-criteria decision-making tools, such as MCE-GIS, are particularly useful within planning frameworks. As demonstrated in the studies by Zhang et al. (2013) and Zaki et al. (2023), these tools offer objective criteria for identifying suitable areas for agroecological production in urban contexts. When integrated with agroecological approaches, these tools promote spatial justice and facilitate the incorporation of food production into wider urban resilience strategies.

The Berkeley Food Institute's (2021) policy brief emphasises the importance of using tools such as data-driven decision-making, social impact assessments, inclusive planning guidelines and resilience budgeting to support urban agroecological initiatives, particularly at the municipal level. Together, these recommendations outline a range of instruments that support a comprehensive systemic transformation across technical, institutional, and operational dimensions within planning and governance.

In this framework, ecosystem modelling studies emphasise that planning tools should encompass more than spatial analysis. Rather, these tools should be understood as components capable of monitoring the continuity of nature-based services, measuring environmental functionality and integrating such insights into decision-making processes (Zhang et al., 2017; Luan et al., 2021). In this regard, Yin et al. (2010) propose a numerical model based on indicators such as carbon and oxygen balance, which makes the climatic and ecological contributions of agroecological areas more visible within planning processes. This approach establishes a strong conceptual link between nature-based resilience and governance-oriented sustainability and reveals that planning tools have political as well as technical capacities. Consequently, the tools and governance models employed in agroecological urbanism lay the institutional groundwork for how resilience is constructed, who is included in the process, and which forms of knowledge are recognised as valid.

3. Methodology

This research adopts a qualitative case study approach to examine how the principles of agroecological urbanism can shape urban resilience strategies. The semi-rural district of Beykoz in Istanbul was selected as the unique empirical context for the study. Beykoz was chosen because of its diverse ecological and agricultural landscape, transitional character between urban and rural areas, and exposure to planning contradictions related to land use, food systems, and ecological degradation.

The primary data for this research were obtained from the "*Production Encounters and Agroecological Roadmap Workshop*," which was held on 17 October 2024. The workshop was structured around the three core pillars of agroecological urbanism: **the societal dimension** (food sovereignty and social justice); **the ecological dimension** (nature-based resilience); and **the institutional dimension** (planning tools and governance models). Specific guiding questions framed each session: identifying systemic challenges related to the agri-food system and urban planning; developing collaboration, monitoring and sustainability strategies; and defining transformative goals for agroecological transition and urban resilience.

The workshop brought together 41 participants from a range of backgrounds, including producers, representatives from central and local governments, academics, members of civil society, and young entrepreneurs. The participants reflected a variety of ages, genders, professions, and geographical locations.

The sessions were conducted with the support of table moderators and rapporteurs, and the discussions were recorded both orally and in writing.

The dataset also included handwritten notes provided by participants, discussion tables, and mapping exercises. The data were coded and categorised using thematic analysis with the help of MAXQDA software. Although the thematic axes outlined in the conceptual framework guided the analytical direction, the coding process was predominantly inductive. First, the findings from each session were examined independently, and then they were subjected to comparative analysis across sessions to identify shared themes, critical turning points, and shifts in actor positions. The workshop findings were contextualised further through an interpretive analysis of Istanbul's planning documents relating to food systems and land governance, relevant agricultural legislation and secondary literature. This holistic methodological approach, which is both interpretive and grounded in local experience and theoretical depth, contributes to the formation of a multi-scalar understanding of agroecological urbanism.

4. Findings: Dynamics of Agroecological Transition

The potential of the principles of agroecological urbanism to guide the development of more resilient urban futures was explored through structured discussions during the workshop. These discussions were grounded in local knowledge and experiential, participatory dialogue. The findings that emerged from these discussions were categorised according to three key thematic dynamics outlined in the conceptual framework: societal, ecological, and institutional processes.

These dynamics are not isolated structures, but rather intersecting and mutually influencing layers of relations centred around issues such as land use, food systems, policy frameworks, and community agency. This thematic classification reveals both the problem areas identified by participants and the potential for transformation. Consequently, it offers a tangible, locally rooted, multi-dimensional foundation for assessing how an agroecological transition could be achieved in Beykoz.

4.1. Social Dynamics through Communities and Food Systems

The discussions at the workshop highlighted the critical role of social justice and food sovereignty in shaping the concept of agroecological urbanism. Participants repeatedly emphasised that food systems are socio-political spaces where access, equity, and autonomy are actively negotiated, not merely networks of production and consumption. Within this framework, the agroecological transition requires a profound societal transformation as well as an environmental one.

Although seemingly aimed at preserving agricultural areas, producers expressed that land use policies often fail to meet the everyday needs of rural communities, particularly regarding housing and intergenerational continuity. For instance, several participants mentioned that rigid zoning restrictions prevented them from building new homes for their children on existing farmland. This has resulted in youth migration and disengagement from agriculture. These accounts reveal a structural disconnect between regulatory frameworks and the lived realities of rural life. This exacerbates spatial injustice and undermines community resilience. This issue is not just a technical matter of housing provision; it highlights a deeper structural problem that disrupts family ties, erodes social belonging and endangers cultural continuity.

The discussions also revealed a growing concern over the erosion of agricultural livelihoods. Rising input costs, a lack of recognition for producers’ labour and institutional neglect were identified as major factors contributing to a sense of disillusionment, particularly among younger generations. Workshop participants frequently described this condition as the ‘invisibilisation of labour,’ referring to the devaluation of farming as a dignified and socially respected profession—one of the key barriers to its transmission across generations. The economic unsustainability of agriculture and the lack of decent working conditions were seen as fundamental obstacles to continuity between generations and long-term resilience. Participants stressed that redefining agriculture as a meaningful, forward-looking profession, and restoring its occupational identity are vital steps towards realising food sovereignty. To this end, they frequently proposed strategies to build societal resilience, such as integrating agricultural education into school curricula, providing entrepreneurship support for young people, and creating platforms to facilitate knowledge exchange.

Participants also envisaged agroecological spaces as domains of solidarity, education, and self-organisation. Although these are sites of food production, they were also described as places where people can come together to care for each other, learn about ecology, and maintain cultural traditions. Micro-scale initiatives such as seed sharing, composting and school gardens were identified as valuable means of rebuilding local knowledge systems and promoting societal development. These practices were noted to have multiple functions—ranging from food production to bridging the mental divide between urban and rural life, encouraging collaborative production, and strengthening the skills necessary for cohabitation and commoning. School-based gardens and seed-sharing initiatives, for example, illustrate the potential of such practices to cultivate environmental awareness and a sense of shared responsibility. However, participants emphasised that the sustainability of these efforts depends on institutional support from educational establishments and local governments. Without such backing, the vitality of civil initiatives tends to weaken over time.

In summary, the workshop revealed that the agroecological urbanism approach—and the envisaged transition for Beykoz—must address deep-rooted social inequalities, intergenerational ruptures, and the structural neglect of agricultural communities. This framework places food sovereignty as a collective right at the heart of planning and social justice, offering a robust pathway towards rebuilding resilient food systems that are grounded in, responsive to, and embedded within local communities. In this sense, agroecological urbanism emerges as a socially grounded approach that enables a transition that is rooted in nature, centred on people, driven by solidarity and guided by equity.

4.2. Ecological Constraints and Land Use Practices

The workshop emphasised the ecological potential and challenges of conserving, restoring, and productively using natural and semi-natural landscapes within the framework of agroecological urbanism. Participants widely expressed concern that current land use practices are inadequate for preserving ecological integrity, particularly in agricultural and forested areas. It was noted that only around a third of arable land is currently cultivated, with the rest largely left idle or held as a speculative investment. This results in a loss of productivity and the degradation of ecological functionality, making it difficult to manage agricultural land responsively in relation to environmental thresholds.

Parcels officially designated as first-class agricultural land—such as those at risk of flooding or with high groundwater levels—have demonstrated how inaccurate ecological classifications can weaken productive potential and undermine conservation efforts. Participants noted that uncertainties surrounding the accuracy and timeliness of the datasets employed in planning systems hinder the ability to make planning decisions based on ecological functionality. For instance, the State Hydraulic Works' planning approach, characterised by concrete-lined irrigation systems and outdated hydrological data, was frequently criticised for being inadequate in addressing the irregular precipitation patterns and flood risks brought about by climate change.

It was also noted that non-agricultural land uses—such as wedding venues, film and television production sets and weekend tourist facilities—have increasingly encroached upon agricultural land due to loopholes in legislation and a lack of institutional oversight. These trends have been reported to accelerate ecological degradation and reduce the environmental effectiveness of agricultural areas. Participants emphasised that, although such structures are often licensed as 'temporary' or 'lightweight' buildings, they have a lasting impact. In this context, participants pointed out the inadequacy of a purely conservation-oriented approach, highlighting the need for an approach based on principles of restorative and productive land use instead.

The importance of integrating the ecological rationale into planning decisions was frequently emphasised, rather than limiting nature-based resilience to the formal preservation of green spaces. Permaculture, agroforestry, and carbon farming were considered to be viable strategies for revitalising soil, supporting biodiversity, and enhancing the ecosystem services of agricultural landscapes in urban and peri-urban areas. The multi-functional objectives of these strategies proposed by participants include increasing land productivity, carbon sequestration capacity, microclimate regulation, and water retention.

However, it was stated that deficits in institutional capacity and knowledge gaps hinder accurate ecological assessments of land parcels, and that field inspections are sometimes carried out superficially or are susceptible to political influence. The lack of technical expertise and weak coordination among stakeholders in environmentally sensitive areas, in particular, limits the systematic implementation of nature-based planning.

Another recurring theme in ecology-focused discussions was the belief that transforming environmental responsibility culture requires education. Participants emphasised the importance of early-stage ecological education, through initiatives such as school gardens and public education programmes, for fostering long-term commitment to sustainable land use. International examples from Europe and the United States, such as waste separation and composting practices, were presented as cases demonstrating how public participation can yield positive ecological outcomes. The fact that some Beykoz producers have started producing their own compost, using local seeds and installing rainwater harvesting systems indicates that this awareness is also taking root locally. Composting and organic waste recycling were regarded as components of a circular food system that could enhance soil productivity in Beykoz and reduce the ecological footprint of urban consumption.

Overall, the findings suggest that the approach to agroecological urbanism in Beykoz should prioritise ecosystem-based planning and adopt restorative land management strategies. In this framework, nature-based resilience encompasses more than adapting to environmental pressures; it also involves re-establishing meaningful ecological relationships and improving the environmental performance of urban systems through inclusive, evidence-based planning. Recasting the human–nature relationship as one of mutual responsibility and commoning reveals that the agroecological transition is an ethical responsibility as well as an ecological necessity.

4.3. Institutional Functioning in Planning and Governance Structures

The workshop revealed the deep institutional fragmentation and governance challenges that hinder agroecological transition. A recurring theme among all participants was the misalignment between central and local institutions. In particular, the lack of coordination between the Ministry of Agriculture and Forestry, urban planning authorities and local governments was emphasised repeatedly. This was framed as a governance issue intertwined with a structural vulnerability that directly affects the sustainability of urban agricultural production.

Participants stated that the root causes of this misalignment lie in overlapping jurisdictions, conflicting legal regulations and political disagreements. Notably, the absence of a shared planning infrastructure based on current data across different institutions leads to uncertainty regarding the status, usage, and potential transformation of agricultural land. For instance, unauthorised constructions on agricultural land technically fall within the jurisdiction of municipalities; however, the lack of coordination with district-level agricultural directorates renders such inspections ineffective. Participants also shared other concrete examples, revealing that an initiative approved by one institution could be blocked by another. In some cases, political tensions were said to influence technical decision-making processes. There was a broad consensus that such governance failures undermine the capacity of the planning system to protect agricultural land and support its productive use.

Agroecological urbanism requires a reorientation of institutions based on participatory, multi-actor governance. Participants in the workshop emphasised the urgent need for an integrated planning approach that includes state institutions, producers, civil society organisations, cooperatives, and educational institutions. The existing institutional structures were criticised for being rigid and top-down, and for excluding producer knowledge and community-based experience from planning and policymaking processes. This was assessed as confining planning culture to a reactive rather than proactive mode. Many participants explicitly expressed this exclusion with the statement, "*decisions about us are being made without us.*"

Participants emphasised that producers should be acknowledged as stakeholders, while also being actively involved in the co-design of agricultural and spatial policies. The proposed mechanisms included participatory budgeting, collaborative land use planning and transparent monitoring systems. It was further emphasised that these mechanisms must have a tangible impact on decision-making processes and not just be a form of symbolic inclusion. Participants also suggested testing and scaling these approaches through pilot projects that allow for institutional innovation at the local level.

It was noted that the legitimacy and professional identity of agricultural labour can only be reconstructed through policy-level recognition and institutional support. Proposed measures included expanding technical support mechanisms, improving access to subsidies, developing agricultural employment programmes for young people and investing in data-driven monitoring systems. The importance of considering agricultural education as a form of governance capacity, as well as a vocational field, was emphasised. In this context, institutions such as faculties of agriculture, cooperative academies, and local knowledge centres were identified as key structures for enhancing producer knowledge and fostering a culture of participatory governance.

Participants expressed the need to reinstate intermediary institutions—such as the State Planning Organisation—or to establish agricultural units at the municipal level that are capable of conducting strategic planning. Public procurement and municipal markets were identified as particularly effective tools for promoting economic justice for producers by eliminating intermediaries and ensuring price stability. These interventions were considered to contribute to the development of economic and governance-related justice.

In conclusion, the findings suggest that implementing an agroecological urbanism approach requires governance models that prioritise coordination, inclusivity, and transparency. The transformation of planning tools into instruments of resilience requires technical capabilities and institutional innovations that are grounded in ecological, social, and economic justice. In the case of Beykoz, aligning planning, agricultural, and community needs within a participatory governance framework is key to the agroecological transition. Developing the institutional capacity in this direction will address current demands while proactively preparing for a future shaped by deepening climate crises and social inequalities.

5. Discussion: A Call to Planning Arising from the Agroecological Transition

The key findings of this research demonstrate that the agroecological urbanism approach reframes urban resilience—viewing it not as a simple response mechanism to crises, but as a holistic opportunity for transformation in the face of the systemic inequalities that produce them. This approach offers a new epistemological orientation for urban planning, influencing both the construction of societal subjectivity and the redefinition of the relationship between humans and nature (Colding & Barthel, 2013; Vale, 2014). The findings from the Beykoz case study reveal that resilience is more than a technical matter; it also concerns justice, representation, and the co-construction of shared urban life.

In relation to the first research question, agroecological urbanism defines resilience not through centralised or standardised solutions, but through strategies that are actor-based, grounded in local knowledge systems, and oriented toward collective production. The experiences from Beykoz offer compelling insights into how such a transformation can take place both spatially and culturally. The everyday practices of producers reveal that agricultural production serves as both a means of livelihood and a foundation for collective existence and a practice of belonging. This aligns with what Tornaghi and Dehaene's (2019) description of 'prefigurative urban practices'—community-led initiatives that model alternative urban futures. Therefore, agroecological urbanism aspires to make cities more resilient to future uncertainties while reimagining them as spaces of shared, egalitarian, and imaginative urban life.

In relation to the second research question, it is evident how vulnerabilities at the societal, ecological, and institutional levels shape resilience strategies. At the societal level, the devaluation of agricultural labour, intergenerational ruptures, and the commodification of rural life; at the ecological level, speculative land use, dysfunctional classifications, and the formalisation of nature-based solutions; and at the institutional level, fragmented governance structures and crises of representation—all represent key manifestations of these vulnerabilities. However, identifying these vulnerabilities alone is not sufficient; they must be addressed through planning practices that are holistic, participatory, and context-sensitive.

At this point, micro-scale initiatives in Beykoz—such as seed sharing, school gardens, composting cycles, and local marketing systems—carry the potential to create alternative spaces of resilience in response to systemic vulnerabilities. These practices contribute to both environmental and economic outcomes and support the development of new societal subjectivities and governance cultures. Still, the sustainability of such practices depends on more than just collective will; it also requires institutional innovation, flexible governance, and multi-level coordination based on knowledge within the planning discipline (Weidner et al., 2019; FAO & The World Bank, 2020). Therefore, planning institutions must possess the capacity to facilitate cross-actor and cross-scale collaboration, trust-building and shared learning processes, as well as technical expertise.

Turning to the third research question, the experience of Beykoz can serve as an instructive model for cities seeking to develop agroecological strategies at the metropolitan scale—demonstrating how the local can be articulated through a universal planning language. Neither fully rural nor a typical urban setting, Beykoz's hybrid character positions it as a living laboratory for multi-functional land use, multi-scalar governance, and the coexistence of cultural diversity. Consequently, the strategies developed here could provide valuable insights for Beykoz and other cities with similar characteristics, as well as for all planning approaches related to metropolitan agriculture, nature-based resilience, and the rural–urban continuum.

From the perspective of urban planning, these findings convey the following core message: agroecological urbanism is not just a new theme or sectoral policy; it is a paradigm that redefines the approach, tools and focus of urban planning. This paradigm positions planning not simply as the management of space, but as a framework for reproducing commons, democratising knowledge systems, and transforming vulnerabilities through justice (Altieri et al., 2015; González de Molina & Petersen, 2019). The success of the agroecological transition depends less on the technical capacity of planning and more on its political courage, ethical orientation and ability to facilitate collective action.

6. Conclusion

This study examines the relationship between agroecological urbanism and urban resilience in Beykoz, conceptualising resilience as a dynamic process that reveals the transformative potential of cities at societal, ecological, and institutional levels, rather than as a capacity limited to crisis response. Agroecological urbanism thus emerges as a strategic framework that goes beyond technical solutions, offering an approach shaped by the principles of social justice, ecological integrity, and pluralistic governance.

The research findings show that agroecological practices in Beykoz have become components of a multi-layered urban infrastructure that constructs resilience through production-oriented interventions as well as by establishing new relationships among people, food, and ecosystems. These examples demonstrate that urban planning must move beyond resource allocation and regulation to recognise the strategic value of collective practices such as community building, knowledge sharing, and the organisation of shared ways of living.

In this context, the concept of 'adaptation' should not be viewed as a passive response to environmental or governance-related changes. From the perspective of agroecological urbanism, on the contrary, adaptation is redefined as a set of practices that can unfold across different scales, strengthening inter-community relationships and enhancing the capacity for transformation. Allowing such practices to be incorporated into planning processes increases environmental resilience and reinforces spatial justice, cultural continuity and social inclusion.

The experience in Beykoz shows that urban planning can evolve into a transformative instrument when agroecological principles are internalised simultaneously at spatial, governance, and cultural levels. This approach is notable for its ability to create coherence within fragmented structures, develop inclusive models in the face of exclusionary systems and incorporate community perspectives into decision-making processes.

Ultimately, this research reveals that the approach of agroecological urbanism should not be understood merely as a collection of local practices, but rather as a transformative urban planning paradigm. Resilience-oriented planning is shaped by ethical considerations, political will and collective action as much as by technical expertise. The construction of cities that are adaptive, just, and capable of engaging in reciprocal relationships with nature requires a commitment to this multi-layered transformation.

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Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article. There is no conflict of interest.

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Assessment of The Effect of Material Type Used in Urban Surfaces on Heat Island Potential

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1. Introduction

Urbanization and industrialization, while improving the quality of human life, also bring several problems such as global warming, industrial waste, and air pollution. In addition to the negative impacts of these issues on a global scale, urban areas characterized by industrial interaction and the use of synthetic construction materials are also affected. Consequently, the natural environment and ecosystem are adversely impacted, leading to an ecological imbalance (Rizwan &Dennis, 2008).

One of the most significant local-scale changes caused by urbanization is its impact on climatic elements. To analyze these changes effectively, it is essential first to understand the concept of the Urban Heat Island (UHI). When discussing urban climate, temperature is the primary element to be examined. It has been a well-established fact for over a century that metropolitan areas are warmer than rural areas (Gulten & Oztop, 2020)

In contemporary urban environments, green spaces have been mainly replaced by tall buildings and various urban elements such as streets, avenues, and sidewalks. The use of motor vehicles, heat emissions resulting from industrialization, and human activities that directly release heat contribute to urban warming. Moreover, surfaces such as concrete pavements, asphalt roads, and buildings constructed with materials like concrete, brick, and cinder blocks absorb solar radiation during the day. This stored energy is subsequently released into the atmosphere as long-wave thermal radiation during the night, leading to an increase in nighttime air temperatures. This phenomenon is known as the Urban Heat Island (UHI) effect (Kum, 2006).

Although the UHI effect is typically observed at night, it is fundamentally the result of energy absorption during the daytime and its delayed release. Therefore, the amount of solar energy absorbed during the day, along with the physical and thermophysical properties of the urban environment, plays a crucial role in the formation and intensity of the UHI effect (Givoni, 1998). At this point, the extent to which different types of materials used on urban surfaces (such as asphalt, concrete, stone, and permeable surfaces) affect the heat island effect emerges as an important research question.

This study aims to investigate the role of different material types used in urban surfaces, such as roofs, building facades, pavements, and streets, on the heat island potential and to compare these materials in terms of their thermal properties. The effects of different materials on Heat Island Potential (HIP) are examined by Computatioanl Fluid Dynamics (CFD) simulations. It identifies which materials are more advantageous for reducing HIP in horizontal and vertical urban elements, and how the right material for each urban element affects HIP.

1.1. Formation of the Urban Heat Island

In urban areas, the temperature increase caused by human necessities leads to the upward movement of atmospheric particles through convective processes. As altitude increases and air temperatures decrease, these particles encounter colder air masses, resulting in a horizontal displacement toward the urban periphery. In these boundary regions, the particles tend to subside (Figure 1).

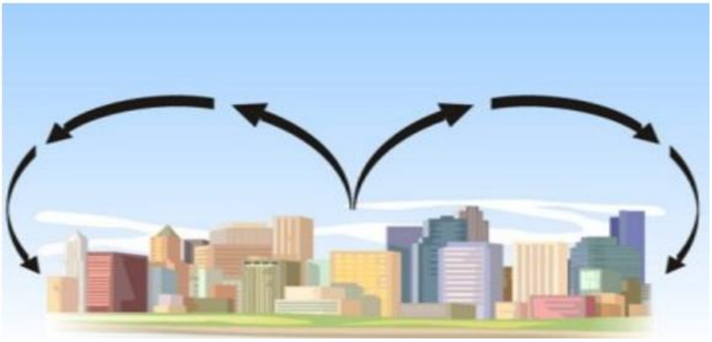


Figure 1. Urban heat island mechanism (Kum, 2006)

As a result, an urban heat island and a "dust dome" are formed, characterized by higher intensity at the city center and decreasing intensity toward the periphery (Göksu, 1993). The particles constituting the heat dome are transported upward from the source area by rising warm air and tend to accumulate most densely in the urban core. The thickness and impact of the heat island vary depending on the anthropogenic heat sources and the physical characteristics of the city (Figure 2).

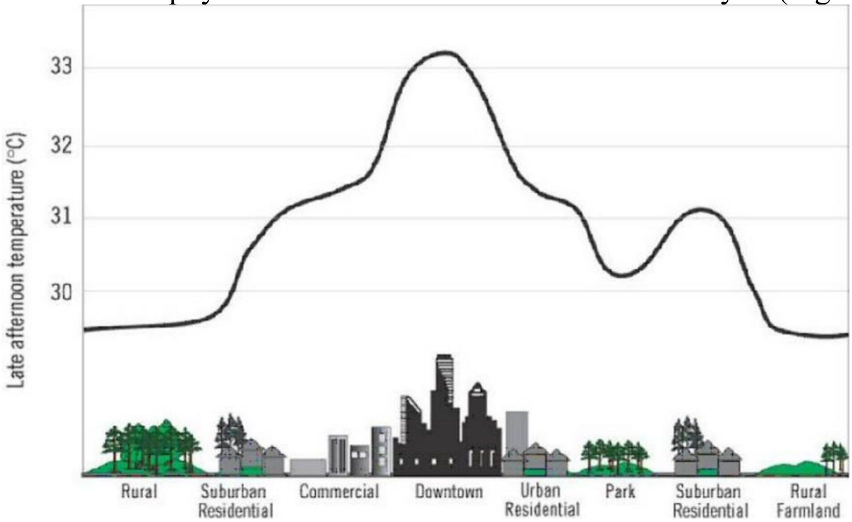


Figure 2. Urban heat island profile varies according to different residential areas (EPA,2008)

This effect becomes particularly pronounced during nights with clear skies. The urban heat island phenomenon is most clearly observed when comparing urban temperatures with those of surrounding rural areas. The primary reason for this discrepancy lies in the differing thermal storage capacities of surface materials in urban and rural settings. In addition, heating of residential buildings and the release of waste heat from fossil fuel use in urban areas contribute to this effect.

Based on the main factors affecting urban climate, the causes of urban heat island formation can be summarized as follows (Kum 2006; Moonen et al 2012):

- Urban surfaces and building materials with high solar absorption capacity,
- Impermeable surfaces that prevent infiltration and cause rainwater to be diverted through drainage systems,
- Urban geometry and building height reducing wind speed and air circulation,
- Limited green spaces that reduce evapotranspiration, leading to increased energy retention,
- Decreased advection and convection along with temperature inversion,
- Heat emissions from vehicles, heating systems, and industrial activities,
- Use of low-quality fossil fuels resulting in incomplete combustion and increased waste heat release.

1.2. The Impact of Urban Heat Island on Climatic Elements

The impact of materials used in urban areas on the heat island is directly related to climatic elements. Factors such as the amount of radiation acting on a surface, its relationship with wind, or humidity and precipitation rates can alter material behavior and, consequently, the heat island effect. Therefore, this section briefly describes the relationship between the urban heat island and climatic elements.

Climatic elements in cities differ from rural areas due to the urban heat island effect. Table 1 shows the differences in the main climate elements. The effects of the urban heat island on the climate elements are also explained.

Table 1. Main Climate Elements

Climatic Element	Parameter	Urban Area (Compared to Rural)
Temperature	Annual average	+0.7%
	Winter maximum	+1.5%
	During cold season	+2% to -3%
Wind Speed	Annual average	-20% to -30%
	Extreme wind	-10% to -20%
	Calm conditions variation	+5% to +20%
Humidity	Annual relative humidity	-6%
	Average (winter)	-2%
	Seasonal (summer)	+8%
Cloudiness	Total cloud cover	+5% to +10%
	Fog	+100% (winter), +30% (summer)
Precipitation	Total	+5% to +10%
	Number of rainy days	+10%
	Number of snowy days	-4%

Urban temperature increases are typically more pronounced toward city centers, where building density and, consequently, population concentration are higher. Although thermal variations may show irregularities due to urban morphology and construction intensity, the general trends in temperature fluctuations within cities—both rising and falling—are distinguishable. Major metropolitan areas can generate their own microclimatic conditions, largely independent of their surroundings (Moonen et al, 2012).

The most significant urban temperature increases are usually observed in the average minimum temperatures. For instance, the central area of London records an average minimum temperature approximately 2 °C higher than that of the surrounding rural zones. Nevertheless, because the shape and intensity of the urban heat island vary considerably depending on time and location, relying solely on average values may result in an inaccurate representation of thermal dynamics (Kum, 2006). In Turkey, which is located in the mid-latitudes, the Urban Heat Island (UHI) effect can have a beneficial aspect by contributing to milder winter conditions in urban centers. However, during the summer months, increased solar radiation combined with the influence of hot air masses affecting the region exacerbates thermal discomfort and the prevalence of heat-related health issues in cities (Memon, Leung &Chunho, 2008)

All surfaces on Earth gain heat through incoming solar radiation (shortwave) and lose heat by emitting longwave radiation back into the atmosphere. On dry surfaces, solar radiation absorbed during the day is converted into sensible heat, leading to an increase in surface temperature. Conversely, solar energy absorbed by vegetated or moist surfaces is transformed into latent heat through evapotranspiration, resulting in a relatively lower rise in surface temperature. The emission of longwave radiation, which facilitates cooling, is a continuous process occurring both day and night (Givoni, 1998).

A portion of the incoming solar radiation is absorbed by the surface and converted into either sensible or latent heat, while another portion is reflected back into the sky, having no direct effect on surface temperature. Although urban and rural areas with similar geographical conditions receive approximately the same amount of solar radiation, urban areas may experience reduced radiation due to air pollution. In such cases, a portion of the incoming radiation is either absorbed or reflected by the urban atmosphere, particularly under polluted conditions. This phenomenon is quantified using the extinction coefficient (α, 1/m), which describes the atmosphere's absorptive capacity (Reiss et al., 2007). In densely built urban environments, the path of solar radiation to building surfaces becomes increasingly complex. A significant amount of radiation strikes rooftops, some reaches vertical surfaces such as walls, and only a small fraction reaches the ground. Especially in areas with tall buildings and narrow spaces, minimal radiation reaches the surface. The radiation that reaches wall surfaces is partly reflected and partly absorbed. Reflected radiation often strikes adjacent buildings, initiating a continuous series of inter-reflections among urban surfaces. Only a minor portion escapes into the atmosphere, while the majority is absorbed by building facades and later released as longwave radiation during evening and nighttime hours.

Urban elements, such as walls, streets, and pavements, emit longwave radiation into the sky. However, the magnitude of this heat loss is closely tied to the surface's ability to "see" the sky. For instance, a wall in an open environment can view only half of the sky dome, resulting in significantly reduced radiation emission compared to a horizontal roof. Consequently, the longwave radiation emitted by a wall is typically about half of that emitted by a roof surface.

In urban settings where buildings are of similar height, rooftop heat loss can be considered comparable to that of rural areas. However, when building heights vary, taller buildings absorb the longwave radiation emitted by shorter rooftops, thereby decreasing overall heat loss within the urban canopy—the volume between the ground surface and rooftop level. In conclusion, urban areas experience more intense warming compared to their rural counterparts due to the thermal effects resulting from the absorption of solar energy and the physical characteristics of the built environment (Givoni,1998).

In urban areas, wind effects, particularly at ground levels, have a direct impact on the amount of energy consumed for heating and cooling, on human health and comfort, and on the formation of air pollutants. During periods of rising average temperature, increasing wind speed reduces the stress that hot weather creates on people, and the urban heat island effect decreases as wind speed increases (Givoni,1998).

In urban environments, tall buildings, due to their height, distance, and orientation, significantly impact the wind speed and direction. A portion of the wind striking a tall building is directed downward in the forward direction, causing undesirable wind circulation and increased speed near the surface. Another portion of the wind drifts toward the edges of the building, resulting in increased wind speeds in these areas. Wind speed decreases at the rear of the tall building. As the building height increases, the amount of calm area at the rear increases (Kural, 2007).

2. Material and Method

In the study, an area in the Elazığ city has been chosen and some simulations have been performed by Ansys Fluent, which is a CFD-based program. Results obtained from simulations were evaluated over a parameter called Heat Island Potential (HIP).

2.1. Heat Island Potential

The concept of heat island potential was first introduced in a study conducted by Akinoru Lino and Akira Hoyano (1996). Defined in the study, "Development of a Method to Predict the Heat Island Potential Using Remote Sensing and GIS Data," heat island potential is a parameter that examines surface temperature distributions and the urban thermal environment in urban areas based on sensible heat flux. Sensible heat flux is a convenient index that allows estimating the effects of the atmosphere on the urban canopy and can indicate how air temperature affects a metropolitan area. The sensible heat flux for a given area can be defined by the formula given below;

$$Q = \frac{\sum \alpha_c T_y - (T_s + T_a) d_y}{A} \qquad (1)$$

Here, Q is the sensible heat flux (W/m^2), αc is the heat transfer coefficient, Ty is the surface temperature (°C), Th is the average air temperature (°C), Ta is the local (at the urban canopy level) and average air temperature difference (°C), and A is the area of the microscopic surface (m^2). In their study, Lino and Hoyano made some assumptions for the heat transfer coefficient and the urban canopy and air temperature difference above it (Lino&Hoyano, 1996; Asawa, Hoyano & Nakaohkubo, 2008). Accordingly;

• If the wind speed above the urban canopy is 1-2 m/s, turbulent flow occurs under both natural and forced convection conditions. This precludes the calculation of the heat transfer coefficient for any surface. However, suppose the wind speed within the canopy is assumed to be equal to the wind speed above the canopy level. In that case, it is possible to calculate the heat transfer coefficient using the Jurges Formula.

• The difference between the air temperature at and above the canopy level is generally 1°C. This difference was ignored in this study, and the temperatures were assumed equal.

Consequently, the heat island potential is calculated based on the sensible heat flux, ignoring the heat transfer coefficient and air temperature difference, and is derived as (Lino&Hoyano, 1996).

$$HIP = \frac{\sum(T_s - T_{air})d_y}{A} \quad (2)$$

Here, HIP is the heat island potential (°C), T_s is the surface temperature (°C), T_a is the air temperature value taken from meteorology (°C), d_y is the surface area (m^2) and A is the floor area of the urban area whose HIP will be calculated (m^2).

2.2. CFD Analysis

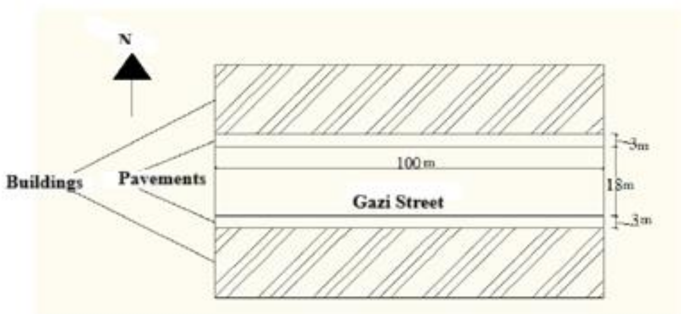
In this study, Fluent, a CFD software that utilizes the finite volume method, was used. Fluent has been used in many industries worldwide since 1983 and is the most preferred CFD software. Thanks to its advanced solver technology and diverse physical models, it is capable of providing fast and reliable solutions to problems involving conduction, convection, and radiation heat transfer in laminar, transitional, and turbulent flows, problems involving chemical reactions, fuel cells, acoustic flow-induced noise, and multiphase flows (Ansys Fluent,2023). In this study, Fluent was integrated into Ansys Workbench. The Ansys Workbench platform is a system built on the superior knowledge of advanced simulation technology. It enables users to perform all simulation tasks on a single screen with drag-and-drop simplicity. The Workbench screen significantly simplifies working with simulation. Projects are visually displayed as connected systems in a flowchart-like diagram. The desired analysis system can be easily dragged and dropped into the project diagram from the toolbox on the left. In this study, Fluent was integrated with Ansys Design-Modeler, a powerful geometry correction and generation tool used to create solid models in the Workbench, and Ansys Meshing, an advanced digital mesh generation tool. The CFD-Post tool was used for the resulting analyses.

2.3. Study Area

Analysis were perfromed for a defined area in Gazi Street which is one of the busiest and most crowded streets in Elazığ. Gazi Street presents the densely constructed residential area in Elazığ and it is oriented east-west direction. Buildings on this street are arranged in a north-south orientation, adjacent to each other, and are generally 7-8 stories tall.

Traffic impact increases during midday and evening hours, while it is significantly weaker in the morning. Currently, there are trees spaced at regular intervals along the street. However, due to the young age of the trees, their impact on the current situation was ignored. Figure 3-a shows the area model definition for Gazi Street while Figure 3-b shows the two-dimensional model for this area.

(a)



(b)

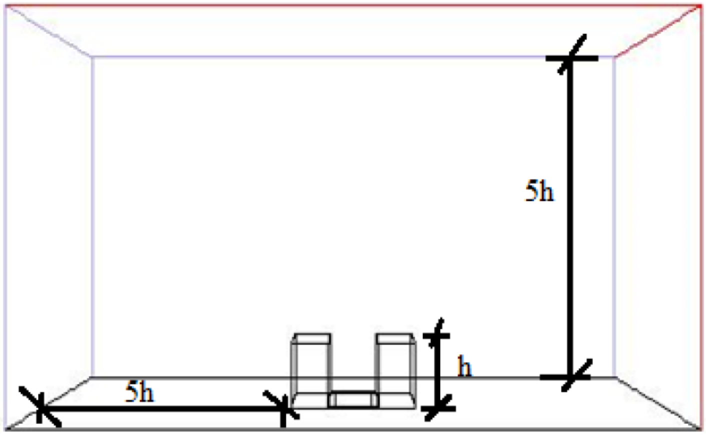
Figure 3. (a) Study area **(b)**Used model in the analysis (Google Earth, 2023)

2.4. Boundary Conditions

For the cubic air volume considered as the workspace, boundary conditions were determined using wind speed, direction, and air temperature data obtained from meteorological sources. For this purpose, hourly wind speed, direction, and air temperature data from the past five years were collected, and average values were calculated (Gülten, 2014). While radiation emissivity and absorptivity coefficients for urban surfaces were obtained from the literature, average hourly meteorological data were utilized to calculate the convective heat transfer coefficients for both horizontal and vertical surfaces (Gülten, Aksoy & Oztop, 2016).

For longwave radiation incoming from the surroundings, an initial simulation was conducted in each case by equating the surface temperature to the air temperature. The surface temperature values obtained from this simulation were then used in a second simulation, and the resulting surface temperatures were used in the HIP calculations (Asawa, Hoyano & Nakaohkubo, 2008).

In the coordinate system used in the program, the X vector represents the east direction, and the Y vector represents the north direction. Accordingly, for wind entering from the main directions, the side surface of the cubic volume facing the relevant direction was defined as the boundary (Figure 4). For wind entering from intermediate directions, it was assumed that the wind enters through the side surfaces facing the two component directions. Domain size established as 5H for all boundary surfaces while the building height is equal to H.



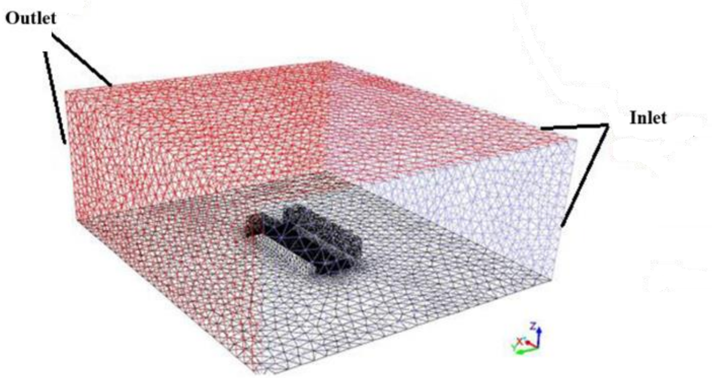


Figure 4. 3D model of the study area and boundary conditions

3. Findings and Discussion

In this study, the HIP values obtained from simulations were calculated by replacing the coating materials accepted for urban elements with alternative materials for each urban element and the results were compared. Table 2 shows the thermophysical properties of the currently accepted materials and the materials chosen as alternatives.

Table 2. Thermophysical properties of urban elements (Çengel, 2011).

Urban Element	Material	Density (ρ) kg/m^3	Specific Heat(c) J/kg°C	Thermal Conductivity(k) W/mK	Emissivity(ε_s)	Absorbtion Coefficient (α_s)
Street	Asphalt	2120	920	0.74	0.93	0.93
	Concrete	2000	880	1.20	0.70	0.60
Building Façades	Plaster	1860	780	0.72	0.93	0.23
	Natural Stone	2680	830	2.80	0.85	0.70
	Clay Panel	1458	880	1.30	0.91	0.40
	Wood Veneer	700	2310	0.17	0.82	0.50
Pavements	Concrete paving	2000	880	1.20	0.70	0.60
	Natural Stone	2680	830	2.80	0.85	0.70

In the initial simulations, the materials chosen were paint over plaster for the walls, concrete paving for the sidewalks, asphalt for the streets, and tiles for the roofs. These are materials commonly encountered in densely populated urban centers. Care was taken to ensure that the surface covering materials chosen as alternatives to these materials were also of a similarly common type. The materials chosen for the walls were natural stone (marble, etc.), wood panels, and clay panels, while natural stone paving for the sidewalks was chosen as an alternative to concrete paving, and concrete for the streets was chosen as an alternative to asphalt. Simulations with different materials were conducted using the modeled geometry for Gazi Street and considering the long-term average data for the July 11th event in Elazığ province (Gülten, 2014).

As seen in Figure 5, the use of different materials on vertical urban elements such as façades did not result in significant differences in surface temperatures when compared to the results obtained with plaster applications. As expected, slightly higher temperatures were observed on the south-facing façade for all material types, with the highest temperatures recorded for the natural stone cladding. The heating and cooling characteristics of materials are related to their specific heat capacities. Materials with low specific heat capacity heat up and lose heat more rapidly. Additionally, the thermal conductivity of materials determines their heating capacity through conduction. When Table 2 is examined, plaster and then natural stone are identified as having the lowest specific heat capacities among the selected façade materials. However, since the thermal conductivity coefficient of natural stone is much higher, it has heated up more.

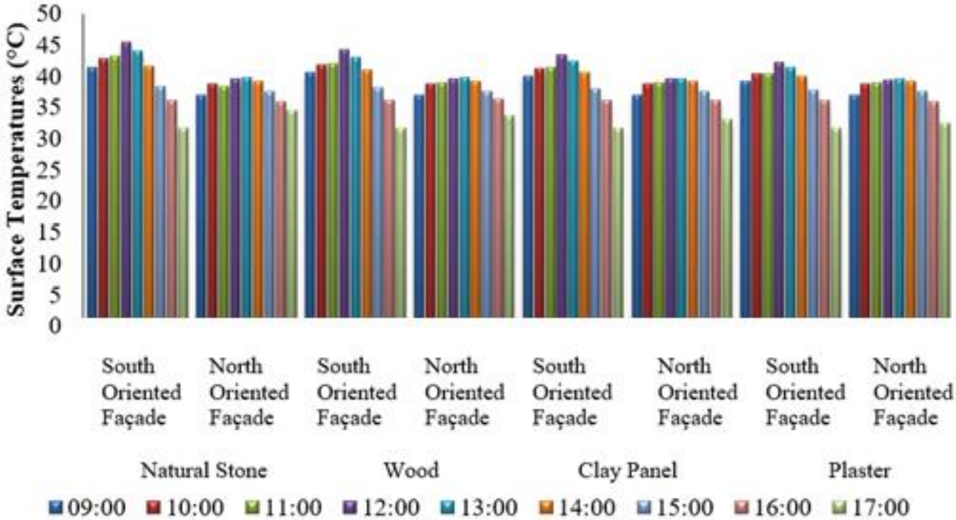


Figure 5. Façade surface temperatures for different materials

As seen in Figure 6, the calculated HIP values for all wall material types yielded very similar results. The highest HIP values were obtained for natural stone, while the lowest values were recorded for plaster. When considering the absorption coefficients of the materials, this ranking is found to be directly consistent with those coefficients. Figure 7 presents the simulation results for a concrete pavement, which was identified as an alternative material to be used on the street. According to the results, replacing asphalt with concrete on the street resulted in an average surface temperature reduction of 4–5 °C at all hours.

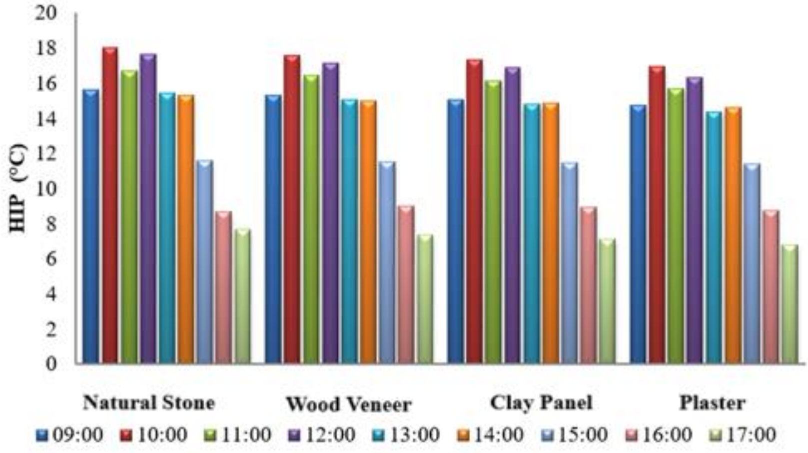


Figure 6. HIP values vary depending on different wall materials

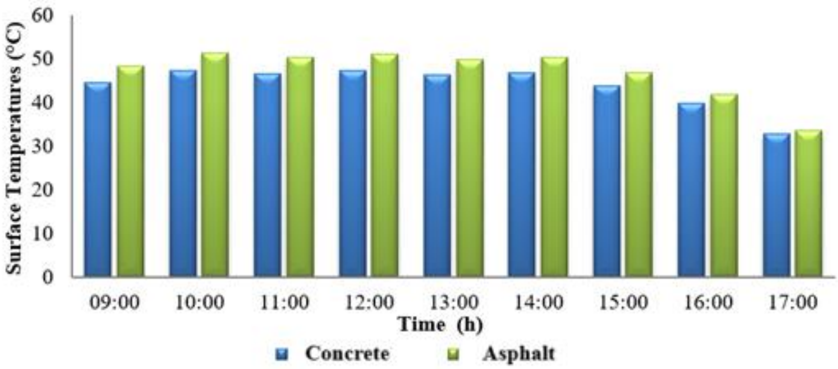


Figure 7. Surface temperature values obtained with concrete and asphalt for the Street

Figure 8 shows the surface temperature values obtained from simulations using natural stone, which was selected as an alternative material for sidewalks. Compared to concrete pavers, natural stone—having a lower specific heat capacity and a higher thermal conductivity coefficient—caused significant temperature increases, particularly on the south-facing sidewalks. While both material types yielded similar surface temperatures for the north-facing sidewalk, the use of concrete pavers appears to be more appropriate for the south-facing sidewalk in terms of urban heat island potential.

Figure 9 presents the HIP values obtained from simulations in which the material type of each urban element was altered. The use of natural stone on façades resulted in the highest increase in HIP, followed by the use of natural stone on sidewalks, which led to the second highest HIP value. The lowest HIP value was obtained from simulations in which concrete was used instead of asphalt for the street, while all other urban elements retained their existing materials. Therefore, it can be stated that materials with high thermal conductivity and high solar absorption coefficients, such as natural stone, have a negative impact on urban heat island potential, regardless of whether they are used for vertical or horizontal urban elements.

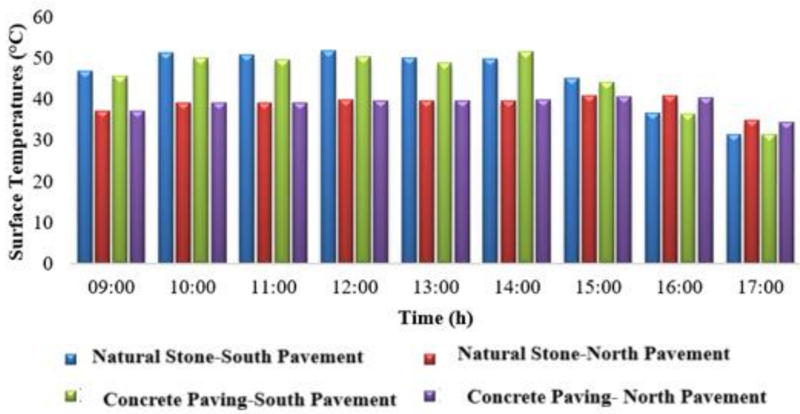


Figure 8. Surface temperature values obtained with natural stone and concrete paving for pavement

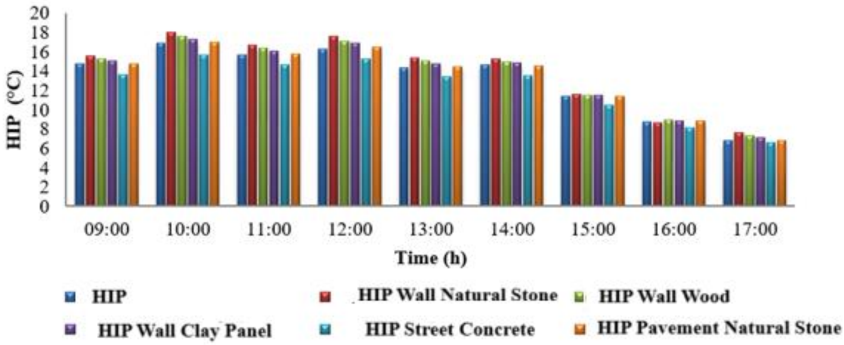


Figure 9. Varying HIP values for different surface coating materials

Moreover, it is evident that the material chosen for the street—which is the horizontal urban element most exposed to solar radiation in an urban canyon—plays a crucial role in terms of urban heat island potential. Indeed, even replacing only the asphalt material—characterized by a high solar absorption coefficient—resulted in a noticeable reduction in the HIP value. For this reason, when selecting materials for horizontal urban elements that significantly affect urban heat island potential, particular attention should be paid to their thermal conductivity, solar absorption, and emissivity coefficients.

4. Conclusion and Suggestions

In this study, which employs computational fluid dynamics, it is possible to create and evaluate different scenario conditions for the examined urban area or any other area by incorporating various parameters. Thanks to the effective use of this method, significant parameters that may influence urban areas have been simulated, allowing for the desired comparisons to be made. Due to both the method employed and the use of the HIP parameter for evaluating results, this study presents a unique application that addresses an issue, potentially providing valuable insights for designers regarding the urban heat island effect in urban design.

The use of different materials generally resulted in minor changes in HIP values. The most significant difference was observed when the material used for the street—the horizontal urban element most exposed to solar radiation—was changed. Therefore, when selecting materials for urban areas, greater emphasis should be placed on their thermophysical properties rather than their visual appearance. Materials with lower thermal conductivity, solar absorption, and emissivity coefficients should be prioritized.

The conscious selection of urban surface materials not only mitigates the heat island effect but also directly contributes to the health and quality of life by improving the thermal comfort of urban residents. However, further research is needed to gain a more comprehensive understanding of the issue. In the future, comparative analyses using innovative and smart materials for different climate zones will provide practical guidance for urban planners, architects, and policymakers.

Acknowledgements and Information Note

Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article. There is no conflict of interest.

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Evaluating Spatial Equity in Urban Park Accessibility: A GIS-Based Analysis of the İzmir Gulf Region, Türkiye

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1. Introduction

1.1. Research Motivation and Problem Context

Urban green spaces (UGS) serve as critical infrastructure for ecological sustainability, climate resilience, and public well-being. In rapidly urbanizing regions, however, their distribution, accessibility, and equity remain profoundly uneven—reflecting and often reinforcing broader spatial and social disparities (Li et al., 2024; S. Wu, Chen, Webster, Xu, & Gong, 2023; Xu et al., 2022). Globally, the intensification of urban heat islands (UHIs), compounded by climate change and densification, underscores the necessity of green infrastructure not only in terms of total provision but also in terms of equitable spatial allocation (Okumus & Terzi, 2023; Yang, Jin, & Li, 2024). Inequities in green space distribution disproportionately impact vulnerable groups, limiting both ecological benefits and access to essential recreational and thermal regulation services (LaReaux & Watkins, 2025; Zhao & Gong, 2024).

Spatial inequity in green space accessibility has been studied from diverse perspectives—including environmental justice, spatial planning, and urban resilience—but often lacks methodological convergence. While accessibility indicators have proliferated (Semenzato, Costa, & Campagnaro, 2023), there remains limited consensus on how to incorporate spatial configuration, population heterogeneity, and network-based proximity into a unified equity assessment (He, Wu, & Wang, 2020; Leng, Sun, Yang, & Chen, 2023). Moreover, a persistent divide is observed between the Global North and South in terms of both total green exposure and adaptation capacity, with cities in the South exhibiting significantly lower average cooling benefits and greater inequities in park access (Li et al., 2024; S. Wu et al., 2023).

1.2. Conceptual and Thematic Background

The debate over green space equity spans horizontal equity—equal access regardless of individual characteristics—and vertical equity—just distribution that accounts for social vulnerability (He et al., 2020; Xia, He, & Zhang, 2024). In this regard, several studies have emphasized the role of socioeconomic and demographic stratification in mediating spatial inequity, particularly among children, women, the elderly, and low-income populations (Jin, He, Hong, Luo, & Xiong, 2023; Kaya & Eminoğlu, 2025; LaReaux & Watkins, 2025; Şenol & Atay Kaya, 2024; Zhao & Gong, 2024). As noted by Guan et al. (2023) , spatial configuration and pattern metrics also shape access disparities, revealing that accessibility is not solely a function of park area or number, but of landscape morphology and connectivity.

Recent advances have refined the methodological toolkit for equity assessment, including network-based service areas (Gao, Xu, Shang, Li, & Wang, 2025), floating catchment methods (Lan, Liu, Huang, Corcoran, & Peng, 2022; Zhao & Gong, 2024), space syntax for pedestrian flow modeling (Huang, Li, Ma, & Xiao, 2023; Kahraman & Çubukçu, 2023), and spatial regression approaches such as GWR and MGWR (Adorno, Pereira, & Amaral, 2025; Wang & Guan, 2025). These approaches increasingly integrate multiple dimensions of accessibility—e.g., visibility, proximity, and service coverage—while seeking to map spatial heterogeneity in explanatory mechanisms.

1.3. Methodological Framing and Innovation

This chapter responds to the need for a multi-method, spatially explicit framework that bridges normative concepts of green equity with empirical measures of spatial configuration and social exposure. It develops and operationalizes a network-based accessibility model for 692 validated urban parks across 237 neighborhoods in the İzmir Gulf Region, Türkiye—an urban corridor of environmental and demographic diversity. The methodology incorporates space syntax metrics, network centralities, and service area modeling at four spatial thresholds (300 m, 500 m, 1000 m, 1500 m), combining them with population-weighted Gini and Lorenz statistics to examine access inequalities.

Following global calls for replicable and rigorous planning tools (Adorno et al., 2025; Martin & Conway, 2025; Rubaszek, Gubański, & Podolska, 2023), the study uses multiscale regression models (OLS, GWR, MGWR) to decompose spatial variability in park accessibility outcomes. Variables such as canopy cover, elevation, built-up density, and impervious surface area are tested across different spatial kernels to reveal local predictors of access deficits. Building on equity classification typologies (C. Wu, Wei, Huang, & Chen, 2017; J. Zhang & Tan, 2023), the results culminate in a tiered priority framework for planning interventions, where Tier 1 neighborhoods exhibit the highest urgency across multiple spatial and social dimensions.

1.4. Research Gap and Study Contribution

Although spatial equity assessments have become increasingly common in urban planning research, most studies continue to rely on Euclidean buffers, omit population heterogeneity, or fail to examine accessibility as a function of network constraints (Leng et al., 2023; Semenzato et al., 2023). This study addresses those limitations by (i) grounding accessibility within real pedestrian networks, (ii) applying population-weighted equity diagnostics for key demographic cohorts, and (iii) integrating spatial regression models to understand place-based drivers of inequity.

Importantly, the İzmir Gulf Region presents a relevant empirical case due to its pronounced topographic variation, dense coastal urbanization, and active green space planning initiatives. Drawing upon lessons from comparative studies in China, Europe, and North America (Adorno et al., 2025; Lan et al., 2022; Martin & Conway, 2025; Z. Zhang, Cenci, & Zhang, 2024), the study contributes an adaptable, scalable framework for evaluating access equity that can inform SDG 11.7 and local sustainability agendas.

The study is further distinguished by its integration of spatial diagnostics (LISA, Gi*), quantitative equity scores, and regression-based decomposition into a single analytical framework, facilitating a policy-relevant synthesis. The resulting classification of high-priority zones provides actionable guidance for urban planners, environmental policymakers, and equity-driven park design interventions (Jin et al., 2023; J. Zhang & Tan, 2023).

Figure 2 illustrates the methodological workflow, detailing data inputs, network-based processing, regression modeling, and spatial diagnostics across the chapter's analytical framework.

2. Material and Method

2.1. Study Area and Units of Analysis

The study focuses on the "İzmir Gulf Region", a contiguous urban corridor encompassing coastal districts of İzmir Province, Türkiye. Defined by the spatial extent of pedestrian networks and urban settlement forms surrounding the inner Gulf, the analysis targets neighborhoods that are functionally integrated with the metropolitan coastline and accessible open space systems.

Following spatial filtering and validation, the final analytical scope includes 237 neighborhoods (mahalle). These units represent the lowest tier of official administrative geography in Türkiye and are widely used for urban diagnostics, planning, and service delivery. They also align with the resolution of available demographic and spatial datasets, supporting consistent aggregation and analysis. As shown in Figure 1, (i) the administrative district layout of İzmir Province (top left), (ii) the bounding box of the Gulf region overlaid on the full provincial extent (middle left), (iii) true-color satellite imagery underlaying the road network and park locations within the study area (bottom left), and (iv) a digital elevation model (DEM) overlay emphasizing topographical patterns and fluvial corridors within the region . Together, these components provide a spatial overview of the landscape conditions and infrastructural context in which park accessibility is evaluated.

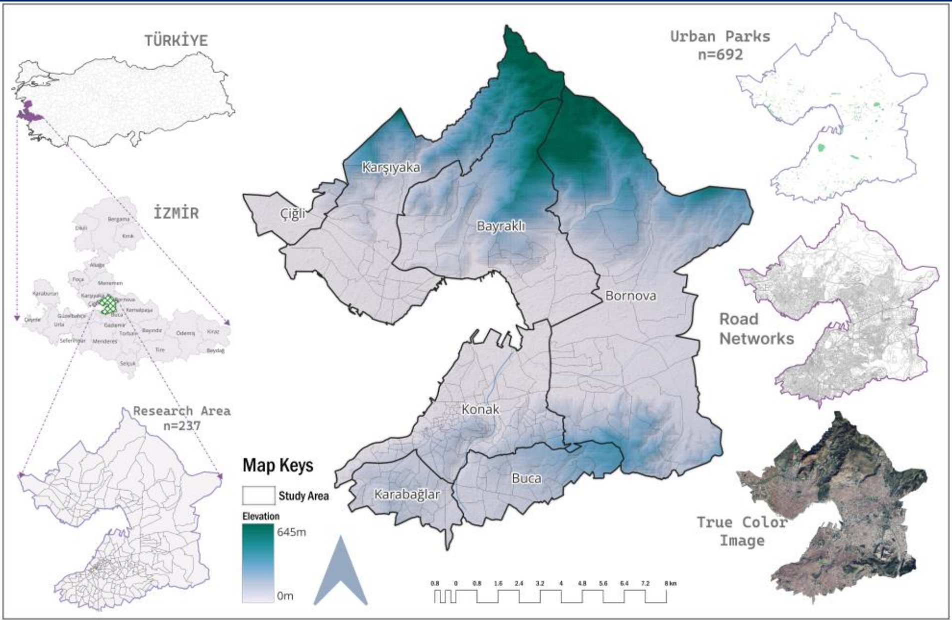

Figure 1. Study area and base layers (İzmir Gulf Region)

All variables in this study are aggregated or attributed at the neighborhood level, including accessibility measures, demographic cohorts, network statistics, environmental indices, and model outputs. Where point representations are required (e.g., for regression kernels or cluster diagnostics), projected neighborhood centroids derived from polygon geometries are used to preserve spatial accuracy. This unit-of-analysis framework ensures compatibility with planning practice, protects the confidentiality of population data, and facilitates reproducibility across urban studies grounded in official territorial hierarchies.

2.2. Data and Variables

This study integrates spatial and sociodemographic datasets to assess pedestrian access to urban parks in the İzmir Gulf Region. All layers were reprojected to a common metric coordinate system (UTM Zone 35N;

EPSG:32635) and processed within a unified GeoPackage. The complete inventory of data sources, resolutions, and preprocessing steps is provided in Table 1.

Table 1. Datasets and sources.

Layer	Geometry / resolution	Source (year)	Preprocessing summary
Neighborhoods	Polygon (admin)	OpenStreetMap extract (2025-07-20)	Attribute cleaning; code harmonization; reprojection.
Urban parks	Polygon	IMM Open Data Portal	Validation; dissolve by park; area recomputation.
Pedestrian road network	Line (graph)	OpenStreetMap extract (2025-07-20)	Filter to pedestrian-permitted links; snap park entrances to nearest node.
Space-syntax segments	Line (graph)	Author-derived using space-syntax toolkit	Segment metrics aggregated to neighborhood median.
Network centralities	Line (graph)	Author-derived (GrassGIS v.net)	Node/edge centralities summarized to neighborhood median.
Building footprints	Polygon	OpenStreetMap extract (2025-07-20)	Coverage % computed by neighborhood.
Impervious surface	Raster/10m	GEE Dynamic World	Total impervious area per neighborhood.
Tree canopy	Raster/1m	Meta and WRI, Tolan et al 2023	Total canopy area per neighborhood.
Elevation (DEM)	Raster/30m	DEM Copernicus-2025-06	Neighborhood median elevation.
Land surface temperature	Raster/30m	GEE Landsat 8-9 2025-05:07 Median	Neighborhood median LST.

The primary dependent variable is park-per-capita (PPC), calculated for each neighborhood as the cumulative area of reachable parks divided by the neighborhood's population, at four walking-distance thresholds: 300 m, 500 m, 1000 m, and 1500 m. This measure captures network-based accessibility to parkland rather than proximity alone, and is sensitive to the number and size of accessible parks, not merely their presence. Equity is assessed by computing the population-weighted Gini index for PPC across all neighborhoods. Gini coefficients are calculated both for the total population and three vulnerable cohorts: children under five, women, and adults aged 65 and older. Lorenz curves are also derived to visually depict the cumulative distribution of accessible park area. These metrics are interpreted by radius and population group to evaluate patterns of distributive justice in green space provision.

The study includes a set of theoretically grounded neighborhood-level predictors hypothesized to influence PPC. These variables are grouped into four thematic domains:

- Network configuration: space-syntax integration (`INT_med`) and graph-based centrality metrics (`c_closeness_med`, `c_betweennes_med`), derived from segment-based and node-based analyses of the pedestrian network.
- Built environment: neighborhood-level building coverage (`building_coverage_pct`) and total impervious area (`imp_total_m2`), both of which are expected to constrain open space availability.
- Green structure: total tree canopy area (`canopy_area_m2`), serving as a proxy for green infrastructure and ecological character.
- Topography and thermal environment: median elevation (`elev_med`) and median land surface temperature (`lst_med`), reflecting possible constraints on access or vegetation presence.

To ensure model validity, variables exhibiting zero variance were excluded, and predictor pairs with Pearson correlation coefficients $r > 0.95$ were screened to avoid multicollinearity. Count and area-based predictors were log-transformed using log1p, then z-standardized prior to modeling.

Population totals and subgroup counts (children under 5, women, and adults 65+) are sourced at the neighborhood level and used both as denominators in PPC calculation and as weights in the Gini and Lorenz metrics. This enables stratified assessments of accessibility equity, emphasizing variation in park provision across vulnerable populations. The variable definitions, coding, and expected relationships are summarized in Table 2 and Table 3.

Table 2. Dependent (access/equity) variables.

Code	Definition	Unit	Interpretation
PPC_300:1500_tot,	Reachable park area per capita at distance d	m² per person	Higher indicates greater accessible park supply via the network.
Ginid_d (total, u5, women, 65+)	Population-weighted Gini of PPC at d	0–1	Larger values denote greater inequality of access.
Lorenzd_d	Lorenz curve of PPC at d	—	Cumulative distribution of access (visual companion to Gini).

Table 3. Explanatory (driver) variables used in OLS/GWR/MGWR

Code	Description	Sign	Rationale
INT_med	Space-syntax integration (median)	+	Greater through-movement potential supports practical proximity to parks.
c_closeness_med	Network closeness (median)	+	Shorter network distance to many destinations facilitates access.
c_betweennes_med	Network betweenness (median)	±	Through-corridor effects can aid or hinder local access.
building_coverage_pct	Building land-cover share	-	Higher coverage reduces open/green availability.
imp_total_m2	Impervious surface total	-	Hardscape correlates with lower green provision and thermal burden.
canopy_area_m2	Tree canopy area total	+	Proxy for green infrastructure and adjacent parkland.
elev_med	Median elevation	±	Topography may constrain pedestrian routes; sign is context-dependent.
lst_med (optional)	Median land surface temperature	-	Heat-prone surfaces tend to coincide with scarce green access.

2.3. Network-Based Service Areas and Park-per-Capita (PPC)

To evaluate pedestrian accessibility, service areas were computed around each of the 692 validated urban parks using network distances of 300 m, 500 m, 1000 m, and 1500 m. A shortest-path graph was constructed to generate service areas reflecting real walking conditions. Each park was linked to its nearest walkable node and assumed to have at least one entrance. Where minor roads bisected parks, polygons were dissolved to preserve continuity. While the single-entrance assumption simplifies modeling, its implications for large parks are noted in Section 4.

Neighborhood-level park-per-capita(PPC) is computed for network-based walking distances $d \in \{300, 500, 1000, 1500\}$m by attributing reachable park area to each neigborhood and dividing by its population. Formally, for neighborhood j,

$$PPC_{dj} = \frac{\sum_{p \in P(dj)} A_p}{N_j} \quad (1)$$

where A_p is park p's area and $P(d, j)$ is the set of parks whose d service area intersects neighborhood j; N_j is the neighborhood population. Cohort-specific PPC measures were also derived using subgroup population counts. These indicators form the basis for the equity metrics and modeling analyses described in subsequent sections.

2.4. Equity Metrics, Spatial Diagnostics, Modeling Framework

This section integrates the procedures for evaluating distributive equity, detecting spatial clustering, modeling explanatory relationships, and synthesizing outcomes for planning relevance. The analytical steps described here follow the structure summarized in Figure 2.

Distributive equity is assessed using the population-weighted Gini index across neighborhoods at each walking distance $d \in \{300, 500, 1000, 1500\}$m. Let X_j denote the PPC value of neighborhood j, and w_j its corresponding population (total or cohort-specific). The weighted Gini coefficient is computed as:

$$G = 1 - 2\int_0^1 L(p)dp \tag{2}$$

where $L(p)$ is the Lorenz curve, representing the cumulative share of PPC across ordered population percentiles. Separate Gini values are computed for the total population and three demographic cohorts: children under five, women, and residents aged 65 and older. Lorenz curves are used to visualize the cumulative distribution of PPC per group and distance.

To identify spatial clustering in accessibility, this study applies Local Indicators of Spatial Association (LISA) to PPC values. Queen contiguity weights w_{ij} are constructed from neighborhood geometries, and local Moran's I statistics I_j are computed as:

$$I_j = z_j \sum_{i \neq j} w_{ij} z_i \tag{3}$$

Where z_j denotes the standardized PPC value for neighborhood j. Significance is assessed using 999 random permutations, and p-values are corrected for multiple testing using the False Discovery Rate (FDR) method. Neighborhoods are classified into high–high, low–low, and spatial outlier categories. A complementary Getis-Ord Gi* statistic is also calculated to detect significant hot and cold spots of PPC. Both LISA and Gi* outputs are visualized at all four radii.

To explain spatial variation in PPC, a staged regression framework is implemented. Ordinary Least Squares (OLS) models are specified with PPC as the dependent variable and eight neighborhood-level predictors reflecting network structure, built form, green infrastructure, and terrain. Variables with zero variance or high collinearity are excluded. Model residuals are tested for spatial autocorrelation using global Moran's I.

Next, Geographically Weighted Regression (GWR) is applied using an adaptive bisquare kernel. The model estimates locally varying coefficients at each neighborhood centroid. Optimal bandwidths are determined via corrected Akaike Information Criterion (AICc), and local R^2 values are extracted to map model fit heterogeneity.

Lastly, Multiscale GWR (MGWR) is conducted to allow each predictor to operate at its own spatial scale. MGWR estimates local coefficients using variable-specific bandwidths, derived by backfitting to minimize AICc. Resulting outputs include global model diagnostics, local coefficient surfaces, and bandwidth distributions per predictor. Predictor importance and spatial consistency are interpreted using beeswarm plots, which illustrate the distribution, sign, and intensity of each standardized coefficient across the study area.

A synthesis step integrates diagnostic results into a composite priority score for each neighborhood. This score combines (i) LISA-based spatial persistence, (ii) MGWR-based predictor strength and fit, and (iii) the magnitude of PPC shortfall. Neighborhoods are assigned to ordinal priority tiers (1–3) based on weighted thresholds. The resulting spatial prioritization supports targeted planning decisions and highlights clusters of underserved communities.

All analyses are conducted using open-source software including QGIS, Google Earth Engine, and Python packages (libpysal, esda, mgwr, statsmodels). Outputs are stored in a reproducible GeoPackage format, and all computational steps are scripted for transparency and scalability. The full analytical sequence—including data processing, accessibility modeling, statistical diagnostics, and synthesis—is visually summarized in Figure 2.

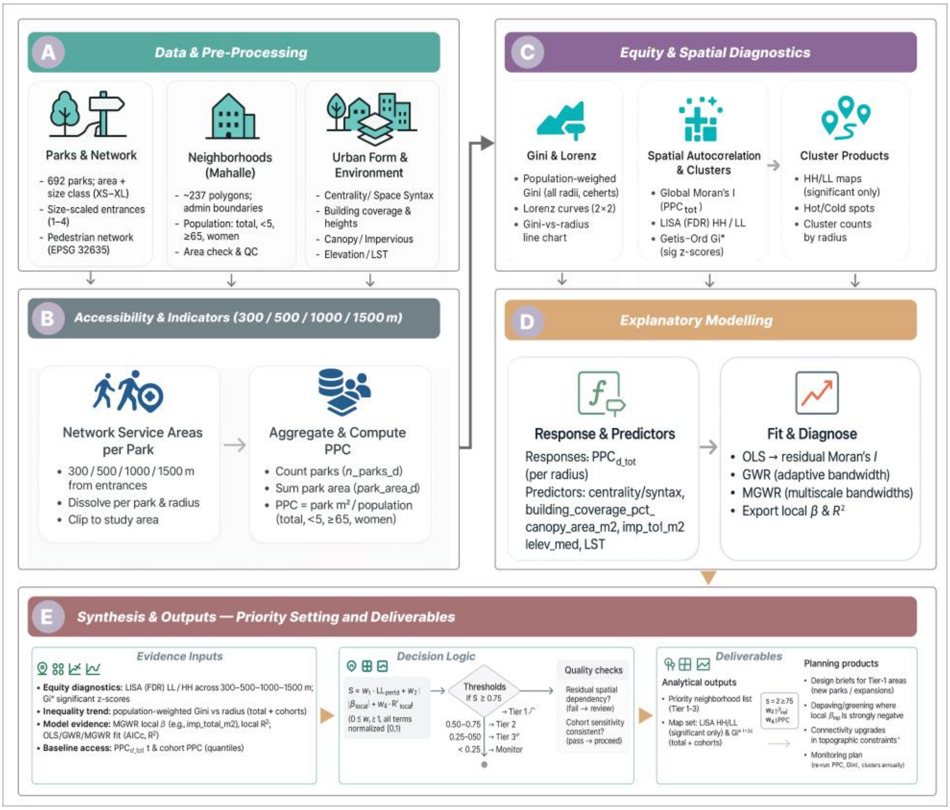

Figure 2. Methodological flowchart of the study.

3. Findings and Discussion

3.1. Network and Access Structure

The structure and configuration of the pedestrian network critically influence the spatial distribution of park accessibility in the İzmir Gulf Region. Figure 3 visualizes the foundational components of the accessibility model across eight panels, combining service areas, park entrance locations, and structural indicators of the urban network.

Panels (A)–(D) illustrate the cumulative pedestrian service areas for 692 validated parks at network distances of 300 m, 500 m, 1000 m, and 1500 m. Park entrances are mapped using the nearest walkable node to each park polygon, and neighborhood boundaries are overlaid to show administrative units used for aggregating accessibility metrics. As expected, coverage increases with distance, though gaps persist in peripheral and topographically constrained zones. The limited reach at 300 m emphasizes local inequities, whereas broader coverage at 1500 m reveals saturation in dense central districts and fragmentation in outlying areas.

Panel (E) maps closeness centrality over network, identifying segments with high accessibility to all other nodes. Panel (F) shows segment length distribution, capturing fine-grained urban fabrics versus coarse ones, with spatial variation aligned with historical development patterns. Panels (G) and (H) present space syntax indicators. Integration scores (G) reflect through-movement potential, revealing global accessibility embedded in central axes. Connectivity scores (H) highlight the number of immediate segment connections, corresponding to local walkability.

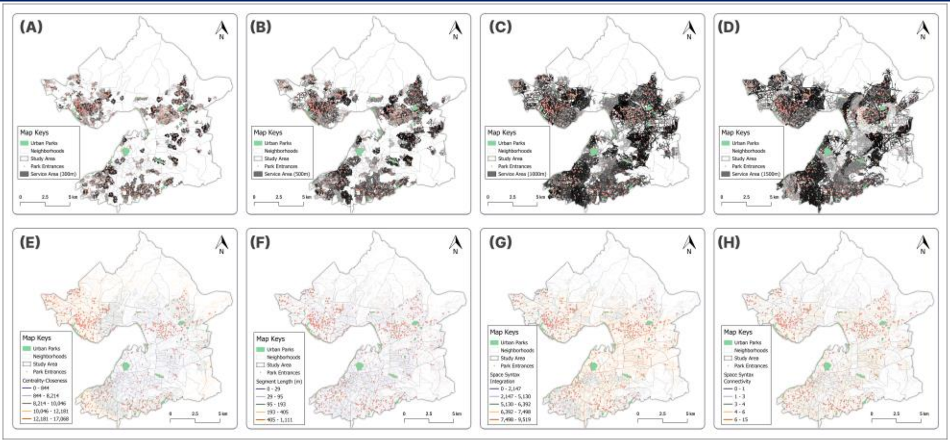

Figure 3. Spatial structure of the pedestrian network and park accessibility in the İzmir Gulf Region.

3.2. Distance-Based Park Access Equity

To evaluate the distributional equity of urban park accessibility, we compute population-weighted PPC metrics and derives associated Gini coefficients and Lorenz curves for four network radii: 300 m, 500 m, 1000 m, and 1500 m. Analyses are conducted for the total population as well as three demographic groups—children under 5, women, and adults aged 65 and older—to reflect differential spatial vulnerability.

Panels (A) through (D) of Figure 4 present Lorenz curves for the total population at each walking distance. At 300 m (Panel A), extreme inequality is evident, with nearly half of the population receiving negligible park access. The Gini coefficient at this radius is 0.736, underscoring the steep concentration of accessible green space. At 500 m and 1000 m (Panels B and C), while nominal coverage expands, inequality worsens—reaching a peak Gini of 0.836 at 1000 m. This counterintuitive rise reflects disproportionate gains in already well-served areas. Even at

1500 m (Panel D), inequality remains high (Gini = 0.793), revealing structural disparities that are not resolved by extended walking thresholds. Panel (E) overlays Lorenz curves for all demographic groups and distances. Children under 5 and adults over 65 consistently experience lower relative access than the total population. For instance, the Gini coefficient for the under-5 group ranges from 0.622 at 300 m to 0.653 at 1000 m, while the 65+ cohort records values from 0.639 to 0.658 across the same distances. Women's access inequality mirrors these patterns, remaining consistently above 0.62. Although inequality declines slightly at 1500 m, with Gini values falling below 0.63 for all three groups, disparities remain substantively meaningful.

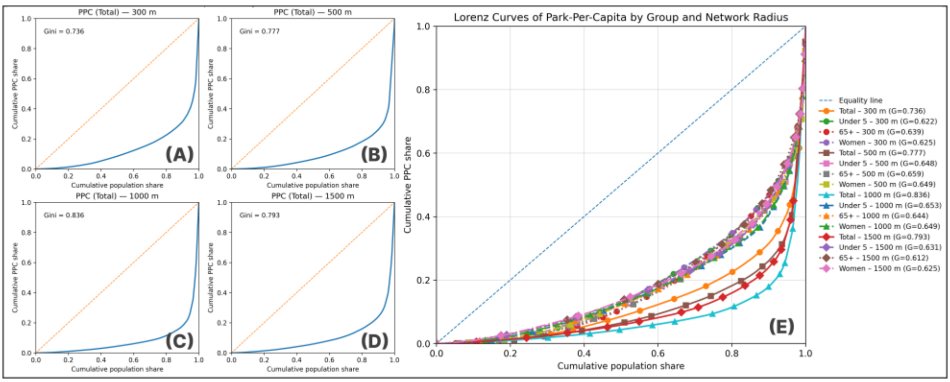

Figure 4. Distributional inequality of network-based park access across İzmir Gulf neighborhoods.

3.3. Spatial Clustering Patterns

To evaluate the spatial dependency and local clustering patterns of park accessibility, this study applies two spatial diagnostic techniques: Local Moran’s I (LISA) and Getis-Ord Gi*, using park-per-capita (PPC) values at four walking distances (300 m to 1500 m). Both approaches help identify areas of spatial autocorrelation and statistically significant hotspots or coldspots of urban park access.

The global Moran's I statistic, computed for PPC at each radius, confirms a strong spatial structure in access values. Spatial clustering is minimal at 300 m ($I = 0.15$) but rises sharply at 500 m ($I = 0.40$), peaking at 1000 m ($I = 0.56$) and remaining high at 1500 m ($I = 0.54$). All results are significant at $p < 0.01$, indicating that neighborhoods with similar access levels tend to be spatially proximate at larger distances.

Figure 5 displays the LISA significance maps for high-high (HH) and low-low (LL) clusters across radii. At 300 m (Panel A), no statistically significant local clusters are detected. At 500 m (Panel B), a small number of HH clusters emerge near central districts ($n = 5$), while a few LL clusters ($n = 3$) appear in low-density peripheries. At 1000 m (Panel C), clustering intensifies with 17 HH neighborhoods in Konak, and 27 LL neighborhoods in outer Karşıyaka, Balçova, Bayraklı and Bornova. At 1500 m (Panel D), this pattern consolidates further, showing 19 HH and 48 LL neighborhoods. Notably, LL clusters align with areas of lower walkability and sparse park coverage, reinforcing prior Gini results.

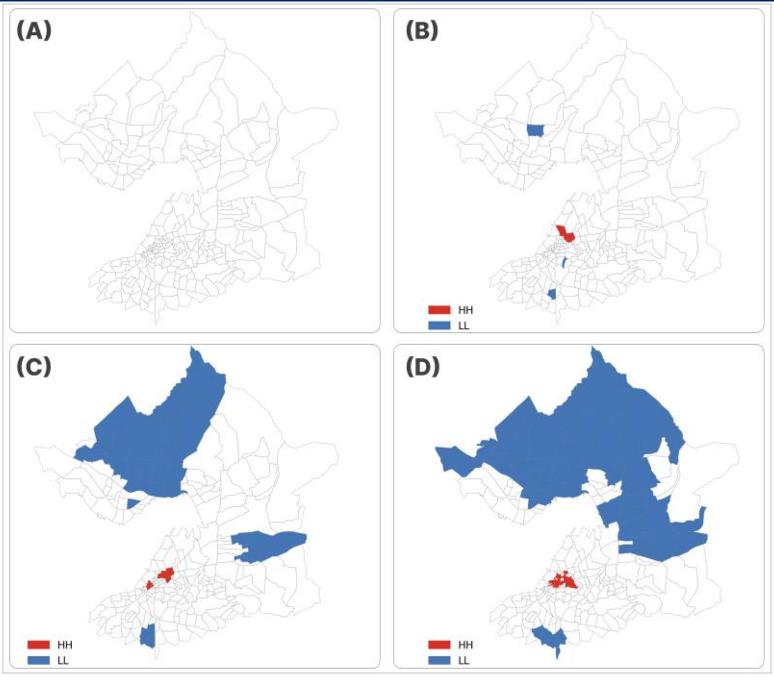

Figure 5. LISA cluster significance maps for PPC by network radius.

Figure 6 shows the standardized Gi* z-scores for each neighborhood across radii. High positive z-scores indicate statistically significant accessibility hotspots, while negative values signal coldspots. At 300 m, Gi* clustering is weak and patchy, but becomes more structured at 500 m and stabilizes at 1000 m and 1500 m. Hotspots consistently emerge in core districts such as Alsancak, Bornova, and central Konak, where both park supply and network connectivity are high. Coldspots align with outlying hillslopes and disconnected peripheries in northern Karşıyaka and southern Balçova.

The results from both LISA and Gi* diagnostics confirm that spatial equity is not uniformly distributed across the Gulf Region. Instead, sharp intra-urban gradients persist even under extended service assumptions. These localized disparities justify geographically disaggregated modeling in the subsequent section.

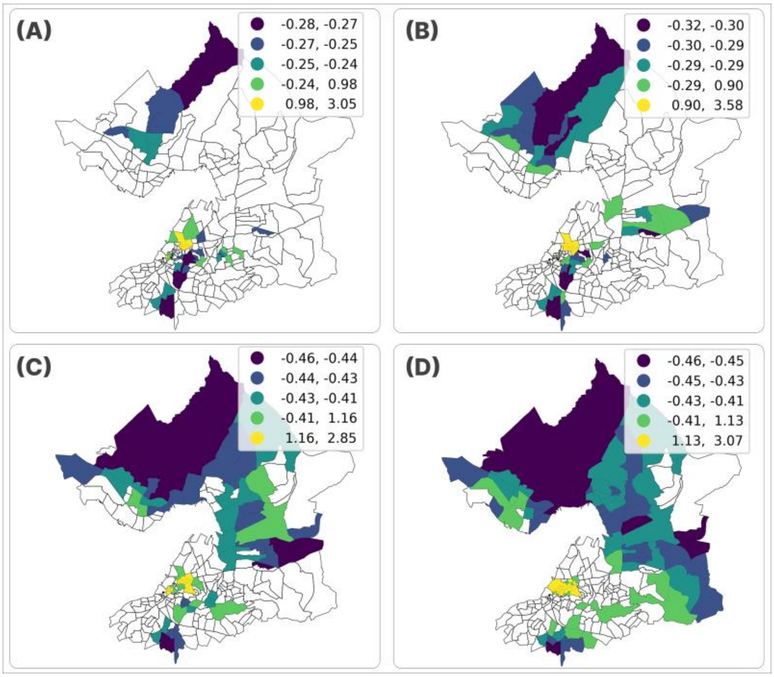

Figure 6. Getis-Ord Gi* z-scores for PPC by network radius.

3.4. Model-Based Insights

To explore the structural determinants of spatial access to urban parks, this study applied a stepwise regression framework incorporating Ordinary Least Squares (OLS), Geographically Weighted Regression (GWR), and Multi-Scale GWR (MGWR). Model performance and spatial heterogeneity were assessed across four network service distances (d = 300, 500, 1000, and 1500 m), using PPC for the total population as the dependent variable. All predictors were standardized, and skewed variables were log-transformed prior to model fitting.

Global model comparison reveals that MGWR consistently outperforms both OLS and single-bandwidth GWR across all radii. MGWR achieves superior R^2 values—ranging from 0.463 at 300 m to 0.821 at 1500 m—while maintaining lower AICc scores. In contrast, GWR yields relatively modest fits at lower radii, especially at 300 m ($R^2 = 0.17$), but improves with scale. These gains demonstrate the importance of multiscale modeling to capture non-stationary spatial processes underlying park accessibility.

Figure 7 visualizes the GWR local R^2 surfaces across the four radii. At 300 and 500 m, model fits are uniformly low, with minimal spatial variation. As the radius increases, spatial heterogeneity becomes more pronounced. At 1500 m, central and southern districts display significantly higher local R^2 values—approaching 0.9 in some neighborhoods—indicating stronger model explanations at broader accessibility thresholds.

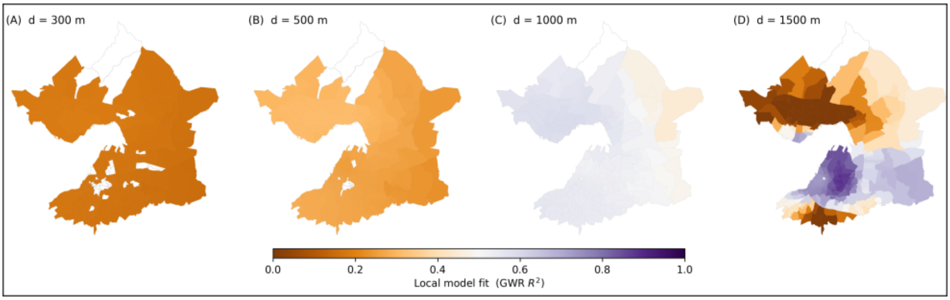

Figure 7. Local GWR R^2 surfaces across service distances.

To unpack these drivers, MGWR coefficient maps are provided in Figure 8 for four key predictors (elev_med, INT_med, building_coverage_pct, and canopy_area_m2) at d = 500 m (top row) and 1500 m (bottom row). Visual inspection reveals distinct spatial patterns. For instance, at 1500 m, the positive effect of tree canopy area (Panel H) is concentrated in the central-southern corridor, while elevation exhibits stronger negative associations in coastal areas (Panel E). These patterns reflect the compound influence of both terrain and green infrastructure on perceived park accessibility.

Complementing these maps, Figure 9 provides a comprehensive beeswarm-style plot of local MGWR coefficients across neighborhoods for all eight standardized predictors and all four radii. Violin curves summarize the coefficient distribution, while dot colors indicate the normalized z-score of each predictor per neighborhood. This visualization highlights both the direction and magnitude of local effects. Notably, the influence of impervious surface (imp_total_m2) and canopy cover (canopy_area_m2) is more consistent across scales, whereas metrics such as network closeness and betweenness centrality show greater local fluctuation.

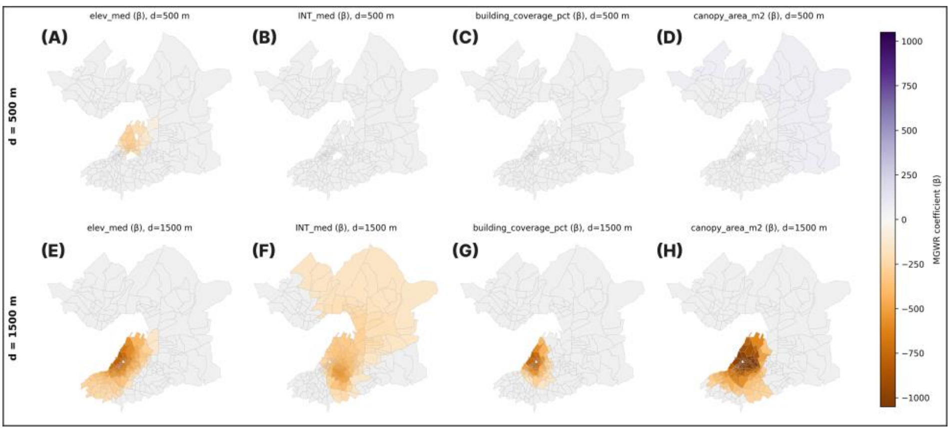

Figure 8. Key MGWR coefficients mapped at d = 500 m and 1500 m.

Taken together, the results underscore the critical role of urban form, spatial configuration, and green infrastructure in shaping the equity of park access. They also confirm that spatial non-stationarity is scale-dependent, reinforcing the need for multiscale analytical strategies in accessibility planning.

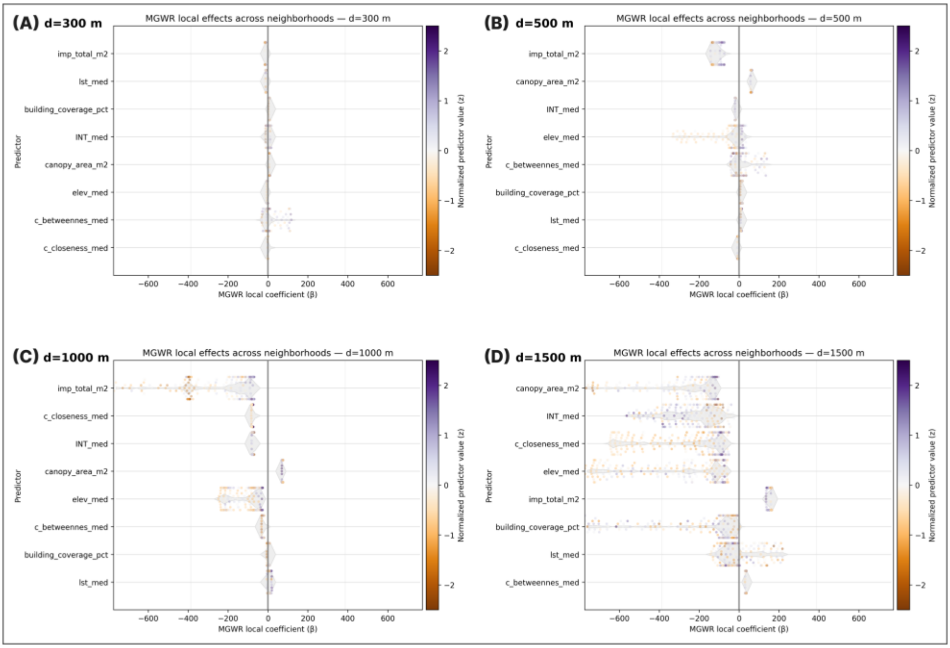

Figure 9. Beeswarm plots of MGWR local coefficients across predictors and radii. Panels (A–D) represent d = 300 m, 500 m, 1000 m, and 1500 m, respectively.

3.5. Synthesis for Planning

To translate the analytical findings into actionable planning guidance, this study developed a composite prioritization framework to stratify neighborhoods based on their accessibility deficits and contextual impediments to urban park access. The resulting classification delineates a four-tier system: Tier 1 (highest urgency), Tier 2, Tier 3, and Monitor (low or uncertain need), as shown in Figure 10A.

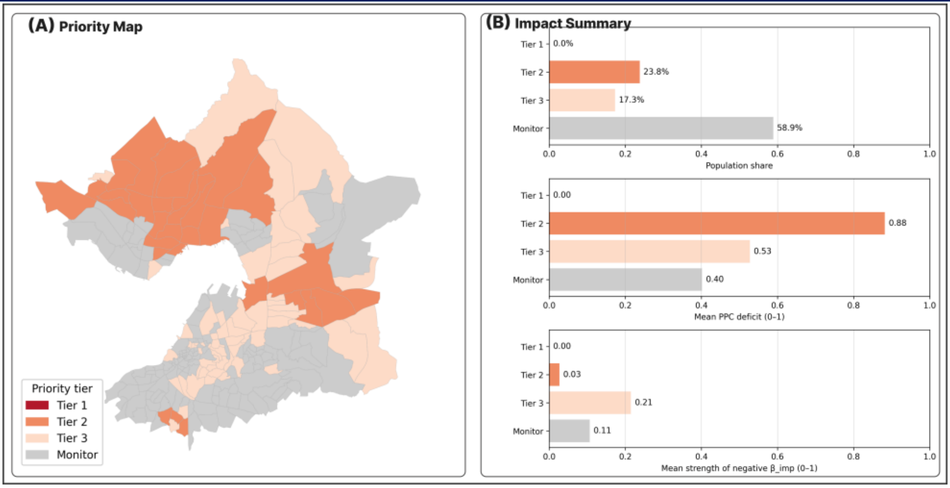

Figure 10. Priority classification for spatial equity interventions.

The prioritization logic integrates three key indicators: (i) population-weighted park-per-capita (PPC) deficit at d = 1500 m, (ii) presence of spatial clustering (Local Indicators of Spatial Association, LISA) indicating low-low access patterns at d = 1000 and 1500 m, and (iii) the average standardized strength of negative MGWR coefficients for impervious surface (β_imp), representing environmental constraints to equitable park provision. All variables were normalized and aggregated into a composite score, with rule-based thresholds guiding tier assignment. Tier 2 neighborhoods exhibit substantial PPC deficits (mean = 0.88) and localized clustering of poor access conditions, alongside moderate levels of imperviousness-related constraint (mean β_imp = 0.03), as detailed in Figure 10B. Tier 3 neighborhoods have milder access gaps (mean PPC deficit = 0.53) but still warrant future interventions, particularly where β_imp effects are stronger (mean = 0.21). Monitor areas show lower urgency across all metrics, though select neighborhoods within this group may exhibit latent needs due to high imperviousness or low canopy cover. Importantly, no neighborhood met all threshold conditions for Tier 1, reflecting either a dispersion of extreme vulnerability or mitigating effects of surrounding green infrastructure. The population-weighted distribution confirms this, with Tier 2 comprising 23.8% and Tier 3 comprising 17.3% of the study area's population. This stratified output facilitates targeted investment planning by enabling planners to spatially differentiate urgency and intervention type. For example, Tier 2 neighborhoods may be prioritized for both new park development and impervious surface mitigation, while Tier 3 areas may benefit from retrofitting access paths or expanding entrances to existing parks.

4. Conclusion and Suggestions

This chapter has presented a spatially explicit, network-based analysis of urban park accessibility and equity in the İzmir Gulf Region, Türkiye. By integrating high-resolution spatial datasets with advanced GIS modeling techniques—including network-based service area analysis, population-weighted equity diagnostics, spatial autocorrelation statistics (LISA and Gi*), and multiscale regression models (OLS, GWR, MGWR)—the study advances the methodological rigor of urban green space equity assessments. The findings demonstrate significant inequalities in neighborhood-level access to parks, with persistent spatial clustering of high- and low-access zones, as well as localized predictors driving these disparities.

Network-constrained accessibility modeling revealed considerable variation in park-per-capita (PPC) values across neighborhoods and distance thresholds. At closer radii (e.g., 300 m and 500 m), accessibility inequities were particularly acute, with population-weighted Gini coefficients exceeding 0.70 for the total population and remaining above 0.62 even for prioritized demographic groups such as children and elderly residents. The composite Lorenz curves further revealed disproportionate concentrations of park resources among higher-access neighborhoods.

These distributional disparities were reinforced by spatial clustering patterns. Significant high–high (HH) and low–low (LL) clusters—detected through LISA—emerged more prominently at 1000 m and 1500 m distances, indicating persistent spatial segregation in park accessibility. Gi* analyses complemented this interpretation by identifying statistically significant cold spots of access that align with socioeconomically vulnerable neighborhoods, thus suggesting spatial injustice in green resource allocation (Adorno et al., 2025; He et al., 2020; Huang et al., 2023; Zhao & Gong, 2024).

Regression modeling confirmed that park accessibility is not spatially random but is associated with distinct urban morphological and environmental variables. MGWR outperformed OLS and GWR in explaining PPC variations, with adjusted R^2 values increasing from 0.46 at 300 m to 0.82 at 1500 m. Locally varying coefficients demonstrated that indicators such as space syntax integration (INT_med), building coverage percentage, impervious surface, and canopy area exerted differential effects across the study area, reflecting strong spatial heterogeneity in the equity landscape. These findings resonate with global evidence showing that physical form and environmental context substantially condition the distribution and performance of green infrastructure (Lan et al., 2022; Leng et al., 2023; S. Wu et al., 2023).

A policy-relevant synthesis was constructed by generating a composite priority score from MGWR local diagnostics, persistent low-access clusters, and PPC deficits. This score was used to classify neighborhoods into three intervention tiers. Tier 1 zones—exhibiting both structural access deficits and weak model fit—are proposed as the highest priority for immediate action. The resulting spatial tiers offer a replicable tool for guiding resource allocation in urban greening interventions. Importantly, this approach aligns with the principles of vertical equity by emphasizing neighborhoods with overlapping environmental and socio-spatial vulnerabilities (Kaya & Eminoğlu, 2025; LaReaux & Watkins, 2025; Martin & Conway, 2025).

From a planning perspective, the study highlights the need for differentiated strategies at multiple scales. For example, high-density urban neighborhoods with limited open space may benefit from micro-scale interventions such as pocket parks, vertical greening, or improved connectivity through redesigned pedestrian networks. In contrast, peripheral districts with larger but underutilized parkland require improved accessibility infrastructure and targeted social outreach. These targeted strategies reflect the growing consensus that one-size-fits-all solutions fail to address complex, spatially situated inequities in green space access (Jin et al., 2023; Xia et al., 2024; J. Zhang & Tan, 2023).

In closing, this chapter contributes a methodologically robust and policy-relevant framework that integrates spatial analytics and planning intelligence. It reinforces the imperative for green infrastructure planning to move beyond aggregate provision metrics toward fine-grained, equity-centered spatial diagnostics. The approach developed here can be adapted to other metropolitan contexts, supporting both global frameworks such as SDG 11.7 and local urban resilience agendas. Future work may further enhance this framework by incorporating temporal dynamics, multi-entrance modeling, user behavior analysis, and participatory data collection to capture emergent needs in rapidly evolving urban landscapes.

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All authors contributed equally to the article. There is no conflict of interest.

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A Study of Anatolia in the Context of the Protection and Sustainability of Traditional Urban Areas: Cases of Elazığ/Harput and Diyarbakır/Suriçi

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1. Introduction

Traditional urban areas hold significant importance for the conservation of historical and cultural identity and are central to contemporary discussions on sustainability. Anatolia, in this regard, offers a rich diversity and serves as a vital field of study for conservation practices (Ahunbay, 2019). This study aims to examine the conservation and sustainability of traditional settlement patterns in Anatolia through a comparative analysis of the cases of Elazığ/Harput and Diyarbakır/Suriçi. Located in Eastern and Southeastern Anatolia respectively, Harput and Suriçi are not only situated in neighboring cities but also stood as significant centers during the Ottoman period. They serve as documentary evidence of the historical fabric of their respective settlements and remain active sites of archaeological excavations and conservation efforts today. The study will evaluate the similarities and differences of these two settlements in terms of conservation policies and the threats they face. The primary goal is to propose strategies to ensure the transmission of these areas to future generations.

The conceptual framework of the study is grounded in urban conservation and sustainability, which denote a complex process requiring an interdisciplinary approach (Akyıldız & Olğun, 2020a). Accordingly, the scope of the study includes not only the physical characteristics of the historical fabric but also the socio-cultural and economic dynamics. The concept of conservation in architecture encompasses interventions aimed at transmitting the physical, cultural and social values of historical buildings and environments to future generations (Jokilehto, 2007). Conservation involves not only the restoration of structures but also the sustainability of their identity and context. This process requires an interdisciplinary approach, involving collaboration among fields such as architecture, archaeology, urban planning, and sociology (Ahunbay, 2019).

International charters and legal regulations constitute the foundation of conservation practices. The 1964 Venice Charter is among the most significant documents outlining the principles of historic building conservation, emphasizing concepts such as authenticity and integrity (ICOMOS, 1964). Similarly, UNESCO's 1972 Convention Concerning the Protection of the World Cultural and Natural Heritage regulates the safeguarding of sites with outstanding universal value on a global scale (UNESCO, 1972).

The UNESCO World Heritage List, a key mechanism for monitoring conservation, aims to safeguard cultural and natural assets with exceptional universal value for future generations. To be inscribed on this list, a site must possess historical significance, retain its authenticity and have adequate legal protective measures to ensure sustainability (Ministry of Culture and Tourism, 2025). Many sites in Turkey, such as the Diyarbakır City Walls and Hevsel Gardens, have been included in the list by meeting these criteria (UNESCO, 2015).

Regarding conservation policies in Turkey, legal frameworks such as the Law on the Conservation of Cultural and Natural Properties (1983) and related regulations are in place. These regulations cover the registration of historic buildings, the authority of conservation councils, and procedures concerning restoration practices (Kuban, 2000).

In conservation practices, public participation plays a role as critical as legal regulations. The exclusion of local communities from the process and the lack of awareness-raising initiatives often lead to the failure of conservation projects (Olğun & Şahin, 2021). In successful examples such as Süleymaniye and Safranbolu, sustainable outcomes have been achieved through community engagement and economic incentives (Akyıldız & Olğun, 2020c).

Today, urban transformation projects, tourism pressure and natural disasters pose new threats to historical settlements. Rapid transformations in many cities have led to the inclusion of some sites in UNESCO's List of World Heritage in Danger (UNESCO, 2019). This has intensified debates on how to balance conservation and development (Erder, 2010). Ultimately, conservation in architecture is not merely a technical intervention but also a socio-legal process aimed at sustaining cultural heritage. In this process, detailed analyses of heritage sites are interpreted through interdisciplinary studies and evaluated in accordance with both national and international legislation. Considering not only international standards but also local dynamics is essential for developing sustainable conservation policies.

Harput and Diyarbakır Suriçi, which are discussed in the context of conservation in this study, are settlements where similar conservation problems are observed, despite having different geographical and historical contexts. The research compares these two historic areas in terms of architectural fabric, current state of preservation and sustainable conservation practices. Additionally, it investigates whether the conservation status of the Diyarbakır City Walls, listed as a UNESCO

World Heritage Site, can serve as a model for Harput, which is currently on the tentative list.

The methodology of the study is primarily based on qualitative research techniques, supported by fieldwork and a comprehensive literature review. Within the scope of fieldwork, observations and photographic documentation were conducted in both settlements to analyze the current conditions. The literature review was carried out through an examination of conservation approaches, national and international regulations, and published works related to the study areas (Jokilehto, 2007). The qualitative data will be analyzed using a descriptive analysis method, offering a comparative perspective. This approach is expected to enhance the understanding of successes and shortcomings within the conservation processes of the two settlements.

Harput and Suriçi stand out as prominent representatives of Anatolia's historical urban fabric. While Harput preserves a unique identity through its medieval architecture, Suriçi is distinguished by its traditional residential pattern and monumental structures (Akyıldız & Olğun, 2020b; Aydın, et al., 2020). Both settlements are challenged by issues such as urban transformation and population decline. This study critically evaluates the effectiveness of various strategies aimed at addressing these and similar problems. Ultimately, the research seeks to present a perspective specific to Anatolia regarding the conservation and sustainability of traditional urban areas. The assessments made through the case studies of Elazığ/Harput and Diyarbakır/Suriçi may serve as a guide for the sustainable conservation of other historic cities. The findings of the study provide suggestions for improving conservation policies and highlight the importance of accurate transmission to future generations, thereby aiming to contribute to the continuity of Anatolia's cultural heritage.

2. Material and Method

This study has been primarily structured using qualitative research methods. Qualitative approaches involve collecting and interpreting data through techniques such as on-site observation, investigation and document analysis to deeply understand and convey various phenomena (Creswell, 2013; Denzin & Lincoln, 2017). In this research, qualitative data collection and analysis methods were employed to compare the preservation status of the traditional urban settlements in Elazığ/Harput and Diyarbakır/Suriçi. The reasons for selecting these settlements as study subjects can be listed as follows:

- Cultural and Architectural Diversity: The selected settlements contain numerous elements representing the architectural diversity of Anatolia, including traditional civil architecture, historical religious buildings, inns, bazaars, and urban layouts surrounded by walls. This allows for the examination of how cultural and architectural values are addressed within the context of conservation.
- Urban Fabric and Topography: The defensive hilltop settlement of Harput and the dense urban fabric of Diyarbakır/Suriçi, surrounded by defensive walls, represent two traditional urban types adapted to the diverse geographical conditions of Anatolia. This diversity offers a rich opportunity for investigation in terms of spatial organization and sustainability.

- Historical Continuity and Multilayeredness: Elazığ/Harput and Diyarbakır/Suriçi uniquely reflect Anatolia's deep-rooted urbanization traditions with their multilayered historical structures, bearing traces of diverse civilizations such as the Urartian, Byzantine, Seljuk, and Ottoman periods. These characteristics offer an important research area for examining the continuity of urban heritage and the spatial traces of different periods.

- Different Approaches in Conservation Practices: The selected settlements are areas where different conservation policies, practices, and intervention styles have been implemented at the national and local levels. These differences constitute suitable examples for evaluating and jointly addressing the outcomes of conservation and sustainability approaches.

- Potential for Association with UNESCO Studies: Diyarbakır/Suriçi is on the UNESCO World Heritage List, while Harput is on the World Heritage Tentative List. This provides a significant research basis for examining how international recognition and conservation efforts are shaped.

- Current Conservation Problems and Sustainability: Both settlements face rapid urbanization, the pressures of modern construction, population changes, and socio-economic transformations. This provides important data for exploring how conservation and sustainability policies can be improved in the face of current threats.

The data collection process consisted of fieldwork-based observations and a comprehensive literature review. During the fieldwork, both historical settlements were examined in situ and the current conditions of the architectural fabric were documented through photographs. The literature review focused on national and international conservation policies, UNESCO criteria and academic publications related to the region. Within this framework, a theoretical basis for conservation practices was established, and areas for potential improvement in practice were identified.

The qualitative data collected were analyzed and interpreted accordingly. This analysis enabled a systematic evaluation of the architectural characteristics, conservation status and the threats encountered in both Harput and Suriçi. Additionally, it was questioned whether the UNESCO World Heritage status of the Diyarbakır City Walls could serve as a model for Harput. The findings and resulting recommendations were interpreted with the aim of developing perspectives for the sustainable preservation of similar historic cities.

3. Findings and Discussion

Elazığ/Harput and Diyarbakır/Suriçi are two significant settlements located in neighboring regions of Anatolia, both reflecting the historical and cultural diversity of the area through their traditional urban fabrics. Both districts have hosted various civilizations throughout long historical processes and possess a rich architectural, social, and cultural heritage (Akyıldız & Olğun, 2020b; Aydın, et al., 2020).

3.1. Characteristics of Elazığ/Harput Traditional Urban Settlement

Harput is a traditional settlement area that embodies the historical and cultural heritage of Elazığ. With a history dating back to the Urartian period, this settlement maintained its significance as a central hub during the Byzantine, Seljuk, and Ottoman eras. Established on a defensible hill due to its geographical position, Harput reflects the characteristics of a medieval city (Sunguroğlu, 1958) (Figure 1). Among the key elements that define its physical fabric are the castle, mosques, churches, and traditional houses.

Figure 1. Location of Harput (adapted from Google Earth, 2025)

The traditional urban fabric of Harput developed in harmony with the region’s climatic and topographic conditions. The houses in the settlement were constructed with inward-oriented plans and thick walls, adapted to the region's cold winters (Sunguroğlu, 1958). Characteristic features of traditional Harput houses include adobe walls with timber reinforcements built on stone foundations, flat roofs, and oriel windows (Topçu, 2014) (Figure 2). These architectural features also represent local building traditions and the use of native materials.

Figure 2. Examples of traditional housing structures in Harput

Harput's religious architecture, like its civil architecture, reflects the traces of its multicultural past. The Grand Mosque is one of Harput's oldest Islamic structures and is regarded as a significant monument of the Artuqid period (Sunguroğlu, 1958) (Figure 3). Christian architectural examples, such as the Virgin Mary Church, are also present (Topçu, 2014) (Figure 3). These religious buildings reveal Harput's cosmopolitan character, where different faiths and cultures coexisted. Furthermore, the monumental structures in the settlement provide valuable insights into the construction technologies and aesthetic sensibilities of their respective periods.

(a)

(b)

Figure 3. The Grand Mosque (a) and Virgin Mary Church (b)

One of the most important components of Harput’s urban fabric is the traditional castle and its surroundings (Figure 4). Ongoing excavations in this area not only trace the city’s history back to ancient times but also provide significant data on daily life, religious practices, and trade (Aytaç, 2017). Additionally, the settlement’s water systems demonstrate original engineering solutions. The fountains constructed to meet the water needs of the area are important for understanding how water was supplied in the past (Olğun, 2023a) (Figure 5). Moreover, the water systems around the castle can also be interpreted as integral to the city's defensive strategy.

Figure 4. Harput Castle

Figure 5. Examples of historical fountains in Harput (Olğun, 2023a)

Harput's traditional urban fabric holds great importance for the cultural heritage of Anatolia (Figure 6). With architectural features that bear the marks of various civilizations, the settlement functions as an open-air museum. Ensuring the continuation of conservation efforts through an interdisciplinary approach and involving the local community in the process is crucial for transmitting Harput's heritage to future generations (Aytaç, 2017). In this context, Harput was included in the UNESCO World Heritage Tentative List in 2018 due to its outstanding qualities.

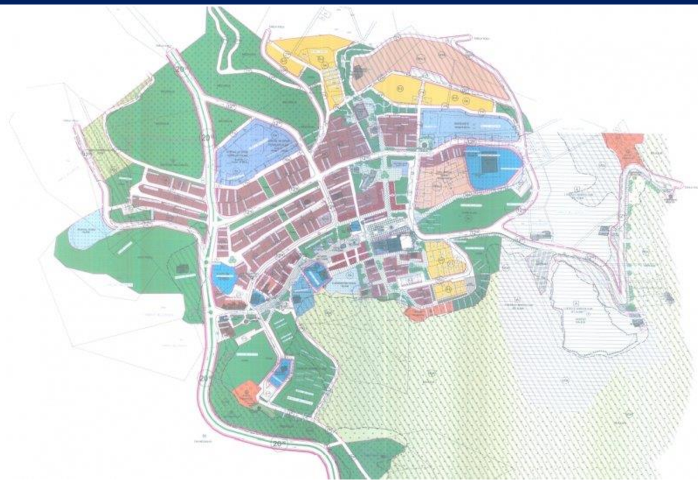

Figure 6. Conservation-Oriented Development Plan for Harput (Elazığ Municipality, 2025)

In addition to the surviving monuments in Harput, it is known that many structures have not withstood the test of time. The Harput described by Sunguroğlu has acquired a different identity today due to the loss of many buildings. His depiction is as follows:

"There are neighborhoods where houses rise by stacking upon each other or by occupying spots on rocks and hills, sometimes descending into hollows and valleys. The city center was relatively flat. Except for a few main avenues, the narrow streets-mostly lined with houses made of stone and partly adobe, with earthen roofs... Streets entirely paved with white, hard stones, free from mud and filth... and clean, too... In every neighborhood, abundant and flowing fountains... Squares, mosques, small mosques, schools, and madrasas... In the skyline of the city, six minarets, including the leaning minaret of the eight-century-old Great Mosque from the Artuqid period... A bazaar, partly covered and partly open, narrow and wide, long, with shops, stores, merchant inns, caravanserais, and public baths!” (Sunguroğlu, 1958) (Figure 7).


(a)


(b)

Figure 7. Harput in the early 19th century and the 1940s (Mared, u. d.)

Although most of the structures mentioned in this description have not survived to the present day, the remaining monuments such as the Great Mosque, other mosques, traditional houses like the Şefik Gül House, and partially preserved and restored public baths highlight the necessity of conserving Harput’s traditional urban fabric. Over time, this fabric has been largely abandoned, and urban expansion has shifted toward lower-lying areas. Although Harput has lost many of its former urban features, it continues to exist with its surviving traditional structures and its place in the collective urban memory**.**

3.2. Characteristics of Diyarbakır/Suriçi Traditional Urban Settlement

The historical Suriçi district of Diyarbakır is a significant traditional area that contains the city's oldest urban fabric and has been inscribed on the UNESCO World Heritage List. Located within the approximately 5,5 kilometer-long Diyarbakır City Walls, Suriçi reflects a historical accumulation of thousands of years through its unique urban texture (Kejanlı & Dinçer, 2011) (Figure 8). Additionally, due to its geographical location, the district serves as a transitional zone between Mesopotamia and Anatolia. In this respect, it has maintained its strategic importance throughout history (Işık, 2023).

Figure 8. Location of Suriçi (adapted from Google Earth, 2025)

An examination of Suriçi's historical development reveals that it dates back to the Hurrian-Mitanni period around 3000 BCE. In this context, Suriçi became an important settlement area during the Roman, Byzantine, and Islamic civilizations, and especially throughout the Ottoman period. The urban fabric, particularly shaped during the Artuqid and Ottoman periods through the construction of mosques, caravanserais, madrasas, and residential architecture, bears important traces of traditional life and culture (Kejanlı & Dinçer, 2011).

From a geographical standpoint, Suriçi is situated in a fertile region along the banks of the Tigris River. The region's climate has greatly contributed to the structural durability of basalt stones commonly used in traditional architecture (Çatalbaş, 2012). Furthermore, the narrow streets within the city walls and the courtyard houses are indicative of passive cooling systems designed to ensure thermal comfort (Ergin, et al., 2020) (Figure 9).

(a) (b)

Figure 9. Examples of narrow streets (a) and courtyard buildings (b) in Diyarbakır

The architectural heritage of Suriçi is considered one of the best-preserved examples of traditional urban fabric in Anatolia. Structures such as the Grand Mosque, Hasan Pasha Inn, Sülüklü Inn, and numerous historical churches and mosques reflect the multicultural character of the district (Kejanlı & Dinçer, 2011; Olğun, 2023b) (Figure 10). In addition, traditional Diyarbakır houses stand out with their inward-oriented courtyards, elaborate stone craftsmanship, and unique spatial organization (Ergin, et al., 2020) (Figure 11). All these qualities are also addressed in conservation development plans (Figure 12).

(a) (b)

Figure 10. Diyarbakır Grand Mosque (a) and Hasan Pasha Inn (b)

Figure 11. An old photo showing traditional texture and houses in Diyarbakır (Diyarbakır Cultural and Natural Heritage Protection Association, 2025)

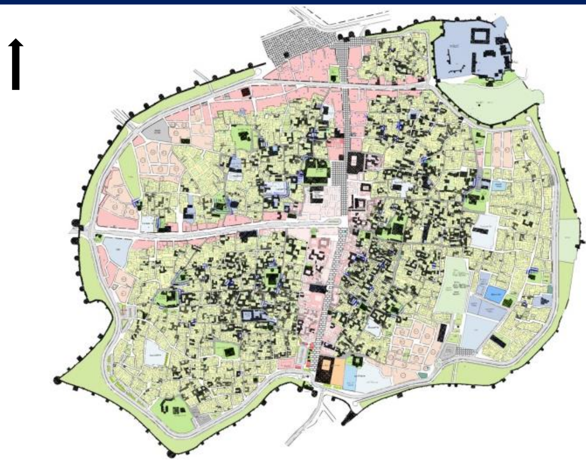

Figure 12. Conservation-Oriented Development Plan for Suriçi (Egeplan, 2025)

When considering the current state of Suriçi, it is evident that, although many elements of its architectural heritage have survived to the present day, there are several challenges in terms of conservation and sustainability. In recent years, armed conflicts and urban transformation projects have caused irreversible damage to the historical fabric (Işık, 2023). Many historical structures have been destroyed; the socio-cultural structure has also undergone significant change, which is reflected in the physical characteristics of the district (Çatalbaş, 2012). Despite all these challenges, Suriçi continues to preserve its traditional fabric through intensive conservation efforts, particularly with the support of UNESCO.

Diyarbakır Suriçi was inscribed on the UNESCO World Heritage List in 2015, whereas Harput was added to the Tentative List in 2018 (UNESCO, 2015; UNESCO, 2018). This difference points to various distinctions in conservation policies and practices. The process of inscription to the permanent list by UNESCO is based on specific criteria that evaluate aspects such as conservation status, authenticity, and integrity (UNESCO Operational Guidelines, 2021). The current designations of the two historical areas reflect their respective conditions in this regard.

The inclusion of Diyarbakır Suriçi on the list is closely linked to its city walls of outstanding universal value, multicultural social structure, and preserved urban form (Çatalbaş, 2012). The 5,5 km-long walls and the historic structures enclosed within reflect the traces of the Artuqid and Ottoman periods in particular. In terms of UNESCO criteria, the preservation of both cultural landscape and architectural integrity has played a key role in Suriçi's recognition (ICOMOS, 2015). Although Harput also hosts a multi-layered history, it has not yet completed the process of being inscribed on the World Heritage List. While both settlements have aspects that need improvement in terms of conservation, it is evident that Harput requires more comprehensive efforts in this regard.

4. Discussion

In Turkey, conservation policies are framed by Law No. 2863 on the Conservation of Cultural and Natural Assets, enacted in 1983. This law outlines the registration of heritage sites, the restoration of structures, and the principles for cultural heritage conservation. Both Harput and Suriçi have been designated as urban conservation areas under this legislation. However, practical differences in implementation have led to significantly different levels of conservation between these two historical settlements (Akyıldız & Olğun, 2020b; Aydın, et al., 2020). While conservation plans in Suriçi are supported through interdisciplinary approaches, practices in Harput are often constrained by uncertainty and lack of resources.

In the conservation process of Diyarbakır/Suriçi, the Management Plan prepared under UNESCO's guidance has supported the development of a sustainability-oriented conservation strategy. This plan adopts a multifaceted approach that integrates spatial planning with cultural heritage management (UNESCO, 2015). In addition, public participation and educational activities were promoted as part of social sustainability objectives. In contrast, such a comprehensive management plan has not yet been fully developed for Harput, though efforts in this direction are ongoing. This represents a major limitation for achieving international recognition.

One of the most important international documents, the 1972 UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage, defines areas of outstanding universal value. Suriçi was listed under this convention due to its recognition as possessing such values. The inclusion of Harput in the Tentative List indicates its potential for possessing these values and its emerging significance. However, to move to the permanent list, comprehensive conservation measures, restoration activities, and multidisciplinary documentation efforts must be intensified, along with improved visibility (UNESCO, 1972).

Although the traditional architectural fabric in Harput has been largely preserved, many historic structures have not survived to the present. Pressures from tourism, unplanned development, and uncontrolled functional changes in historic buildings emerge as major threats to the integrity of the area. While Suriçi also faces similar issues, interventions there are monitored more frequently through UNESCO's oversight mechanisms. This international system of monitoring and supervision serves as an important factor in enhancing conservation quality. In Harput, although the situation has improved since its inclusion in the Tentative List, monitoring is still largely localized and hampered by resource limitations.

In academic literature, Suriçi is often cited as a model in the integrated conservation of historic city centers and in discussions on cultural sustainability (Yıldırım, 2006). The projects conducted in this area encompass not only physical but also socio-economic components. Academic studies on Harput, on the other hand, have primarily focused on individual buildings; however, more recent research has begun to address the settlement as a whole through various disciplinary perspectives (Azar, 2019). This suggests that Harput's academic visibility and thereby its international recognition—is still at an early stage. It is important to promote and enhance both the quantity and quality of these studies.

Academic research and interdisciplinary publications play a crucial role in the monitoring, documentation, and critical evaluation of conservation processes. While scholarly work on Suriçi supports this process, studies on Harput have mostly focused on field reports and regional inventories. This situation adversely affects Harput's representation in the academic and scientific community. Therefore, promoting national and international publications is of great importance for the holistic conservation of Harput. Such scholarly contributions would strengthen institutional and public awareness alike.

In Suriçi, religious and civic buildings such as the Grand Mosque, Hasan Pasha Inn, and various Armenian and Syriac churches reflect a multicultural architectural heritage. This diversity has provided a major advantage for UNESCO's "multicultural heritage" criteria (UNESCO, 2015). Although Harput also possesses a similar historical diversity, the surviving architectural elements are more limited in number and condition. For instance, Harput Castle, the Grand Mosque, and some Armenian churches can be cited as representatives of this multicultural past (Azar, 2019). However, systematic conservation and promotional strategies for these structures have not yet been adequately developed in Harput.

According to national regulations, "Conservation-Oriented Zoning Plans" aim to integrate heritage areas into physical planning processes. In Suriçi, these plans are largely implemented and regularly updated. In the case of Harput, however, similar plans often face setbacks during the implementation phase (Akyıldız & Olğun, 2020b). The continuity and supervision of these plans are of critical importance for conservation success. Without consistent application, the degradation of historic urban fabric becomes inevitable.

Extensive restoration activities are carried out in both Suriçi and Harput, yet there are notable methodological differences between them. In Suriçi, restoration projects emphasize documentation of registered buildings and the use of authentic materials. In Harput, by contrast, the use of modern materials and structural additions have sometimes negatively affected the authenticity of heritage structures (Akyıldız & Olğun, 2020b). This constitutes a negative aspect in terms of UNESCO's criteria on authenticity. Scientific principles must be strictly followed in restoration practices.

The promotion of these areas and their integration with cultural tourism also affect their conservation status. Thanks to its UNESCO designation, Suriçi has been widely incorporated into tourism-oriented cultural routes. Despite its significant potential, Harput has not yet achieved the same level of integration. This results in disadvantages not only economically but also in terms of conservation (Olğun, 2023b). Promotion strategies based on scientific planning are vital for addressing this shortcoming.

UNESCO’s proposed "Historic Urban Landscape" (HUL) approach involves multiple dimensions—social, economic, physical, and cultural (UNESCO, 2011). Suriçi, with practices aligned with this holistic approach, appears to be ahead in terms of effective conservation. In Harput, this approach has yet to be fully reflected in practice. If Harput adopts this methodology in the near future, its conservation level can significantly improve. This would also pave the way for its transition from the Tentative List to the World Heritage List, provided that expert support, financial resources, and local capacity-building efforts are mobilized.

Table 1. Comparison of the current status of Harput and Suriçi in terms of protection and sustainability

STUDIES IN THE CONTEXT OF CONSERVATION AND SUSTAINABILITY	ELAZIĞ/HARPUT	DİYARBAKIR/SURİÇİ
MULTICULTURAL HERITAGE	Yes, but structural integrity has not been fully preserved	Available and largely preserved structural integrity
URBAN SITE STATUS	Urban protected area	Urban protected area
INCLUDING ON THE UNESCO WORLD HERITAGE LIST	On the provisional list	On the list
CONSERVATION PLANNING AND HOLISTIC CONSERVATION APPROACHES	Uncertainties and resource deficiencies are evident	Supported by interdisciplinary approaches
UNESCO SITE MANAGEMENT PLANNING	None - development work is ongoing	Available
RESTORATION PRACTICES FOR AUTHENTICITY	There are interventions that contradict the original	Mostly original and controlled interventions
TOURISM AND PROMOTION ACTIVITIES	Development work is ongoing	Extensively developed
ACADEMIC STUDIES	Needs to be increased	Available in large numbers

5. Conclusion and Suggestions

In this study, the conservation and sustainability of traditional urban areas in Anatolia are comparatively examined through the neighboring settlements of Elazığ/Harput and Diyarbakır/Suriçi. The findings reveal that both historical fabrics host a significant cultural and architectural heritage; however, they differ in terms of the scope and effectiveness of conservation practices. The inclusion of Suriçi in the UNESCO World Heritage List has enhanced the site's national and international visibility and facilitated the implementation of conservation policies within a more systematic framework. In contrast, Harput’s status as part of the tentative list remains a limiting factor in the execution of such practices.

An analysis of the spatial, social, and cultural fabric of Harput and Suriçi shows that both areas possess a rich composition of traditional residential architecture, religious structures, and other public spaces. Nevertheless, in terms of conservation, it is evident that physical interventions alone are not sufficient; public engagement and awareness-raising among local communities also play a decisive role. The Site Management Plan implemented in Suriçi alongside the UNESCO process can be considered a significant model in this context. In Harput, although conservation efforts are ongoing, a similar management approach has yet to become widespread, and existing practices appear to be concentrated more on individual buildings. This situation highlights the need for multidimensional and inclusive perspectives in the sustainable conservation of traditional urban areas.

The current conservation status of the Diyarbakır City Walls, which are included in the UNESCO World Heritage List, along with related efforts, may serve as a potential model for Harput, which remains on the tentative list. However, the sustainability of this model is not solely dependent on physical conservation criteria; it also requires a strong correlation with administrative components such as management, financing, education, and community participation. The monitoring and evaluation mechanisms applied in Suriçi may serve as valuable references for developing effective policies for Harput. That said, considering Harput's unique context and multiple potentials, the Diyarbakır model should not be treated as a direct template, but rather as an adaptable example shaped by the shared geography and cultural proximity of the two settlements. Within this framework, the sustainable preservation and emphasis on Harput's authentic values are essential for its inclusion in the permanent list. Accordingly, the following recommendations should be considered for the sustainable conservation of both settlements:

- A comprehensive Site Management Plan should be prepared for Harput and structured in alignment with UNESCO standards.
- The monitoring, reporting, and participatory mechanisms applied in Suriçi should be maintained and flexibly adapted to Harput, taking its local context into account.
- Educational and awareness-raising programs should be conducted to ensure the active participation of local communities in the conservation process in both areas.
- Digital inventory systems should be developed to document and archive registered structures.
- Conservation practices should prioritize the use of traditional building materials and techniques.
- Sustainable tourism policies should be implemented to prevent tourism pressures from damaging the authenticity of the historic fabric.
- Multidimensional collaborations should be encouraged through national and international funding sources.
- Partnerships with universities and expert institutions should be established to support conservation practices academically and promote scholarly dissemination.
- The visibility of structures reflecting cultural diversity should be enhanced to strengthen the emphasis on multicultural heritage in both settlements.

In conclusion, this study reveals the differences and commonalities in the conservation of traditional urban areas in the Anatolian context through the cases of Harput and Suriçi. The experience and outcomes derived from Suriçi's UNESCO World Heritage journey offer valuable insights for other sites like Harput that are still on the tentative list. However, the unique contextual characteristics of each site must be taken into account, and conservation policies should be designed accordingly. Sustainable success can only be achieved not through structural interventions alone, but through public participation, good governance, and resource continuity, as well as fabric-scale approaches. In this regard, it is deemed essential to promote holistic, participatory, and locally rooted conservation strategies.

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The article complies with national and international research and publication ethics.

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Adaptive Reuse of Tokat Deveciler Khan: An Assessment in Terms of Sustainability and Cultural Integrity

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1. Introduction

Today, protecting cultural heritage involves not only preserving the physical structure of buildings but also making them functional by integrating them into modern life. In this context, adaptive reuse is an effective method for preserving historic buildings. Casal (2003) states that this approach is widely used, especially for buildings that are in good condition, spatially adaptable, and architecturally significant. It aims to give the building a new purpose while maintaining its historical and cultural features (Ijla & Broström, 2015).

Adaptive reuse closely aligns with sustainability principles. Yung and Chan (2012) emphasize that this approach extends the lifespan of buildings, reduces demolition waste, and supports the local economy. Dyson & Matthews (2015) describe this strategy as a sustainable development tool that combines environmental benefits with social values. Therefore, this method is not only a conservation tactic but also a key element of sustainable urban transformation.

The concepts of authenticity and integrity also play a critical role in these applications. While the Venice Charter (1964) states that the aesthetic and historical values of the building must be preserved, the Nara Certificate of Authenticity (1994) stresses that the cultural and functional aspects of these values must be considered, along with their physical aspects. Therefore, during the adaptive reuse process, in addition to physical protection, the social and visual integrity of the building must also be addressed (Jokilehto, 2006; English Heritage, 2008).

Khan buildings in Anatolia have historically held an important place in urban life as centres of not only accommodation and trade but also social and cultural interaction. Built during the Seljuk and Ottoman periods, these buildings responded to the economic, spatial and sociocultural needs of their period and became the main components of local production and circulation systems (Aslanapa, 1984; Koç and Asar, 2017). However, today, many khans have lost their original functions and are at risk of losing their original qualities due to long-term disuse, incorrect restoration practices or functional transformation pressures (Ahunbay, 2009; Karakuş, 2022).

For this reason, the adaptive reuse of Khans to contemporary life is important not only in terms of physical protection but also in terms of the sustainability of social memory and identity (Kim, 1998). Through adaptive reuse, both the architectural features of historical structures are preserved, and their integration with urban life with new functions is ensured. These approaches support the continuity of the spatial and cultural connection established with the past, especially in structures with a distinct architectural language, such as khans (Ijla & Broström, 2015; Diamonstein, 1978).

Deveciler Khan, located in Tokat province, is one of the original examples that should be evaluated in this context. Although its construction date is not certain, this building, which is thought to have been built in the 15th century, currently serves as a hotel and restaurant. However, studies on Deveciler Khan are quite limited in the existing literature. Existing publications mostly focus on the structural system and reinforcement techniques of the structure; the adaptive reuse process is only superficially addressed in the context of a short-term conservatory function. Therefore, there is a need for a comprehensive evaluation of the methods followed in the adaptive reuse process of the building, the spatial transformations applied and the relationship with the principles of sustainability.

This study aims to reveal how the cultural heritage value of the building is preserved with contemporary functions and how it can be evaluated in terms of sustainability by addressing the adaptive reuse process of Deveciler Khan within the framework of the principles of authenticity and integrity.

2. Methodology

This study examines the methodology followed in the adaptive reuse processes of Tokat Deveciler Khan. It evaluates how the building's original character is preserved, how it is adapted to modern needs, and how it overlaps with sustainability principles. The study's methodology has three main stages (Figure 1).

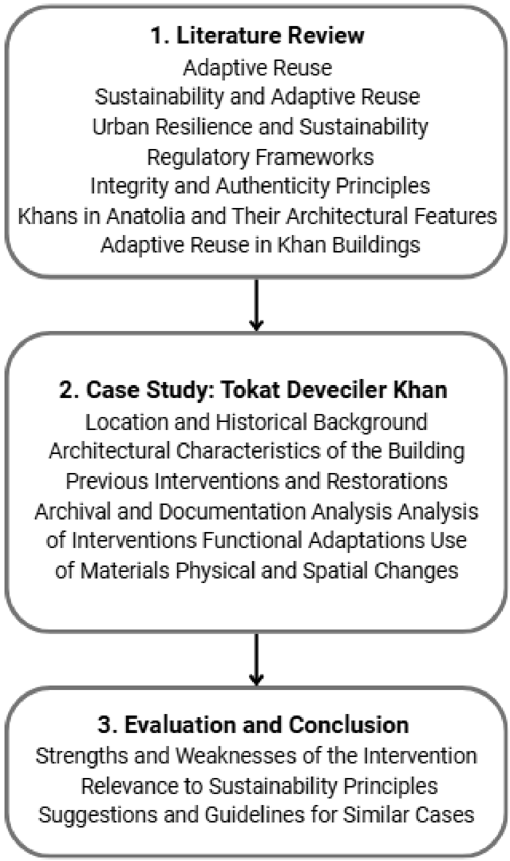

Figure 1. Workflow Diagram (created by the Authors)

Firstly, the literature review was conducted to examine the concepts of adaptive reuse, sustainability and urban resilience and the studies on the relationship between these concepts. In addition, the focus was on regulatory frameworks (charters-declarations), principles of integrity and authenticity, historical and architectural features of khan buildings in Anatolia and adaptive reuse in khan buildings.

In the second stage, a case study was conducted. Tokat Deveciler Khan was introduced with its location, historical past and architectural features, then the survey-restoration studies of the building together with archive documents were examined and the interventions and restoration processes of the building were analyzed. The spatial and functional adaptations required by the new functions, the material preferences used, and spatial changes were examined in detail.

In the last stage, the interventions made to the building during the adaptive reuse process were evaluated, their compliance with the sustainability principles was examined and guiding suggestions were presented for similar structures. This methodology systematically presents an effort to establish a balance by addressing the relationship between the protection of cultural heritage and contemporary uses, sustainability and urban resilience in the adaptive reuse of historical buildings, as in the case of Tokat Deveciler Khan.

3. Literature Review

Over time, buildings lose their original function to adapt to changing user profiles and needs and are reused by adapting them to serve modern needs. (Douglas, 2006); defines adaptive reuse as 'maintenance and repair work aimed at changing the capacity, function or performance of a building'. (Casal, 2003); argues that adaptive reuse is a method widely applied worldwide, especially in well-preserved, spatially flexible and residentially valuable architectural examples.

Adaptive reuse, which is one of the most frequently preferred approaches in the preservation and survival of historical structures, aims to protect the cultural heritage and create a sustainable environment by utilizing the existing potential of the building; This process is not limited to restoration, but aims to preserve the historical, cultural and architectural values of the building and to provide it with new functions. It is based on the principle that the history, identity and original character of the building must be respected in all cases (Ijla & Broström, 2015).

While buildings are generally constructed for specific functions, over time, they inevitably go beyond these functions due to social, economic and technological changes. Adaptive reuse involves making physical changes to buildings to adapt to different usage needs in response to these changes (Conejos, 2013). When the historical process is examined, it is seen that in many societies, old buildings have been adapted to new functions through methods such as expansion, decoration and reconstruction (Fitch, 1990). On the other hand, not only functionality but also efficiency of energy and resource use as well as future redevelopment potential have been considered in the construction processes (Arfa, et al. 2022).

Adaptive reuse is an important part of the term sustainability. This adaptation process focuses on reusing existing buildings with functions that suit today's needs, rather than reconstructing them. The adaptive reuse approach contributes significantly to the conservation of natural resources, saving materials and energy, and reducing waste (Yung &Chan, 2012). With this approach, environmental impacts can be minimized while extending the life of buildings.

Sustainability is not limited to the environmental dimension; it also encompasses a more holistic approach that includes economic, social, and cultural elements (WCED, 1987). In this sense, the reuse of historical structures supports regional socio-cultural revitalization while also contributing to local economies and tourism (Ijla & Broström, 2015). Yung & Chan (2012) defined adaptive reuse as 'an essential component of sustainable urban renewal, extends the lifespan of buildings while preventing demolition waste, promoting the reuse of embodied energy, and providing significant social and economic benefits to society' in the term of urban resilience.

This term aims to make cities and historical buildings resilient to future crises and environmental threats, while preserving social integrity and local identity. The term urban resilience is defined as the capacity of structural and social systems to adapt, exhibit flexibility, and reconstruct in response to unexpected shocks, such as natural disasters, economic fluctuations, and climate change, by evaluating them as a whole (Kayar and Kutlu, 2022).

In this context, adaptive reuse practices of historical buildings support not only physical sustainability but also the holistic resilience of the urban system. Indeed, a reuse project targeting environmental sustainability also contributes to the construction of a durable urban fabric that connects with the memory of the society, strengthens social networks and creates economic vitality (Tuğaç, 2020). Therefore, sustainability and resilience should be considered as complementary strategies that feed each other in the protection of cultural heritage. At this point, adaptive reuse is considered one of the fundamental tools not only for sustainability but also for creating a crisis-resistant, flexible and sustainable urban fabric.

Adaptive reuse preserves the value of historic buildings, minimizes environmental impacts, and contributes to society, economy, and the environment in line with sustainability principles. Adaptive reuse of buildings supports urban sustainability by combining both historic heritage and the needs of contemporary life. According to the Venice Charter, the adaptive reuse process is an important method for protecting historical structures and their adaptation to contemporary functions. However, during this process, the plan, decorations and historical character of the structure must be preserved (ICOMOS,1964).

A monument's aesthetic and cultural values should not be compromised during the reuse process, and its original qualities should be preserved to the greatest extent possible (ICOMOS,1964). Adaptive reuse provides both environmental benefits and contributes to achieving sustainable development goals by maintaining the cultural and architectural integrity of historic structures.

However, in this process, it is essential to comply with the principles of authenticity and integrity. Interventions made during adaptive reuse must not harm the historical value and aesthetic integrity of the structure; on the contrary, these elements must be supported and adapted to modern functions. Therefore, adaptive reuse plays a critical role in the protection of historical heritage as well as environmental and social benefits.

3.1. The Notion of Authenticity and Integrity

3.1.1. Authenticity

The concept of authenticity in the field of architectural conservation has been widely documented and has become an important criterion in many different areas (Jokilehto, 2006; ICOMOS, 2014). However, in documents such as UNESCO's Convention on the Tangible and Intangible Cultural Heritage or the Florence Declaration, it has been stated that there is a hesitation towards authenticity.

Munjeri (2000) states that preserving the vision of the past is important in order to guide the future. Cultures are built on the continuity of messages from today. However, the concept of authenticity must have a flexible understanding in line with different influences and changes. Otherwise, living cultures may be endangered. It was stated that in interventions to be made on structures, changes should be noticeable to the ordinary eye (English Heritage, 2008).

In the Venice Charter (ICOMOS, 1964), authenticity is associated with aesthetic and historical values (Plevoets and Van Cleempoel, 2011). In addition, within the scope of the 1972 World Heritage Convention, in areas to be nominated for the World Heritage List, four main criteria such as design, material, workmanship and environment were sought for authenticity tests (UNESCO, 1977, Article 9).

Following these developments, the Nara Authenticity Document (ICOMOS,1994) addressed the concept of authenticity in a broader framework. It was emphasized that not only tangible elements but also intangible elements such as *traditions, techniques, language, spirit* and *feeling* should be evaluated (ICOMOS, 1994, Article 7). After 1994, the concept of authenticity was expanded to include elements such as traditions, techniques, language, spirit and feeling (Jokilehto, 2006).

3.1.2. Integrity

The concept of integrity is an important tool for assessing the value of historic structures. The World Heritage Operational Guide (2005) defines integrity as follows:

"Integrity is the level of integrity and soundness of the natural and/or cultural heritage and its attributes. The assessment of integrity involves analysing whether the structure contains all the elements necessary to express its Outstanding Universal Value, whether it is of sufficient size and

whether it has not suffered from adverse effects of development or neglect."(The World Heritage Operational Guidelines, 2005, par. 88)

Integrity is addressed in three main dimensions (Taylor, 1991; English Heritage, 2008). Firstly, it is important to preserve *the physical integrity of the structure*. Secondly, the *historical and aesthetic values of the structure* should be accurately reflected, that is, the *principle of honesty* is emphasized. Finally, the qualities of the structure should be fully presented, that is, a *full representation* should be provided.

Jokilehto (2006) also explained the concept of integrity in detail with three additional parameters. Accordingly, *socio-functional integrity* refers to the preservation of the social function of the structure, while *structural integrity* refers to the preservation of the structural strength of the structure. *Visual integrity* refers to the visual perception of the structure remaining in harmony with its historical identity.

Integrity, just like originality, should be based on a comprehensive understanding that will prevent the loss of the values of the structure in the interventions to be made (English Heritage, 2008; ICOMOS, 2014).

3.2. Khan Buildings: A Historical and Typological Review

Khans have historically been divided into two different types in terms of function and architecture: "caravanserais" outside the city and "city khans" in city centres (Campbell,2011). Cerası (2001) defined the khan as "structures with arcaded courtyards without any enclosed space, called ribat in Central Asia, built by the military aristocracy to support transit trade and host merchants". Akozan (1963) defined the khan as "structures built entirely of masonry to accommodate travellers and caravans and preserve goods on busy streets and in guesthouses". Hasol (2002) also describes the khan as "buildings with rooms, courtyards, warehouses and stables for the accommodation of travellers".

Although the terms "khan" and "caravanserai" are often used interchangeably, they differ in terms of function and location. While caravanserais were built on intercity roads, in areas far from settlements, khans were located on the main roads of cities, in city centres (Sönmez,2007).

3.2.1. Typology and Architectural Features of Khans

Since the Middle Ages, khans and caravanserais were built as accommodations for merchants and travellers travelling on trade routes. These buildings were designed with a courtyard in the centre and rooms around it (Figure 2), reinforced with thick walls and corner towers for defensive purposes (Pope, 1971). Their plans were usually square, circular or octagonal, with a central courtyard and surrounded by walls. The entrance to the building was usually provided through a large gate positioned diagonally to the main road axis. The inner courtyard was surrounded by porticos (Pope, 1971).

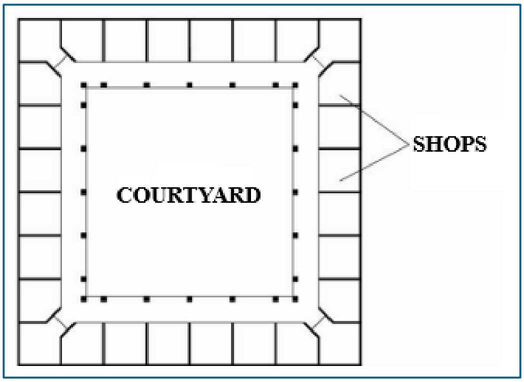

Figure 2. An example of a typical khan plan (Sözen&Tanyeli, 1986) adopted by Authors.

The courtyard was used for animals, while the rooms were designed for the accommodation of passengers. Toilets were usually placed in corner towers. Over time, additional areas for animals were added between the living areas and the outer walls (Ahmad and Chase, 2004). Although the form of the khan and caravanserai structures was initially likened to castles (forts) (Michell, 1978), this understanding changed during the Ottoman period and facades that were more in touch with the environment and open to commercial activities were designed (Altan and Özsoy, 2017). In terms of architecture, the principle of symmetry was observed in khan and caravanserai structures; elements balanced on the axis were emphasized in the designs (Golombek, 1968).

3.3. Historical Development of the Khans in Anatolia

The oldest examples of caravanserais were called "ribats" during the Karakhanid period. The Great Seljuks and Anatolian Seljuks developed these structures, specially constructing structures with a palace-like richness with their four-iwan courtyard layout and corner towers (Aslanapa, 1984). The development process of Turkish caravansarais progressed in parallel with the increase in the number of caravans and the importance of trade. Initially built for religious and military purposes, ribats gradually transformed into commercial facilities and became the first examples of caravansarais (Sönmez, 2007).

The Anatolian Seljuks continued the influences of Turkestan architecture, developed original elements and created their khan typologies in Anatolia (Güran, 1978). Three basic types of khans are seen in this period (Aslanapa, 1984). These are; khans with four iwans and open courtyards, khans without courtyards and completely closed, and mixed-form khans consisting of a combination of these two types. For example, the Sultan Khan (Figure 3) on the Konya-Aksaray road is one of the important examples of this architectural concept with its square-planned mosque and monumental portal (Aslanapa, 1984).

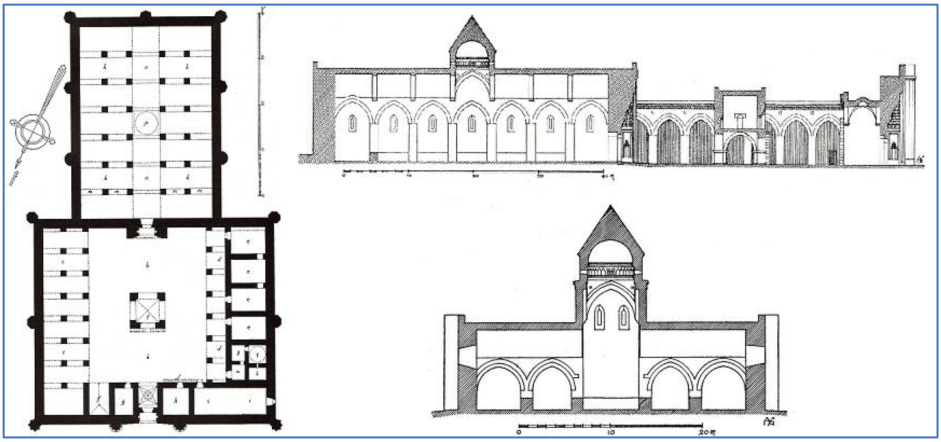

Figure 3. Sultan Khan Plan and Sections (URL1)

Caravanserai and khan constructions continued during the Ottoman period, and there were developments in both inner-city and outer-city structures (Koç & Asar,2017). Ottoman city khans generally had an open courtyard and a portico layout. Over time, changes in form occurred in khan plans depending on the land and road conditions; the form of the courtyards became freer, and animal and passenger spaces were clearly separated (Koç & Asar,2017). Ottoman-era khans can be divided into three groups. These are closed khans without courtyards, khans with open courtyards, and city-based caravanserais.

Khans are generally divided into two types according to their functions as Passenger Khans and Trade Khans. Passenger Khans are designed to meet the accommodation needs of travelling merchants and passengers, located outside the city or in the city centre. In these khans, there are units such as storage and stables on the lower floors, while the upper floors are reserved for rooms for passengers to stay (Özdeş, 1998; Atalan & Arel, 2016).

Trade Khans are structures located in city centers and serve mostly commercial activities. There are shops and warehouses on the lower floors, while the upper floors are used for office or storage purposes, and limited accommodation opportunities are offered (Akozan, 1979; Akar, 2009).

3.4. Adaptive Reuse and Socio-Cultural Sustainability in Khan Buildings

Khans are important components of the Ottoman and Turkish-Islamic urban fabric and are versatile structures that offer trade, accommodation and social interaction functions together. Having lost their original functions throughout history, khans are today adapted to the needs of modern life through adaptive reuse and are thus evaluated in terms of cultural sustainability. For example, most of the khans in the city centre of Kastamonu have been brought into social life with functions such as cafes, restaurants, hotels or bazaars (Karakuş, 2022).

The ability of a historical structure to maintain its function ensures the preservation of its architectural identity: Structures that lose their function turn into an archaeological element over time. Therefore, re-functioning is an important tool for functional sustainability (Ahunbay, 2009). However, in this process, the plan, ornamentation and historical character of the structure should be preserved. According to the Venice Charter, the aesthetic and cultural value of the monument should not be harmed during reuse.

Another important principle in reuse is reversibility. New functions added to the structure mustn't prevent it from returning to its original state in the future (Kuban, 2000). Especially in structures with a distinct architectural character such as khans, new use designs should continue to reflect the original architectural language.

The adaptive reuse of khans supports not only physical protection but also the principle of socio-cultural sustainability. Sustainability aims to increase the capacity of societies to adapt to change while preserving their identities (Kim, 1998). Giving a new function to a khan building suitable for today's conditions both preserves the collective memory from the past and contributes to the continuity of social life.

According to Ijla & Broström (2015), adaptive reuse of khans contributes to the revitalization of the neighbourhood fabric by preserving the connection of the space with the past. It also increases the social and cultural vitality of the historic environment. This process supports the sustainability of the buildings both economically and socially. Diamonstein (1978) says 'Re-functionalized khans create a connection with the past, creating an identity for the local people and contributing to tourism.'

As a result, adaptive reuse of khans ensures that historical structures are preserved and transferred to the future, while also allowing societies to keep their cultural identities alive. Each intervention plays a critical role in both physical protection and the continuity of social memory.

4. The Case of Tokat Deveciler Khan

Tokat is a city located in the inland of the Central Black Sea region of Türkiye (Figure 4). It borders Samsun to the north, Ordu to the east, Sivas to the south, Yozgat to the southwest and Amasya to the west. The surface area of Tokat is 9,958 km² and its altitude above sea level is 623 meters. There are 12 districts, 65 towns and 609 villages in Tokat, including the central district (Ünal, 2005).

Figure 4. The location of Tokat Province (URL2, 2024) adopted by Authors.

Tokat is an important settlement that has been home to many civilisations. Following the Battle of Malazgirt's victory, Tokat was conquered by the Turks and transformed into an Islamic city. Upon joining the Ottoman Empire, it became a significant urban centre. It was annexed to the Ottoman Empire after the conquest of Fatih Sultan Mehmet in 1461 (Gökbilgin, 1988). Tokat is situated on trade routes and has hosted many cultures together due to its diverse socio-cultural structure. Especially during the Ottoman period, Tokat attracted attention with its lively trade activities and population diversity (Afyoncu, 2014).

Among the important trade buildings in Tokat, khans stand out. The history of Tokat has been shaped by the existence of many buildings due to its location on trade routes. These buildings functioned not only as centres of trade but also as social areas where people came together. Important structures such as Gök Medrese, Pervane Hamamı, Taşhan, Deveciler Khan and Hatuniye Mosque from the Seljuk and Ottoman periods in Tokat bear traces of the city's cultural and commercial past (Korumaz & Erarslan, 2019).

Regarding the development of trade in Tokat, it has been stated that the number of khans recorded in cities such as Afyon, Tokat and Beypazarı in the 16th century was quite high. Tokat became the centre of regional trade during this period (Faroqhi, 1994). In addition, the oldest trade centre of Tokat is Sulu Street and its surroundings to the south of the castle, and the city, which grew over time, formed three important trade areas during the Seljuk and Ottoman periods: Sulu Street and its surroundings, the area around the Ali Pasha Mosque, and the area between the Hatuniye Mosque and Taşhan (Akın, 2009).

It is stated that among the commercial and cultural buildings in the city, many buildings around the Ali Pasha Mosque were destroyed as a result of the great fire that broke out in 1914 (Beşirli, 2001).

4.1. Architectural Features of Deveciler Khan

Deveciler Khan in Tokat stands out as a typical example of Ottoman city khans (Figure 5). The name of this structure, which is estimated to date back to the 15th-16th centuries, is mentioned as "Taş Khan" in Ottoman documents, while it is known as "Deveciler Khan" among the public. It is thought that this name spread because camels were kept in the stable. The building offers a balanced combination of functionality and aesthetics shaped according to trade and accommodation needs (Altaş, 2002). When the distinctions are taken into consideration, Tokat Deveciler Khan is classified as a Passenger Khan with its large courtyard, shelter and storage areas on the lower floor and accommodation rooms on the upper floor.

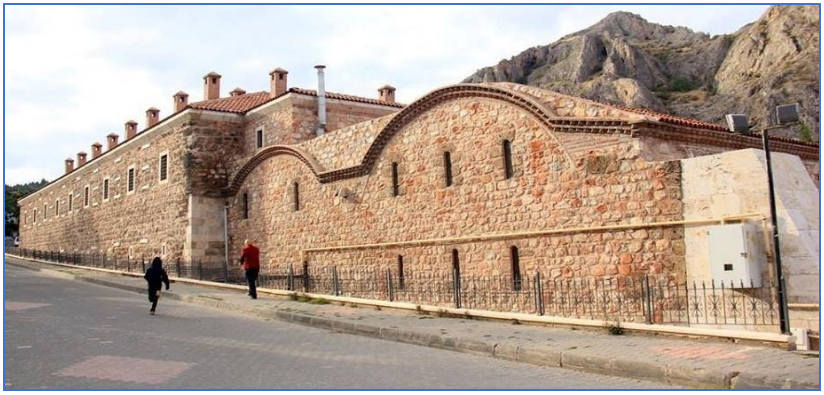

Figure 5. Tokat Deveciler Khan (URL3, 2024)

The khan is a two-story structure with a rectangular plan. The entrance is provided by a square-planned, pointed-arched, domed area on the north facade. This entrance leads to the courtyard with a pool in the middle. The courtyard is surrounded by porticoes on both the ground floor and the upper floor. The ground floor consists of a total of 27 square-planned rooms with private rooms in the four corners. The stable area is a structure with two naves supported by four square columns. On the upper floor, there are 17 square-plan, and 5 rectangular-plan rooms lined up behind the porticoes. In addition, 18 shops are located on the north facade, suitable for commercial activities (Saka Akın & Demiroğlu İzgi, 2021).

Some parts of the structure were damaged by earthquakes over time after its construction. In the photographs taken in 2007, it was observed that the interior porticoes were destroyed and the vaults of the stable section collapsed (Figure 6). After the restoration works, it was made suitable for both commercial and cultural use (Çavuş & Arslan, 2023).

Figure 6. View of the courtyard and camel barn section of Deveciler Khan (OTS Project & Consultancy Archive, 2007).

The materials used in the construction of Deveciler Khan are durable materials such as cut stone and rubble stone. In addition, brick was used for the vaults and domes. The architectural features of the structure reflect the aesthetic and functional understanding of Ottoman-era architecture, and this understanding was preserved during the restoration process and the structure was given a new life (Aksulu, 1991; Altaş, 2002).

Deveciler Khan is one of the structures of the Ottoman period and was built in the 15th century. The main purpose of the building was to provide a suitable environment for caravans and people to come and stay with their camels. According to sources, people continued to come to this khan with their camels until the 1950s, which shows that the building was used for its original function for many years after its construction (Altaş, 2002).

However, a major earthquake in 1939 caused serious damage to the structure and the inscription of the khan was lost in the process. Since the building was not repaired after the earthquake (Figure 7), it is understood that the damages negatively affected the use of the building for different purposes over time (Saka Akın & Özen, 2013).

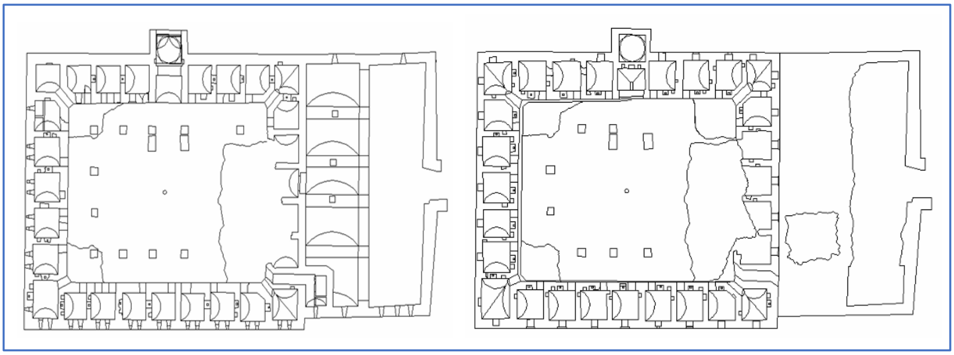

Figure 7. Ground and First Floor Survey Plans (Tokat Regional Directorate of Foundations Archive).

After the 1950s, Deveciler Khan was used as a forestry depot, then served as a livestock market and a weekly Friday market by the municipality. In the 1980s, the building was used as the municipal cleaning directorate for a while and then served as a vehicle depot for 2-3 years. These processes reveal that the functionality of the khan constantly changed according to the needs of the period and the identity of the building evolved with different forms of use (Saka Akın & Demiroğlu İzgi, 2021).

4.2. Restoration Process and Adaptive Reuse of the Khan

Deveciler Khan emerged in its original state after the shanty house annexes adjacent to the east and west walls of the building, which were in a very dilapidated state, were demolished during the restoration works initiated in 2007. This restoration aimed to bring the original structure to light while preserving the historical features of the building. The khan given a new function as Tokat Gaziosmanpaşa University State Conservatory Turkish Music Department in 2012. The historical rooms inside the khan were transformed into lecturer rooms and private tutoring centres. In addition, some rooms were combined to create classrooms and large spaces (Figure 8). However, at the end of 2019, the building used as a conservatory was vacated and re-restored as a boutique hotel.

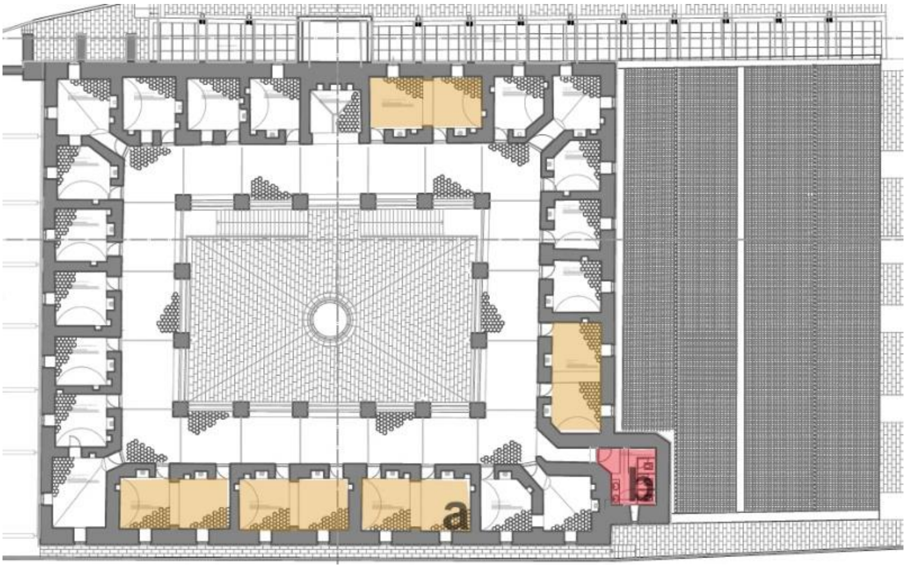

Figure 8. Deveciler Khan First Floor Plan, Restoration in 2012 (a) combined rooms and b) wet spaces) (Tokat Regional Directorate of Foundations Archive)

Tokat Deveciler Khan was converted into a boutique hotel in 2019 and underwent various interventions to adapt to modern needs during this process. The changes in the ground floor and courtyard area (Figure 9) include important arrangements for adapting the structure to modern functions. The camel barn part of ground floor was reorganised for commercial functions as a restaurant and its kitchen. With this transformation, the old functions were largely lost, and the historical use of the structure was erased.

Instead of a traditional roof cover, a removable steel system was integrated into the courtyard. This new roof made the use of the courtyard flexible, while at the same time changing the original light and space perception of the structure. The wooden profiles in the courtyard were also used to hide the installation systems. These large-section wooden profiles interfered with the visual texture of the courtyard and damaged the aesthetic integrity of the original structure.

Figure 9. The changes on the ground floor and courtyard (roof covering system, wooden profiles) (Silk Road Hotel Archive, 2025)

The changes to the rooms and first floor include additional modifications to adapt the khan to its hotel function (Figure 10). The rooms on the upper floors were reorganized with partitions containing toilets and showers. This change altered the cellular structure of the original rooms and aligned the interior layout of the historic building with modern accommodation needs. Door openings were created in the stone wall as needed. Additionally, the old stove openings were converted into modern fireplaces, allowing the rooms to be reshaped in terms of aesthetics and functionality.

Figure 10. Deveciler Khan First Floor Plan, Restoration in 2019 (a) door openings b) wet spaces c) steel roof cover) (Tokat Regional Directorate of Foundations Archive)

The wall surfaces of the rooms were generally renovated by painting, which caused the original material texture of the old structure to be lost. Plasterboard panels were added to conceal the electrical installations, resulting in the disappearance of the historical wall texture. Modern window systems were installed in the old openings using new wooden joinery, doors, and glass casings. Additionally, fireplaces were added to the rooms, transforming the old stoves into modern fireplaces (Figure 11).

Figure 11. Interventions in the rooms (Silk Road Hotel Archive,2025)

Structural reinforcement was performed in 2009, and it continued serving as a hotel. Steel struts and tension rods were added to enhance the structure's stability. These reinforcements ensured safety but created a visual mismatch with the building's historical aesthetics. Although such interventions are necessary for security, they may also harm the historical character of the structure.

As a result, the transformation of Tokat Deveciler Khan aimed to preserve the building's historical values while making significant changes to incorporate modern functions. The interventions improved the structure's usability but, in some cases, led to the loss of original structural and aesthetic features. This transformation process emphasizes the need for a more careful approach to protect the building's cultural and historical significance in the future.

According to the Venice Charter, the intervention process must follow the order of consolidation, repair, and restoration; restoration should only be performed when necessary and in a way that does not compromise the artistic integrity of the structure. Non-original additions should be removed if they lack historical or artistic value; however, they should be kept if they possess such value. New additions should be made in a contemporary style, avoiding imitation, and should be distinguishable from the existing structure. All interventions must be documented, photographed, and archived, and the restoration should be marked by an inscription placed on the historic structure (ICOMOS,1964).

The restoration of historical buildings requires the application of various techniques to preserve the original qualities of the structures. In this context, the reinforcement of the carrier system or environmental elements with methods such as consolidation, injection, clamping and support is of great importance (Zakar, 2013). Integration refers to the completion of missing or damaged sections, based on reliable documents and remaining faithful to the original design (Ahunbay, 1995). Renovation is the restoration of parts that have lost their original features with appropriate materials and the sustainability of the function of the structure (Zakar, 2013).

Reconstruction is the construction of copies of structures that have been destroyed by fire, war or natural disasters, based on original materials and documents. Cleaning is the removal of dirt or additions that have formed on the surfaces of structures over time with chemical or mechanical methods (Ahunbay, 1995). Finally, transportation involves the replacing of structures from their original locations to another area for their protection (Tellioğlu & Satıcı, 2023).

The restoration of Deveciler Khan, which started in 2007, includes restoration principles such as consolidation, integration and renewal, together with the adaptive reuse approach. Adaptive reuse aims to make the existing structure functional according to contemporary needs while preserving the historical and cultural values of the structure.

4.3. Analysis of Interventions

Adaptive reuse interventions carried out in Tokat Deveciler Khan have been evaluated within the framework of authenticity, integrity and reversibility principles in terms of their effects on the structure (Table 1).

The reorganisation of the ground floor with commercial functions such as a restaurant, souvenir shop and service area is an example of adaptive reuse that supports the contemporary use of the structure. However, this transformation has caused the structure to move away from its original khan function and weakened its connection with its traditional use. Although it is physically possible to transform, the interventions can be considered limited in terms of reversibility since they may leave permanent traces. Spatial integrity has also been significantly damaged by this change of function.

The removable steel roof system placed over the courtyard (Figure 12) increased user comfort but damaged the traditional open courtyard character of the khan. Although it is technically possible to remove this cover system added to the structure later, the intervention is not fully reversible due to the integration of the support elements into the structure. In addition, this addition weakens the original emptiness and openness of the courtyard and creates a negative impact in terms of both authenticity and visual integrity.

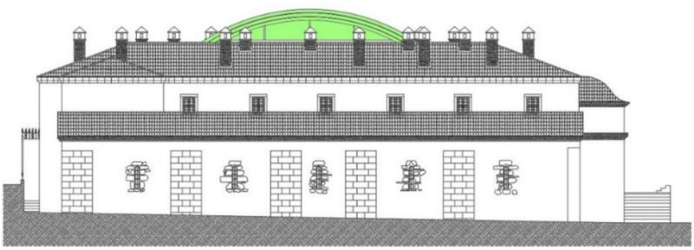

Figure 12. Steel Roof System placed over the courtyard (Tokat Regional Directorate of Foundations Archive, 2025)

The large wooden profiles in the courtyard were placed to hide the modern installation systems; however, they have become a very dominant and permanent visual element in the structure. Although technically removable, these profiles are likely to leave permanent effects on the courtyard volume due to their height and the area they cover. This intervention has disrupted both the original volume perception and the visual reading of the traditional texture, damaging authenticity. At the same time, the principle of integrity has also been damaged due to material incompatibility and proportion problems.

The addition of toilet and shower areas with the divisions made in the rooms has provided a functional solution for the hotel's function. However, these divisions have changed the original cellular plan scheme of the rooms, creating both a physical and functional transformation. Although these divisions can be revoked from the structure in most cases, they are inevitable to leave traces due to the interventions made on the walls and floors. This situation both weakens the principle of authenticity and disrupts the integrity of the interior.

In some rooms, the existing stove openings have been converted into fireplaces, giving the structure a nostalgic but non-original character. This transformation is irreversible and has caused a significant loss in terms of original use and cultural expression. Similarly, although the newly manufactured wooden door and window joinery was made with aesthetic harmony in mind, it is seen that the authentic character has been lost due to proportional differences and contemporary manufacturing techniques.

The strengthening applications implemented in the structure's carrier system in 2009 are mandatory structural interventions in terms of safety. Although such interventions are irreversible, they are considered necessary in terms of functionality and sustainability since they aim to protect the strength of the carrier system. However, they create a contradictory situation in terms of the visual aesthetic integrity of the structure; these elements, which damage the perception of the traditional carrier system, can damage authenticity, especially when they are in visible areas.

In conclusion, while most of the interventions made to Tokat Deveciler Khan are efforts to adapt the structure to its new function, some applications are far from being reversible and have qualities that contradict the principles of authenticity and integrity. Adaptive reuse can only become sustainable when carried out in balance with conservation principles, both the new function and cultural heritage values.

Table 1. Analysis of Interventions

INTERVENTIONS	ADAPTIVE RE-USE	REVERSIBILITY	AUTHENTICITY	INTEGRITY
Use of the ground floor as a restaurant, kitchen	It has joined public life with a new function.	Spatial transformation is reversible.	Conversion to restaurant use detracts from authenticity.	The original plan scheme and usage integrity have been damaged.
Covering the courtyard with a retractable roof cover	The cover is provided with a mobile steel carrier system, aiming for seasonal comfort.	Although the awning system is detachable, the steel carrier system may leave marks.	It weakens the traditional open courtyard perception.	It negatively affects the integrity of light, space and volume.
Adding thick wooden cladding profiles	It is a solution for contemporary needs, to hide the installation.	Although it is removable, the application may leave marks.	The original material and facade character are lost.	Visual balance and volume perception are disrupted
Covering the wall surfaces with plaster and paint.	It was done as a requirement of the accommodation function.	It can be physically undone.	The original stone/brick texture is hidden.	The originality of the material and the surface integrity are damaged.
Adding plasterboard panels to the walls and interventions for interior installations	It was done in line with modern installation needs	It can be removed, but it leaves holes and marks.	It disrupts the traditional surface perception.	The integrity of the wall is damaged.
Constructing toilet-bathroom partitions in the rooms.	It is a mandatory modern need for accommodation function.	The partitions can be removed, but they leave marks on the surfaces.	The room plan and proportions have changed, the cellular structure has been disrupted.	The integrity of the interior layout has been lost.
Converting the existing stove openings into fireplaces.	It was done to create a nostalgic atmosphere.	It can be removed.	The original stove traces are lost.	Functional historical traces have been erased.
Constructing new wooden door-window joinery	It was done to continue use.	It can be physically removed.	Differences in size and workmanship distance it from authenticity.	Visual proportion and rhythm have changed.
Structural reinforcement	It was done to strengthen the carrier system.	It is an irreversible but necessary intervention.	The traditional structural perception has changed.	The carrier integrity of the structure has been preserved, but the visual integrity has been damaged.
Doorways opening into stone walls	A necessity may arise to provide new functionality, but it means intervening in the original structure of the structure.	Returning to original state is difficult. Reversible methods should be preferred.	It disrupts the original stonework and form, leading to loss of authenticity.	It damages the physical and visual integrity of stone walls and affects the continuity of the structure.

5. Recommendation and General Assessment

The adaptive reuse of the Tokat Deveciler Khan contributed to its physical preservation and functional continuity. However, the implemented interventions present several shortcomings when evaluated in terms of the fundamental values emphasised in international conservation principles. In particular, the principles of preserving the unique character and cultural meaning of historical buildings and maintaining their authenticity were not fully observed due to the Tokat Deveciler Khan being limited to a hotel function. This will weaken the building's multilayered identity and place in social memory.

While the Khan was historically designed to serve various functions such as trade, social interaction, and travel, its current use solely for accommodation has led to it straying from its original purpose. The physical interventions are generally compatible with the original materials and techniques. While this has a positive effect, detaching the building from its socio-cultural context undermines historical continuity. Furthermore, treating the Khan solely as a tourist attraction weakens its relationship with the local community and contradicts the notion that heritage should be kept alive within society.

Today, the concepts of sustainability and urban resilience should be considered together in the preservation of cultural heritage. In this context, in addition to its accommodation function, assigning public functions such as local product sales areas, traditional handicraft workshops, cultural event venues, or travelling exhibitions to the Tokat Deveciler Khan could contribute to its reintegration into social life. Such an approach would increase the diversity of users and make the Khan's life cycle sustainable and permanent.

In conclusion, the example of the Tokat Deveciler Khan demonstrates that adaptive reuse should be addressed holistically, not only in terms of physical preservation but also in terms of cultural, social, and functional integrity, as well as urban resilience. It is important that preservation practices be supported by approaches that strengthen ties to the past, keep local memory alive, and transform the building into a living heritage site.

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The article complies with national and international research and publication ethics.

Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article.

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Urban Resilience Research: A Comprehensive Bibliometric Analysis

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1. Introduction

In the face of increasing environmental, social, and economic uncertainties on a global scale, the resilience of cities has become central to the sustainable development agenda of the 21st century. In particular, the increasing frequency and intensity of shocks such as climate change, natural disasters, and pandemics have made it imperative for cities to prioritize not only growth but also the development of resilience against crises (Cutter et al., 2010; Ahern, 2013). In this context, the concept of "urban resilience" has emerged as a new paradigm not only in risk management but also in multidimensional areas such as urban planning, infrastructure design, social participation, and governance (Meerow, Newell & Stults, 2016).

Urban resilience has been addressed using different theoretical frameworks due to its interdisciplinary nature. For example, the ecological resilience approach developed by Holling (1973) focuses on the system's capacity to sustain itself despite various stresses and shocks, while social scientists such as Pelling (2010) and Davoudi et al. (2012) have integrated this concept with justice, governance, and learning processes. However, in recent years, concepts such as green infrastructure, nature-based solutions, smart cities, and inclusive planning have increasingly found their place in the urban resilience literature (Elmqvist et al., 2019; Frantzeskaki, 2019).

Despite this theoretical diversity, there are only a limited number of studies that systematically map the general trends, key thematic clusters, most influential authors, and emerging topics in scientific publications in the field of urban resilience. Particularly following the COVID-19 pandemic, research addressing the concept of urban resilience has increased. This research focuses on the pandemic's impact on urban planning, design, and management processes (Sharifi & Khavarian-Garmsir, 2020).

At this point, bibliometric analysis offers a highly functional method for discovering structural patterns in the literature, identifying leading authors and topics, and identifying gaps for future research. Keyword co-occurrence analyses, author collaboration networks, citation and bibliographic matching maps conducted using software such as VOSviewer, CiteSpace, and Bibliometrix reveal both the temporal evolution of knowledge accumulation and thematic concentration areas in detail (van Eck & Waltman, 2010).

2. Literature Review

Global climate change, rapid urbanization, environmental degradation, and social vulnerabilities have made cities increasingly complex, multi-layered, and vulnerable structures. In this context, the concept of “urban resilience” refers to the capacity of cities to withstand, adapt to, and transform in the face of these multidimensional threats. Especially the COVID-19 pandemic and increasing climate disasters have turned urban resilience into not just a theoretical concept but also an urgent planning necessity.

Urban resilience has developed as a concept that requires a multi-layered analytical framework, ranging from ecological systems to social structures, infrastructure to governance (Ahern, 2011; Meerow et al., 2016). While early studies focused primarily on physical infrastructure and disaster management, in recent years socio-political dimensions such as social justice, governance, and inequality have also entered the literature (Chelleri et al., 2015; Ziervogel et al., 2017). Ecosystem services, green infrastructure, and nature-based solutions constitute the ecological dimension of urban resilience. Kabisch et al. (2017) have shown that nature-based solutions can reduce inequalities in cities by producing not only environmental but also social benefits. McPhearson et al. (2015) noted that urban ecosystems play a critical role through functions such as microclimate regulation and flood risk reduction. The social dimension of urban resilience is related to social cohesion, inclusivity, and the empowerment of vulnerable groups. In this context, Leichenko (2011) emphasized the concept of "social resilience" and drew attention to the resilience-enhancing effect of social ties in times of crisis. In addition, Anguelovski et al. (2016) noted that resilience planning can sometimes create new inequalities and that social justice must therefore be included in the conceptual framework. Infrastructure systems are seen as a decisive factor in the resilience of cities. In the discipline of urban planning, the role of nature-based solutions and multi-level governance structures in increasing resilience has come to the fore (Davoudi et al., 2012; Frantzeskaki, 2019). Bulkeley & Castán Broto (2012) emphasize the development of innovative approaches alongside experimental planning models in urban management. Recent studies have developed sub-concepts such as "transformative resilience," "just resilience," and "urban adaptability" (Kim & Lim, 2016). In addition, technologies such as artificial intelligence-supported decision-making systems and digital twins have begun to be integrated into urban resilience studies (Batty et al., 2021).

2. Material and Method

This study adopted a bibliometric analysis approach to reveal the scientific trends in the urban resilience literature. To this end, the Web of Science (WoS) Core Collection database was used. The literature review was conducted on June 4, 2025, using the keywords “urban resilience” OR “city resilience” OR “resilient cities” in the Topic field. This search strategy enabled a comprehensive search that included title, abstract, and keywords. The search yielded a total of 3.996 scientific records.

The search results were exported from the WoS platform as a plain text (.txt) file in “Full Record and Cited References” format. The obtained dataset was processed and analyzed using VOSviewer (version 1.6.20), one of the open-source bibliometric analysis software programs. VOSviewer is a frequently used tool for visualizing keyword co-occurrences, author collaborations, country-based productivity, and source journal relationships.

In the study, general terms (e.g., “article,” “study,” “model”) in the dataset were first filtered out through the VOSviewer interface, and only scientific keywords capable of establishing meaningful conceptual relationships were included in the study. The Author Keywords field was particularly emphasized. Co-occurrences between keywords were analyzed using VOSviewer software, and clustering was performed based on the frequency with which these keywords appeared together in the same studies. The distribution of keywords over the years was evaluated, thereby visualizing how the primary research themes in the urban resilience literature have evolved over time. The overlay visualization method in VOSviewer was used to identify emerging topics in more recent studies. The conceptual structures were visually analyzed through both network visualizations and density visualizations, and the thematic relationships between clusters were interpreted in detail. The clusters obtained were evaluated in terms of content; each cluster was interpreted according to the theme it represented in the literature (e.g., "climate adaptation," "infrastructure resilience," "participatory planning," "disaster management," etc.). In order to fully reflect the evolution in the literature, no starting year restriction was imposed in the study. All records from the earliest dates were included in the evaluation. Thanks to this methodological structure, not only the concepts frequently repeated in the literature but also the structural and thematic relationships between these concepts were revealed in detail.

3. Findings and Discussion

3.1. Publication Trends

The first publication on the subject was made in 2003, and publications have shown a marked increase since 2020, continuing to rise steadily since then. The citation pattern shows similar trends to the publication pattern, with the highest number of citations occurring in 2024. Figure 1 shows an increasing momentum in the number of publications in 2024. Considering that this study reflects data from the first half of 2025, it is anticipated that the increase will continue.

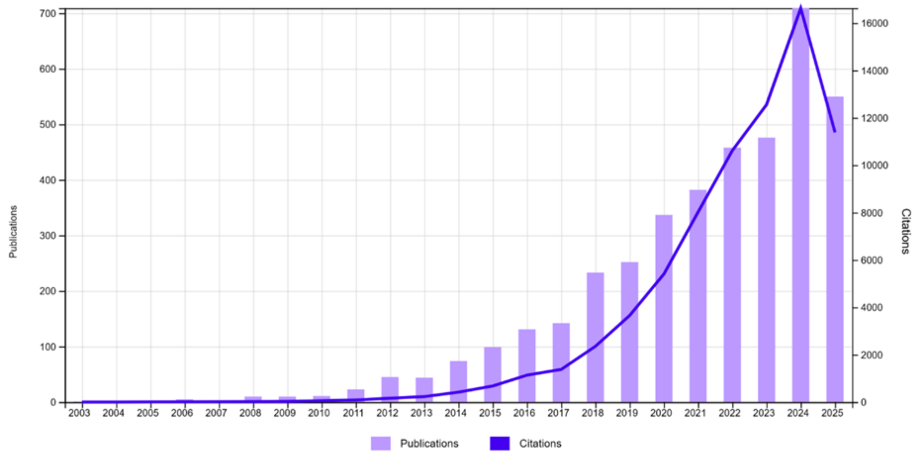

Figure 1. Number of publications and citations by year.

Of the publications covered by the study, 3.281 were articles, 293 were review articles, 288 were proceeding papers, 161 were book chapters, 98 were early access publications, 97 were editorial material, 39 were book reviews, and 8 were books (Figure 2).

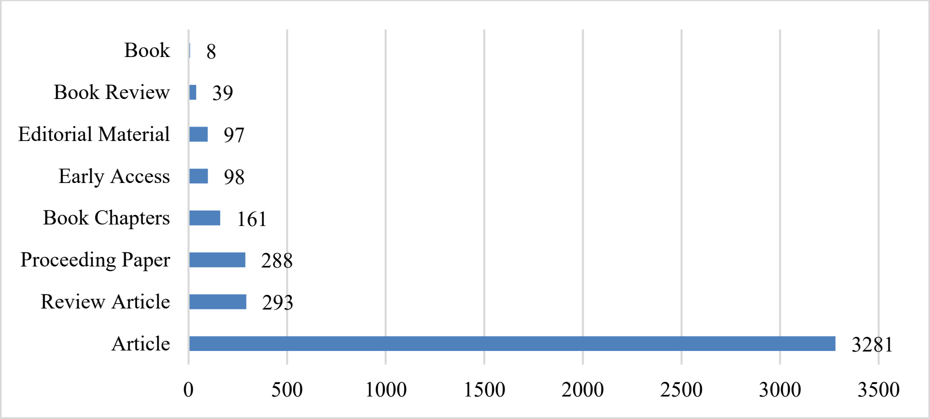

Figure 2. Number of publications by publication type

3.2. WOS Categories and Index

The distribution of publications on urban resilience according to Web of Science (WoS) categories clearly reveals the multifaceted nature of this interdisciplinary concept. The three categories with the highest number of publications are Environmental Sciences (n=1222), Environmental Studies (n=1062), and Green & Sustainable Science & Technology (n=805). This indicates that urban resilience studies primarily focus on environment-centric themes such as environmental sustainability, climate change, and nature-based solutions.

In contrast, categories such as Urban Studies (n=769) and Regional & Urban Planning (n=355) emphasize the importance of the concept in the context of spatial planning and urban transformation. Themes such as Meteorology Atmospheric Sciences (n=349) and Water Resources (n=343) indicate intersections with areas such as disaster risk, climate extremes, and water management. In addition, the significant number of engineering-based categories such as Engineering Civil (n=304) and Geosciences Multidisciplinary (n=291) indicates that structural resilience and physical infrastructure also play an important role in the studies (Figure 3).

Among the categories that contribute less in terms of numbers but are thematically meaningful are Public Environmental Occupational Health, Architecture, and Engineering Environmental. These data demonstrate the strong intersection of urban resilience research with diverse fields of knowledge, including environmental sciences, engineering, planning, public health, and architecture. Furthermore, they demonstrate a growing trend toward integration across these fields.

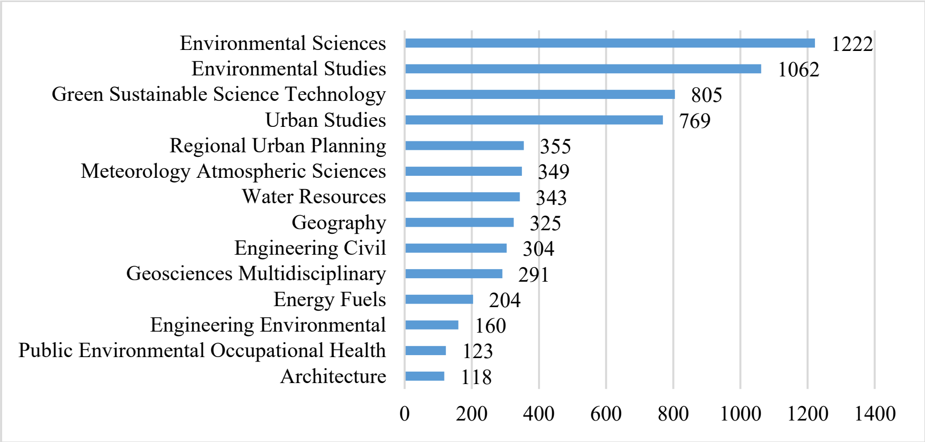

Figure 3. Distribution of publications according to Web of Science categories

While 1,982 studies were indexed in Science Citation Index Expanded (SCI-EXPANDED), 1,575 were indexed in Social Sciences Citation Index (SSCI) and 833 in Emerging Sources Citation Index (ESCI) (Figure 4).

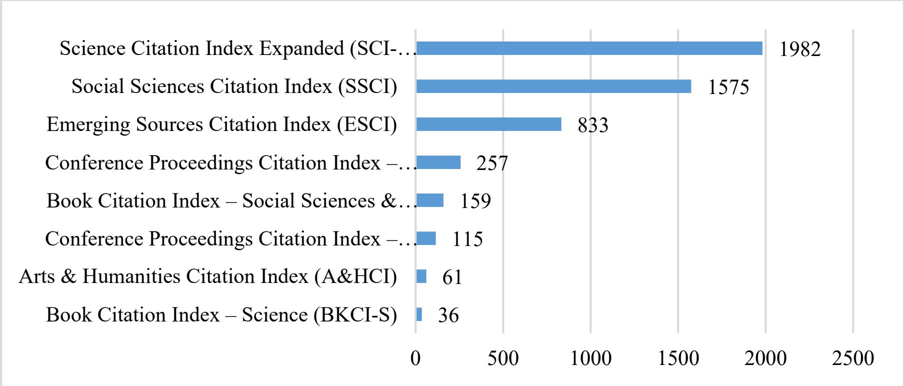

Figure 4. Number of publications according to Web of Science Index

3.3 Publications

The articles reviewed were published in 200 different journals. This shows that studies on "urban resilience" are multidisciplinary and appear on a wide scale. The top three journals that have contributed the most to the literature by publishing the highest number of studies on the subject are, in order, "Sustainability" (n=367, 9.177%), "Sustainable Cities and Society" (n=148, 3.701%), and "Cities" (n=132, 3.301%). These journals indicate that the literature on this topic revolves around sustainability and urban development. Furthermore, it appears that urban resilience research focuses on sustainability and that solutions are looked at the city level. A common feature of these journals is their openness to interdisciplinary articles and their support for policy frameworks that encompass both environmental and social governance.

Journals such as the International Journal of Disaster Risk Reduction (n=101) and Urban Climate (n=63) host studies particularly focused on disaster risk management and climate change adaptation. The prominence of journals such as Land (n=88), Water (n=47), and Journal of Cleaner Production (n=51) highlights the critical importance of resource management, land use, and environmental production processes within the framework of urban resilience (Figure 5).

Journals that address more technical or specific sub-themes include Urban Science, Natural Hazards, Journal of Environmental Management, and Buildings. The presence of journals such as Urban Forestry & Urban Greening, which focus on nature-based solutions, indicates that ecosystem-based approaches have found significant resonance in the literature. This table shows that research on urban resilience is not limited to risk reduction, but also considers cities as sustainable, green, flexible, and multi-layered systems. Since these journals are open to interdisciplinary content, urban resilience is addressed not only from an engineering perspective but also from social, environmental, and governance dimensions.

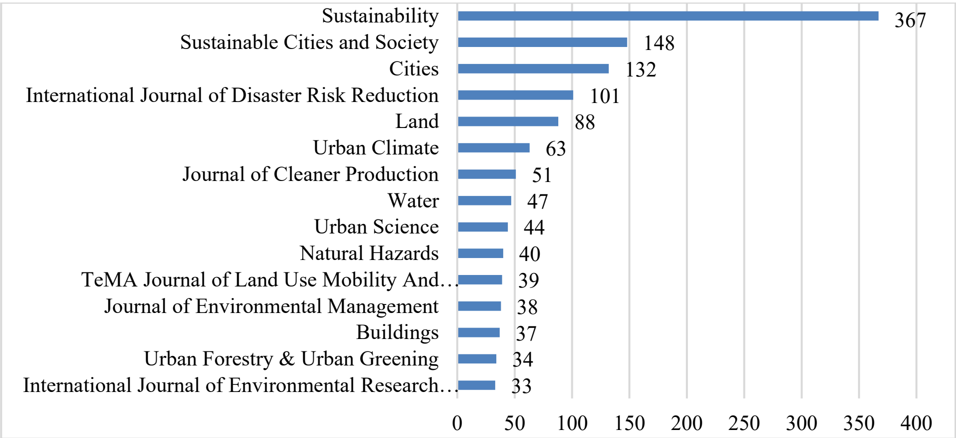

Figure 5. Number of publications by journal

3.4. Contributing Countries

China (n=955) and the US (n=610) are the leading countries in terms of publication volume in this field (Figure 6). China's high number of publications reveals intense academic interest in themes such as urban transformation, climate adaptation, and infrastructure resilience, driven by both urbanization pressures and central planning policies. The US's contribution, on the other hand, is notable for its multidisciplinary approach, applied planning models, and integration of social sciences. These two countries play a pioneering role in the evolution of the concept, both through their academic infrastructure and policy implementations. Countries such as Italy (n=378), the United Kingdom (n=337), Australia (n=252), Germany (n=221), and Spain (n=207) produce publications from an European perspective, particularly on climate change, sustainable urbanism, community participation, and governance. For example, the

United Kingdom and Germany contribute more in terms of political-economic and social justice dimensions, while Italy contributes through ecological planning and regional resilience. European literature has a publication trend that is community-based and conceptually rich. Countries such as Iran (n=123), India (n=100), and Brazil (n=106) contribute to applied, problem-oriented literature due to their increasing urbanization, fragile infrastructure systems, and climate-related disasters. Themes such as floods, droughts, and infrastructure disruptions are prominent in these countries.

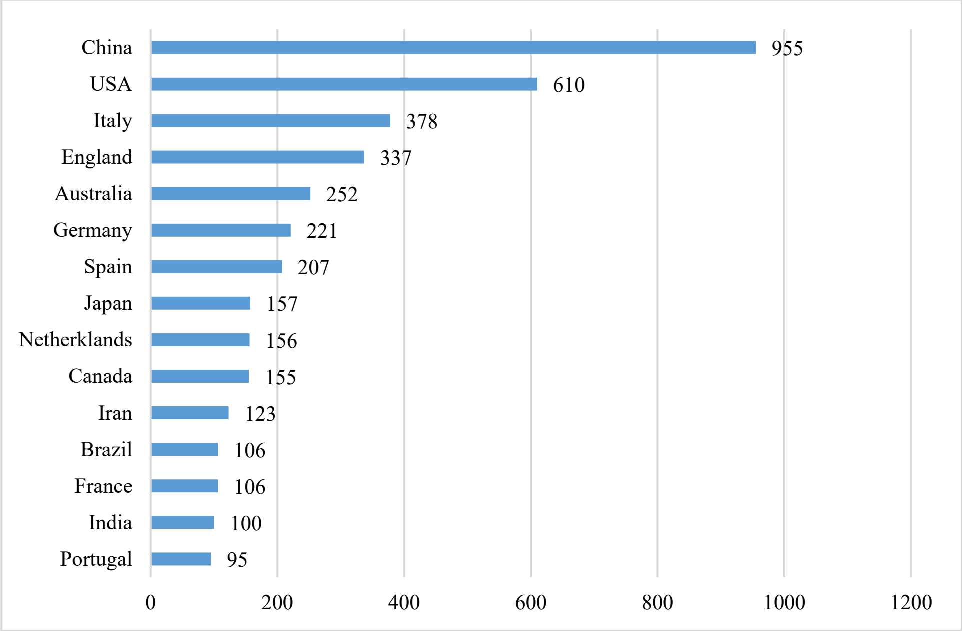

Figure 6. Number of publications by country

3.5. Contributing Authors

Sharifi, Ayyoob is the clear leader in this field with 59 publications (Figure 7). Sharifi's work focuses mainly on sustainability, urban planning, and urban resilience indicators. He has also developed numerous systematic literature reviews, conceptual models, and framework proposals. In second place is Serre, Damien (n=21), who focuses on urban infrastructure systems, flood risk, and systemic resilience. He can be seen as one of the pioneers in technically addressing urban resilience through infrastructure dependencies and chain reactions. Third is Coaffee, Jon (n=18), who establishes the intersection of the concept of resilience with critical urban studies and governance theories, reading resilience not only as a technical defense but also as a political and social position (Table 1).

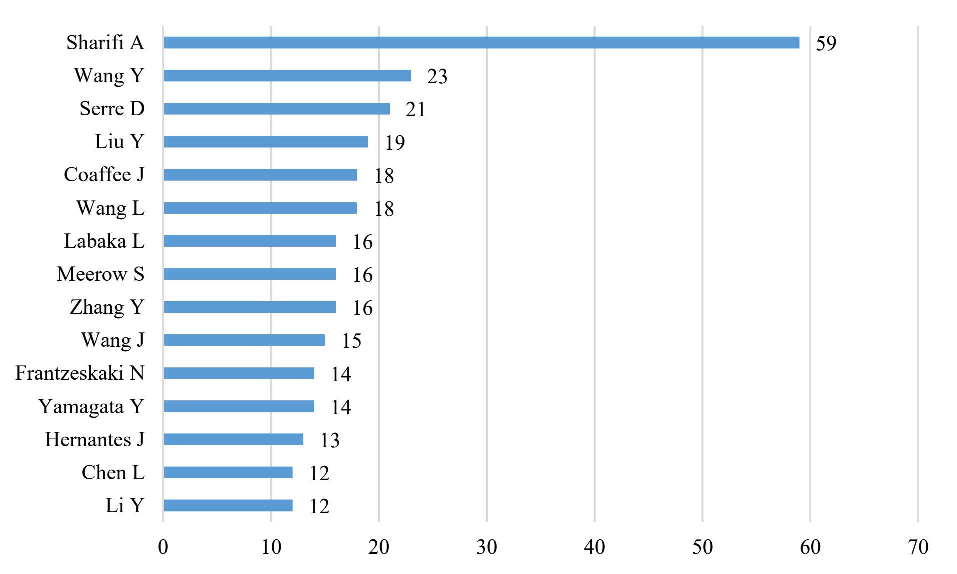

Figure 7. Number of publications by authors

Table 1. Authors' impact themes

Author	Number of Publications	Field of Impact	Thematic Focus
Sharifi, Ayyoob	59	Conceptual models / Decision support systems	Conceptual / Theoretical
Wang, Y.	23	Ecosystem services	Ecological / Nature-based
Serre, Damien	21	Critical infrastructure / Flood risk	Engineering

Liu, Y.	19	Urban planning / Climate resilience	Policy / Governance
Coaffee, Jon	18	Urban security / Terrorism	Security
Wang, L.	18	Disaster recovery / Community resilience	Social
Labaka, Leire	16	Organizational resilience / Critical infrastructure	Institutional
Meerow, Sara	16	Urban resilience conceptualization	Conceptual / Theoretical
Zhang, Y.	16	Climate adaptation planning	Environmental Planning
Wang, J.	15	Urban vulnerability / Climate risk	Environmental Risk
Frantzeskaki, Niki	14	Nature-based solutions	Ecological / Sustainability
Yamagata, Yoshiki	14	Urban energy systems / Smart cities	Urban Energy / Technology
Hernantes, Josune	13	ICT in disaster response	Digital / Infrastructure
Chen, L.	12	Disaster management	Hazards
Li, Y.	12	Urban resilience strategies	Urban Policy

3.6. Affiliations

The top three affiliations contributing the most publications in the field are the Chinese Academy of Science (n=67), the University of Naples Federico II (n=65), and Arizona State University (n=57) (Figure 8).

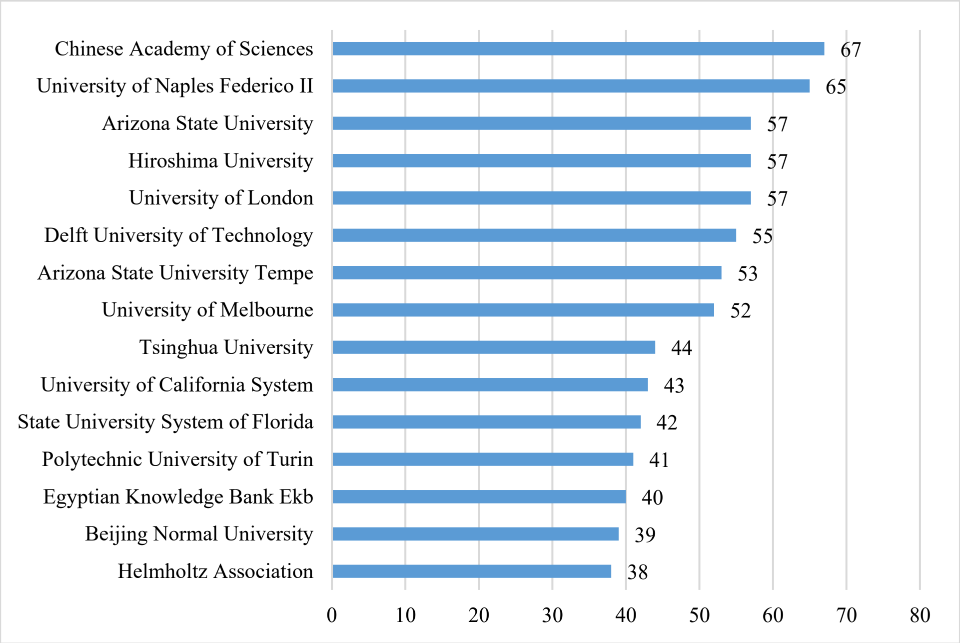

Figure 8. Number of publications by institution

3.7. Leading Documents

Within the scope of this study, the 15 academic publications with the most citations were identified in a search of the Web of Science database using the keywords "(urban resilience OR city resilience OR resilient cities)." The table below summarizes the bibliometric characteristics of each publication (author name, publication year, source journal, WoS citation count, etc.), along with the main topic of the study, its academic category, and prominent thematic emphases. This table aims to present, in a clear and comparative manner, how the concept of urban resilience is addressed in the literature, which disciplines it intersects with, and which aspects are emphasized.

In particular, the study titled "Defining Urban Resilience: A Review" by Meerow et al. (2016) stands out as a leading source in the literature, addressing urban resilience from an interdisciplinary perspective within a conceptual framework. Two other highly cited studies, written by Godschalk (2003) and Ahern (2011) and focusing on topics such as disaster risk reduction and systemic flexibility, are also noteworthy for their theoretical depth and impact on planning practice. Table 2 lists the 15 most cited articles.

Table 2. Most cited publications

Title	Authors/ Years	Journal/ Citations	Scope	Category	Themes
Defining urban resilience: A review	Meerow, S; Newell, JP; Stults, M 2016	Landscape and Urban Planning 1594	Comprehensive conceptual clarification of 'urban resilience' with interdisciplinary insights.	Theoretical Framework	Definition of urban resilience, interdisciplinary perspectives, conceptual ambiguity
Urban Hazard Mitigation: Creating Resilient Cities	Godschalk, DR 2003	Natural Hazards Review 899	Framework for hazard mitigation in urban planning for resilience.	Risk Mitigation	Urban hazard mitigation, resilient infrastructure, planning strategies
From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world	Ahern, J 2011	Landscape and Urban Planning 732	Transitioning planning paradigms from rigid systems to adaptive resilience.	Urban Sustainability	Safe-to-fail systems, adaptive capacity, planning under uncertainty
Sustainable-smart-resilient-low carbon-eco-knowledge cities	de Jong, M; Joss, S; Weijnen, M 2015	Journal of Cleaner Production 668	Analysis of overlapping urban concepts and their policy implications.	Urban Typologies	Conceptual proliferation, urban branding, sustainable urbanization
Sustainability and resilience for transformation in the urban century	Elmqvist, T; Andersson, E; Folke, C 2019	Nature Sustainability 644	Calls for integrated transformation of cities for global sustainability.	Transformative Urbanism	Sustainability transitions, resilience thinking, urban transformation
Climate change and	Leichenko, R 2011	Current Opinion in	Literature synthesis on	Climate Adaptation	Vulnerability, adaptation,

urban resilience		Environmental Sustainability 518	urban resilience within climate change discourse.		resilience framing
Benefits of restoring ecosystem services in urban areas	Elmqvist, T; Setälä, H; de Groot, R 2015	Current Opinion in Environmental Sustainability 514	Ecosystem services restoration for climate-resilient cities.	Urban Ecology	Green infrastructure, ecosystem services, urban biodiversity
Urban resilience for whom, what, when, where, and why?	Meerow, S; Newell, JP 2019	Urban Geography 500	Political critique of urban resilience focusing on justice and equity.	Critical Urbanism	Social justice, resilience politics, spatial and temporal scales
Urban flood impact assessment: A state-of-the-art review	Hammond, MJ; Chen, AS; Mark, O 2015	Urban Water Journal 485	Review of flood resilience metrics and modeling in urban areas.	Flood Resilience	Urban flooding, vulnerability assessment, modeling approaches
Resilient cities: meaning, models, and metaphor	Pickett, STA; Cadenasso, ML; Grove, JM 2004	Landscape and Urban Planning 474	Conceptual exploration of 'resilient city' as a metaphor.	Conceptual Metaphor	Resilience metaphors, socio-ecological systems, disciplinary integration
Planning the resilient city	Jabareen, Y 2013	Cities 470	Proposes a conceptual model for urban resilience planning.	Planning Theory	Resilience dimensions, planning strategies, systemic risk
Seven lessons for planning nature-based solutions in cities	Frantzeskaki, N 2019	Environmental Science & Policy 429	Insights from European cities on implementing nature-based solutions.	Nature-based Solutions	Implementation challenges, co-benefits, institutional learning
Urban landscape sustainability and resilience	Ahern, J 2013	Landscape Ecology 422	Integrating ecology in urban planning for resilience.	Landscape Ecology	Transdisciplinary planning, ecological design, green infrastructure
How is COVID-19 reshaping activity-travel behavior?	Shamshiripour, A; Rahimi, E; Mohammadian, A 2020	Transportation Research Interdisciplinary Perspectives 396	Empirical study on mobility shifts under pandemic-induced disruption.	Mobility & Behavior	Pandemic impact, travel behavior, resilience to disruption
Urban resilience: A conceptual framework	Ribeiro, PJG; Gonçalves, LAPJ 2019	Sustainable Cities and Society 394	Proposes a structured framework to define and assess urban resilience.	Framework Development	Indicator-based assessment, urban systems, conceptual clarity

According to the contents of the 15 high-impact publications listed in the table, the concept of urban resilience has been addressed primarily within a multidisciplinary framework. The literature has not only associated this concept with the resilience of physical infrastructure. It has also been closely linked to various fields, including social inequalities, ecological sustainability, public policy, climate change adaptation, disaster risk reduction, and planning theories. This situation demonstrates that the concept of "urban resilience" has evolved beyond being merely a technical planning term to become an inclusive paradigm encompassing socio-ecological systems, politics, community participation, and knowledge production.

3.8. Keyword Co-occurrence Analysis: Thematic Cluster Interpretations

As a result of the analysis conducted with a minimum occurrence count of 5 for the most frequently used keywords, it was observed that 456 keywords grouped into 16 clusters formed 5,545 connections (Figure 9). According to the Overlay Visualization analysis, a significant paradigm shift has been observed in the field of study in recent years. While studies conducted up to 2019 focused more on fundamental theoretical concepts such as "urban planning," "resilience," and "governance," the literature after 2020 has shifted to the application dimension of concepts such as "urban resilience" and "green infrastructure." Recently, data-driven and technological approaches such as "remote sensing," "machine learning," and "resilience evaluation" have come to the fore, indicating that the discipline is undergoing a digital transformation process. These findings suggest that the research agenda is trending toward integration with the climate crisis and disaster management.

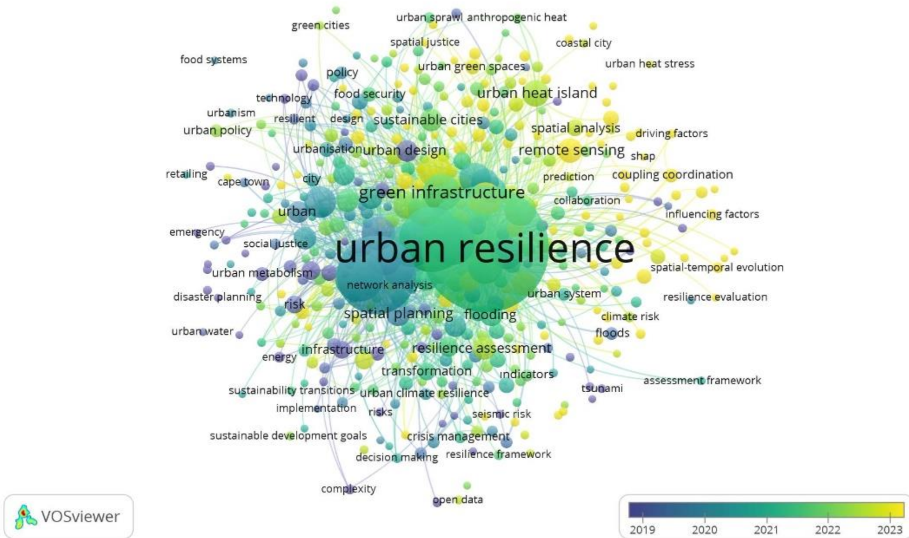

Figure 9. Keyword links

The first cluster represents a combination of literature examining the relationship between urban heat effects, climate change adaptation strategies, and environmental health risks. Terms such as “urban heat island,” “anthropogenic heat,” and “land surface temperature” emphasize the heat accumulation caused by dense urbanization and human activities, while expressions such as “adaptation strategies,” “green roofs,” and “cooling effect” point to solutions aimed at mitigating these effects. Additionally, the joint consideration of environmental and physiological risk factors such as “air pollution” and “heat stress” demonstrates that urban resilience is examined from both a health-based and spatial adaptability perspective in a multidimensional manner. Therefore, this cluster highlights the importance of both spatial planning and environmental management in making cities resilient to the climate crisis. The second cluster highlights the increasing role of digital technologies and modeling approaches in making cities more flexible and predictable in the face of climate risks. Terms such as “agent-based model,” “machine learning,” and “artificial intelligence” reflect the methods used in simulating urban systems and modeling their behavioral dynamics, while expressions such as “decision support system,” “climate risk,” and “resilience evaluation” show how these methods are integrated into policy-making and planning in practice. In particular, the presence of the concepts of “geospatial analysis” and “driving factors” emphasizes that decision support processes are based not only on data but also on spatial context. This cluster represents how the link between technological capacity and data-driven planning approaches and urban resilience is established in the current literature.

The third cluster centers on the interaction between governance mechanisms developed at the urban level in response to climate change and principles of social justice. The concept of “climate justice” draws attention to the unequal effects of environmental threats on different segments of society, while terms such as “adaptive governance,” “collaborative governance,” and “transformation” emphasize the importance of flexible and inclusive policies in managing these inequalities. At the same time, the emergence of risk factors such as “uncertainty” and “drought” indicates that decision-making processes must be based not only on existing data but also on the management of uncertainties. This cluster represents a literature trend aimed at rebuilding urban resilience not only at the physical or technological level but also at the social and administrative levels.

The fourth cluster focuses on social vulnerability, social capital, and community-based resilience. In this context, it is emphasized that resilience to disasters is built not only through physical infrastructure but also through social interaction, trust relationships, and participation mechanisms. Participatory planning processes, collective learning, and the strengthening of social bonds highlight the social dimension of resilience. The fifth cluster covers urban mobility, accessibility, and pedestrian-oriented transportation. Shaped by the 15-minute city, compact city, and public transportation systems, this cluster addresses the restructuring of physical transportation as the cornerstone of sustainable urban planning. The sixth cluster is structured around green infrastructure, ecosystem services, and nature-based solutions. The protection of urban ecology, the preservation of biodiversity, and environmental integrity form the core focus of this cluster. The seventh cluster focuses on disaster risk reduction, hazard assessment, and urban resilience strategies. In this context, risk perception, resilient infrastructure, and climate adaptation planning are prominent. The eighth cluster covers energy efficiency, green building practices, and carbon emission reduction. Building performance, environmental sustainability, and renovation strategies are the main approaches in this area. The ninth cluster includes topics such as urban water management, flood risk reduction, and water-sensitive urban design. Blue infrastructure, flood modeling, and resilient water systems are the focal points of this cluster. The tenth cluster examines the effects of rapid urbanization processes on land use and spatial transformations. Urban sprawl, transformation scenarios, and adaptation planning are analyzed within this cluster. The eleventh cluster focuses on processes such as social learning, knowledge co-production, and participatory governance. These concepts highlight the social and cultural dimensions of urban resilience. The twelfth cluster examines the creation of resilient cities in the context of the United Nations Sustainable Development Goals. Integrated planning and policy alignment, particularly Goal 11, are addressed within this framework. The thirteenth cluster encompasses approaches based on urban nature, biodiversity, and ecological restoration. Nature-friendly urban design and habitat conservation are at the heart of this cluster. The fourteenth cluster assesses resilience building through local government institutional capacities, policy integration, and planning tools. The fifteenth cluster covers smart city technologies, real-time monitoring, and data-driven planning tools. This cluster is important in the context of monitoring vulnerabilities and rapid response capacities. The sixteenth cluster deals with the intersection of climate finance, sustainable economic tools, and public-private partnerships with resilience policies.

3.9. Co-authorship of Authors Analysis

Co-authorship analysis is particularly important for understanding the structure of academic collaborations and leading researcher clusters. The analysis was conducted based on the criterion that each author had at least three publications, and it was found that 137 authors, grouped into 18 clusters, had a total of 546 connections and 324 links (Figure 10). The most productive co-authors were Ayyoob Sharifi (n=59), Sara Meerow (N016), Jon Coaffee (n=15), Leire Labaka (n=14), and Niki Frantzeskaki (n=14).

According to the co-authorship network, Ayyoob Sharifi is at the center of the network in terms of both the number of publications and the number of connections, collaborating with a large number of different clusters and demonstrating a global interdisciplinary research profile. While authors such as Frantzeskaki and McPhearson specialize in nature-based solutions and urban transition themes, Asian-based researchers such as Yamagata and Wang focus particularly on sustainability, energy efficiency, and technological urbanization. The clustering seen in the map shows that, despite intensive interdisciplinary collaboration, certain thematic groups still remain largely within their own networks. When evaluated in terms of time scale, it can be seen that Asia-centered collaborations have increased in recent years and that these groups have strengthened their position in the scientific literature.

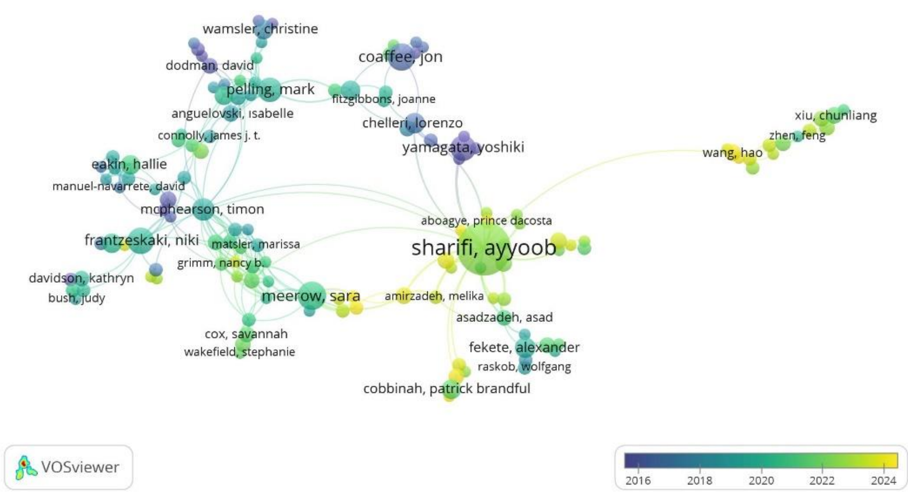

Figure 10. Co-authorship links

3.10. Citation of Authors Analysis

This author citation analysis map visualizes authors who are frequently cited together in the research field. Each point represents an author, and the size of the points represents the frequency of citations. The lines between the points show the frequency with which authors appear together in the same bibliography (co-citation strength). Based on the criterion that each author must have at least 3 publications and 3 citations, the map shows that 531 authors, grouped into 29 clusters, have formed 6380 connections (Figure 11). Sharifi, Ayyoob, who stands out in the map, is positioned as a central figure in the field with strong connection density and large node size. Authors such as Frantzeskaki, Niki, Meerow, Sara, Pelling, Mark, and Labaka, Leire, who surround him, are also other important names that are highly co-cited in the literature and can therefore be evaluated within a common paradigm or thematic context. The color distribution on the map reflects the distribution of cited works by year, showing that authors such as Sharifi had a concentrated influence prior to 2018, while authors such as Wang, Yifei, Cavan, and Gina have come to the fore in more recent works. This analysis contributes to mapping the intellectual structure of the field while also providing important insights into the key reference authors and emerging research clusters that the knowledge base focuses on.

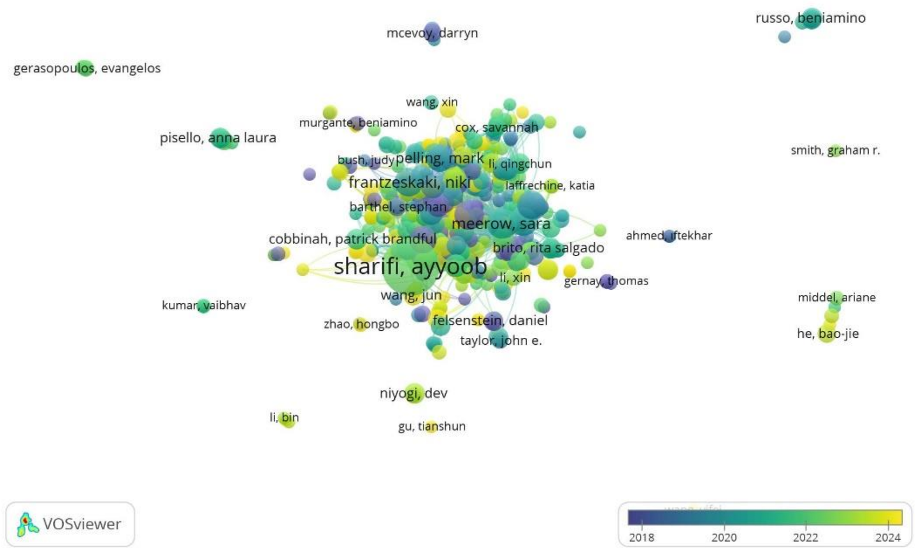

Figure 11. Author-citation connections

3.11. Bibliographic Coupling of Authors Analysis

This bibliographic connection map reveals the intellectual proximity in the literature by visualizing the extent to which documents are connected to each other through common references (Figure 12). According to the analysis, studies such as Meerow (2016), de Jong (2015), Elmqvist (2019), and Frantzeskaki (2019) stand out as the cornerstones of the field in terms of both size and connection density. These documents share similar sources that are frequently cited in the literature and, in this respect, shape the fundamental theoretical background of the field. The color spectrum reflects the years of publication: purple documents are from 2016 and earlier, while those transitioning to yellow are more recent publications. In this context, it can be seen that recent publications such as Liu (2022), Hong (2021), and Ntounis (2022) build on this intellectual heritage by establishing strong links with the existing literature. Overall, the analysis demonstrates the temporal and structural positioning of key documents in the field, clearly revealing the direction of information flow and which studies have played a central role.

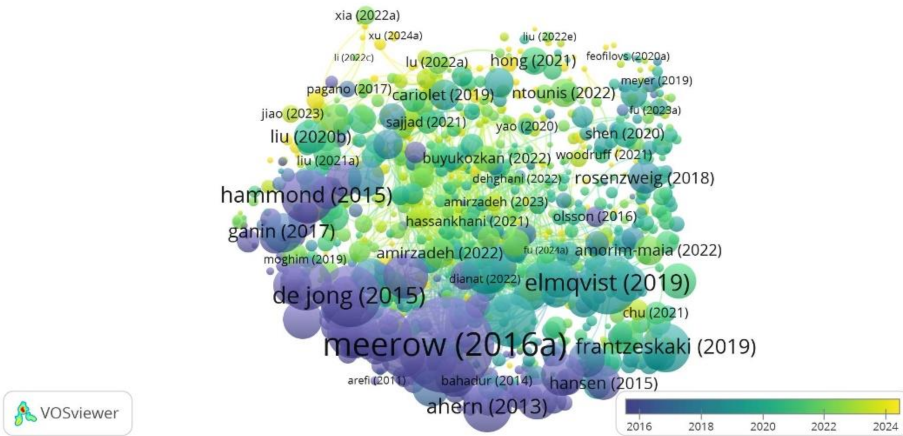

Figure 12. Bibliographic coupling of authors

4. Conclusion and Suggestions

This study presents a comprehensive bibliometric analysis aimed at mapping the structural and thematic landscape of the urban resilience literature. The analysis of the 3.996 publications obtained from the Web of Science database through keyword co-occurrences, author collaborations, country contributions, and citation patterns has made it possible to reveal the multidimensional nature of the subject. The data obtained demonstrate which concepts dominate the literature. It also demonstrates how these concepts are grouped, how they have evolved over time, and how collaborative networks have been established among academics.

The general concept of the article reveals that the concept of urban resilience is not merely a technical planning tool; it is also strongly intertwined with areas such as social equality, governance, digitalization, and ecological sustainability. In particular, the emergence of key concepts such as "green infrastructure," "climate justice," "machine learning," and "adaptive governance" in distinct clusters shows that urban resilience is currently being addressed within both a normative and technological conceptual framework.

Thematic clusters in the literature clearly reveal the contributions of different disciplines; however, it is also evident that knowledge production is highly concentrated in some areas, while research gaps remain in others. For example, while there are strong accumulations in areas such as disaster risk management, nature-based solutions, and green infrastructure, the literature is still in its infancy in newly emerging areas such as energy justice, climate finance, and data-driven governance. This situation indicates that urban resilience studies will diversify and develop further in the coming period.

The concept of urban resilience first appeared in the literature in the early 2000s, particularly in the context of disaster management and infrastructure planning. Studies conducted during this period focused largely on reducing the fragility of physical and structural systems (e.g., transportation, energy, and water infrastructure). Early studies, such as those by Godschalk (2003) and Cutter et al. (2008), discussed how cities could be made safer against natural disasters and proposed "safe-to-fail" systems instead of "fail-safe" ones. During these years, urban resilience was primarily addressed as a reactive and protective planning strategy.

Starting in the 2010s, the concept began to be addressed in a more holistic and systemic manner, with themes such as ecological resilience, social vulnerability, and governance coming to the forefront. Authors such as

Meerow, Newell, and Stults (2016) have highlighted the diversity in definitions of resilience, arguing that the concept requires a multidisciplinary analytical framework. In this context, topics such as nature-based solutions (green infrastructure), adaptive governance, participatory planning, social inequalities, and climate justice have been integrated into the urban resilience literature. With the pandemic period (post-2020), new areas such as the fragility of health systems, digital infrastructure, and food supply chains have also been included in the urban resilience context. Today, urban resilience studies cover a wide range of topics, including climate change adaptation, social participation, digital transformation, and data-driven decision support systems.

Bibliometric analysis findings indicate that the urban resilience literature will increasingly focus on digitalization, data science, and artificial intelligence-based approaches in the near future. The rise of keywords such as “machine learning,” “remote sensing,” “geospatial analytics,” and “resilience evaluation” indicates that automated decision systems, scenario modeling, and smart city technologies will play a more central role in this field. Furthermore, terms such as “climate finance,” “public-private partnerships,” and “resilient investment planning” indicate that urban resilience strategies will be supported not only by technical but also by economic and political tools.

However, conceptual debates are also expected to deepen in the future. Critical urban studies and justice-based planning approaches are likely to come to the fore around normative questions such as “Resilience for whom?” and “Against which risks?” At the same time, closer links with areas such as global climate injustice, energy transitions, and environmental dispossession are expected.

Bibliometric analysis findings indicate that the urban resilience literature will increasingly focus on digitalization, data science, and artificial intelligence-based approaches in the near future. The rise of keywords such as "machine learning," "remote sensing," "geospatial analytics," and "resilience evaluation" indicates that automated decision systems, scenario modeling, and smart city technologies will play a more central role in this field. Additionally, terms such as "climate finance," "public-private partnerships," and "resilient investment planning" indicate that urban resilience strategies will be supported not only by technical but also by economic and political tools.

The findings show that the concept of urban resilience has moved beyond a disaster-focused technical approach and has become a broad research axis intersecting with multidimensional areas such as social justice, governance, climate adaptation, and digital transformation. Thematic clusters clearly reveal the centers of intensity and research gaps in the literature, while temporal analyses show that the field is increasingly moving toward data-driven and integrated approaches.

The study not only makes the existing knowledge architecture visible but also offers strategic directions for future academic production, proposing a guiding framework for urban resilience research. In this respect, the study is a valuable resource for researchers, planners, and policymakers.

Among the limitations of the study are its focus solely on the WoS database and the absence of open-access publications in some datasets.

Future studies could conduct a broader analysis by including alternative databases such as Scopus, Google Scholar, etc.

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The article complies with national and international research and publication ethics.

Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article.

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Documentation and Examination of the Conservation Problems of Rural Architectural Heritage: Yozgat Topçu Village

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1. Introduction

Rural architecture, which holds a significant place among cultural assets worthy of preservation, is highly important in terms of reflecting the authentic fabric of a settlement. Analyzing rural settlements through their residential structures provides valuable insights into the region's traditional architecture, way of life, and cultural characteristics. However, it is possible to state that architectural examples belonging to rural settlements—important representations of cultural heritage—as well as values reflecting daily life, beliefs, and traditions, are entering a process of disappearance without being documented.

Since the second half of the 20th century, increased mechanization, the shift of populations dependent on agriculture into other sectors, and the growing demands for improved health services, infrastructure, education, and comfort have led to demographic changes in rural areas, even resulting in significant population decline.

Although inventory and documentation efforts related to rural architecture in recent years are promising, they have not been sufficient to prevent the deterioration of the architectural fabric of settlements. The negative state of preservation in rural settlements and the lack of control over new constructions are causing many rural areas in Anatolia to suffer increasing damage day by day.

In this study, Topçu Village—located in the central district of Yozgat Province—has been selected as the study area. The primary aim is to identify architectural elements worthy of preservation that reflect the rural architectural characteristics of the Central Anatolia Region. The existing fabric and conservation issues of the settlement, which does not possess any protected area or registered heritage status, have been identified, and suggestions have been developed accordingly.

Through on-site investigations in Topçu Village, the current map of the settlement has been updated, and analyses of the building stock under specific categories have been conducted. In addition, plan schemes have been prepared for accessible residential buildings that display rural characteristics, in an attempt to reveal the typological features of the settlement. The analyses and plan schemes prepared to reveal the unique values of the settlement also aim to establish the originality of the study itself.

Thus, the study aims to highlight the importance of Topçu Village's rural architectural features that are worthy of preservation, to provide a basis for potential conservation practices, and to take a pioneering step toward protection by documenting structures that are at risk of disappearing.

1.1. Rural Architectural Heritage and Its Conservation

According to the definition in the Encyclopedia of Architecture, rural architecture includes all houses and other buildings constructed by the people themselves. Also referred to by various terms such as vernacular architecture, anonymous architecture, architecture without architects, or folk architecture, rural architecture refers to construction that reflects local and regional characteristics (Dırık, 2025; Rudofsky, 1964; Hasol, 1979; Bektaş, 2002). This form of production, which reflects the cultural features of a settlement, is widely found across Anatolia in various systems and characteristics.

Rural architecture, with building types that vary according to region, is shaped by numerous components such as the use of open and closed spaces, topography, climate, spatial organization, façade character, traditional lifestyles and production methods, beliefs, and geographic location. These components not only influence the design of functionally diverse rural structures but also affect the formation of auxiliary units attached to residential buildings (Dırık, 2025; ÇEKÜL, 2012). In rural architecture, where functionality is prioritized over aesthetics, it is possible to consider these buildings as significant examples of architecture where the architecture itself precedes the architect, and where the users' connection and respect for nature and their environment is clearly evident (Yıldız, 2019).

When examining rural settlements in Anatolia, it is observed that the settlements were planned with a central square in mind, around which commercial, religious, and public bath buildings were located, and with access routes extending from the square to the residential structures. The layout of the houses was decided based on the area's topographic features, climate, environmental conditions, and cost—determining, for example, whether buildings would be constructed in attached or detached styles, and which direction transportation axes would follow (Kucak Toprak, 2020; Muşkara, 2017).

One of the fundamental features of rural architecture is the use of natural building materials sourced from nearby areas, which significantly contributes to ecological and sustainable construction. Rural architecture is typically produced by local craftsmen without the involvement of architects, and the exact builders of many of these examples are generally unknown (Genç, 2019; ÇEKÜL, 2012; Rudofsky, 1964; Bektaş, 2001; Kucak Toprak, 2020).

Rural architecture must be evaluated not only in terms of individual buildings but also with regard to the use of open spaces, shared social spaces, streets, and the relationships among the structures. Accordingly, rural settlements should be considered as a whole—together with the qualities of their buildings, settlement features, and socio-cultural fabric (Genç, 2019).

Anatolia is the region where traditional rural architectural culture is richest in Turkey; however, in large cities that are constantly developing and transforming due to various factors, the conservation of rural architectural heritage is becoming increasingly difficult over time (Muşkara, 2017). Issues surrounding rural architecture and its conservation are interconnected with the broader multidimensional problems affecting rural areas. The rural population and rural architecture are directly influenced by the transformations brought about by globalization. These issues are not unique to Turkey but are also observed in many developed countries today (ÇEKÜL, 2012; Muşkara, 2017).

Rural settlements, which have traditionally been shaped in harmony with their geography, now face many conservation challenges due to ever-changing and diversifying needs (Aktaş, 2019). These problems can be both social and economic in nature, and they can significantly harm the architectural fabric of the settlements. Due to reasons such as lack of employment opportunities, inadequate social amenities, unmet technological needs, and a decline in agricultural and livestock activities, rural-to-urban migration is widespread. As residents move to urban areas, unused houses begin to deteriorate and, over time, this process accelerates, leading to their complete disappearance (Eres, 2016; Tunca & Akyüz Levi, 2020).

Preventing the deterioration of rural settlements is crucial for keeping cultural values alive, making it essential to develop solutions to the conservation problems faced in these areas (Aktürk, 2021; Naycı, 2012).

2. Material and Method

The selected subject of this study, Topçu Village in Yozgat, is a rural settlement affiliated with the central district (Figure 1). As an exemplary case in the context of rural architectural heritage conservation, the village reflects the typical characteristics of rural settlements through its settlement decisions, construction system, material use, spatial organization, and façade character.

The content of this study has been shaped within the scope of the Rural Design Guide prepared for the course MİMYL 526.1 – Rural Architectural Heritage and Conservation Problems, part of the graduate curriculum of the Institute of Graduate Studies at Yozgat Bozok University during the Spring Term of 2024–2025.

Within the course framework, various tasks were carried out to identify the current structure of the settlement. These included updating the existing base map, conducting several analyses (such as solid-void relations, function, construction system, building materials, number of floors, roof type and covering material, usage status, damage assessment, heritage value status, and conservation suggestions), identifying physical and social changes, and determining the necessary boundaries for physical and social interventions in the settlement's development process.

The work prepared for the course was intended to be shared on a broader platform in order to raise awareness, document the settlement, and provide conservation proposals. The study covers the entirety of Topçu Village. Accordingly, data were collected from all buildings that were accessible during the analysis and documentation phases.

As for the methodology, it involves obtaining data through a literature review on the settlement and conducting on-site investigations. A current version of the base map obtained from Yozgat Municipality was updated during fieldwork, and the analysis data were overlaid onto this updated map. Schematics were created and presented to determine the plan typologies of residential units and their plot layout decisions. Additionally, spatial changes experienced by residential units over time were added to the plan diagrams and documented accordingly.

These transformations were evaluated within the scope of conservation issues, and suggestions were developed based on the findings.

3. Rural Architectural Heritage of Topçu Village

In order to identify the rural architectural fabric and characteristics of Topçu Village, both field surveys and a literature review were conducted. Although sufficient information about the historical background of the settlement itself could not be obtained, data related to the city center were used as supportive references.

As part of the on-site studies conducted in the village, the current settlement layout and its relationship with the natural environment were examined. Public common areas, functions (such as residential buildings, auxiliary structures, places of worship, education, and commerce, as well as open spaces like fields and threshing areas), construction systems, usage status of buildings, building materials, roof typologies and materials, building damage, conservation status, the relationship of buildings to roads, and the hierarchical structure of roads were all identified and recorded on updated base maps.

To determine the residential plan schemes of the settlement, floor plans were drawn for accessible residential buildings, and their spatial organization was analyzed. Auxiliary structures located on the same plots as the residences were also added to the plan diagrams, revealing the functional and spatial characteristics of rural land use.

3.1. The Fabric and History of Topçu Village

Anatolia, which has hosted many different civilizations, has a deep-rooted history. The city of Yozgat is also a settlement with a rich heritage, with remains and artifacts found in regions such as Alişar, Alacahöyük, Kerkenes, Çengeltepe, and Tavium/Atvium, dating back to approximately 3000 BCE. The Turks began settling in this region following the Battle of Malazgirt in 1071. This settlement, which started during the Seljuk period, continued through the Beyliks period and the Ottoman period, evolving into its present-day form (https://islamansiklopedisi.org.tr/yozgat).

Topçu Village is located on the Yozgat-Boğazlıyan road (Atatürk Road) and is affiliated with the central district of Yozgat Province. According to a local story, the village was named Topçu (meaning "artilleryman") because soldiers sent to war during the Turkish War of Independence were assigned to artillery units (Erdogan Budak, 2021).

Topçu Village is situated 17 km from the city center and is part of the central district. It lies along the Kayseri road, very close to the highway. A water channel that divides the settlement into two parts running northeast to southwest is located at the lower elevation between slopes rising to the northwest and southeast. Research indicates that this channel was built to prevent floods and potential damage caused by heavy rainfall (Erdogan Budak, 2021). The village settlement is located on the slope in a manner that aligns with the topography, considering the direction of the slope, the view, and the relationship between streets and buildings.

In Topçu Village, the economy was traditionally based on agriculture and animal husbandry during both summer and winter seasons when villagers lived in the village year-round. Over time, the younger population became less interested in farming and livestock, leading to migration from the village to the city. As the population decreased and due to the village's proximity to the city center, the local health clinic and its lodging, as well as the primary school building, have lost their functions and are no longer in use. Due to migration, animal husbandry has nearly disappeared. Those villagers who remain in the village mainly during the summer, who engage in agriculture (such as chickpeas and wheat), do so not for economic gain but for their own consumption.

In the center of Topçu Village, there is the Topçu Mosque (Figure 2) and the village hall.

Figure 1. Village Settlement Plan

Figure 2. Topçu Mosque

The climate of Topçu Village generally resembles that of Yozgat, with cold and harsh winters and hot, dry summers. The village's location between two hills protects it from Yozgat's colder climate and positively influences agricultural activities. During the summer, especially around holiday periods such as religious festivals, the village population increases. Vehicle access to the village is via Atatürk Road. The main road is asphalted, while the internal village roads are mostly stabilized earth roads, with paved roads using interlocking stone blocks in front of commercial units. All buildings within the village, including houses, coops, barns, wood storage areas, and tandır ovens, constitute the rural architectural heritage of Topçu Village.

When examining the local residential buildings, adobe (mudbrick) was commonly used as the construction material due to its easy availability and insulating properties. Roof materials consist mainly of tiles, with roof types such as gable and hipped roofs preferred due to the climate. The preferred construction method was the load-bearing (masonry) system.

Over time, as settlement progressed, reinforced concrete construction systems have gradually replaced adobe load-bearing structures. The deterioration of existing adobe buildings, lack of preservation efforts, and alterations made to structures—along with the addition of new buildings that do not conform to the existing fabric—pose significant obstacles to the conservation of the rural architectural heritage.

3.2. Current Status Assessment Studies of Topçu Village

3.2.1. Building Usage Status

The village settlement is located southwest of the Yozgat-Kayseri highway. A water channel divides the settlement into two parts, and access across the channel is provided by bridges where the roads intersect the channel (Figures 3 and 5). All buildings within the settlement have gardens of various sizes. The placement of buildings on their parcels is either facing the street or positioned freely within the garden. There are also examples of contiguous (attached) buildings facing the street (Figure 4).

Outside of the building parcels, there are public open spaces equipped with urban furniture that allows for communal use. Among these, three neighborhood fountains located in different parts of the settlement are actively used (Figure 5). Due to the sloping terrain of the village, the main access routes run parallel to the slope. Streets perpendicular to the slope are quite short and have a suitable gradient for use. The streets vary in width, and on the wider streets, there are seating and resting areas intended for communal use.

The village economy is based on agriculture and animal husbandry, and farmland and dairies form the boundaries of the settlement. A cemetery is located on the southeastern edge of the settlement, and there are also areas identified as threshing floors (Figure 3).

Figure 3. Built-Vacant Analysis Map

Figure 4. Examples of Residential Buildings

Figure 5. Water Channel and Fountain Examples

3.2.2. Building Function Types

The vast majority of the buildings in the settlement consist of residential houses, but there are also various other functions suitable for a rural settlement. Within the residential parcels, there are auxiliary units such as barns, tandır ovens, storage rooms, toilets, chicken coops, and wood sheds, while some commercial, religious, and public function buildings are still in use (Figure 6). Currently, the village's primary school, health clinic, housing units, and cooperative buildings are out of use and in a state of disrepair. The village's close proximity to the city center allows some of these functions to be served by facilities in the urban center, resulting in these buildings becoming functionally obsolete.

The only mosque in the village, Topçu Mosque, is located in the center of the settlement and is actively used. The mosque includes a courtyard with a şadırvan (ablution fountain) and a lodging building. It has two minarets. The first minaret, built during the mosque's initial construction, was made of adobe in a masonry style, while the second minaret was added later during a repair process and constructed with cut stone.

Figure 6. Function Analysis Map

3.2.3. Building Material Types

There are variations in the types of materials used in the building stock of Topçu Village. The use of local materials in rural settlements is also true for Topçu Village. Adobe is the most commonly used material in the construction of buildings in Anatolian rural settlements. Adobe is preferred due to its ease of production, easy accessibility, and its contribution to thermal insulation. To protect the adobe material from ground moisture, the buildings are constructed with stone masonry up to the plinth level. There are also a few examples in the settlement where the entire building is made of stone masonry (Figures 9 and 10). Additionally, stone and wood materials are used in construction. Wood is utilized in elements such as lintels, door and window frames, flooring, ceilings, and railings, while stone is used for constructing garden walls outside the buildings (Figures 7 and 8).

Figure 7. Building Material Type Analysis Map

Figure 8. Examples of Building Materials

Figure 9. Construction System Analysis Map

Figure 10. Examples of Construction Systems

During on-site studies, it was observed that some of the adobe (kerpiç) masonry buildings that are still in use have undergone modifications using modern materials. Due to the challenges of adobe requiring regular maintenance each year, concrete plaster has been applied as a protective measure for these structures. Additionally, it was noted that recently constructed buildings in the settlement use different materials. Besides reinforced concrete structures, there are also many masonry buildings built with more modern materials such as breeze blocks (briket) and bricks. These newer buildings, aimed at improving comfort conditions, have floor plans designed in accordance with the traditional settlement's layout.

3.2.4. Building Number of Floors Analysis and Roof Characteristics

Buildings in the settlement are generally shaped as one- or two-story structures. Contrary to this, there is one three-story building (Figure 11). Considering the slope of the land and the relationship between buildings, the number of floors has been kept low. This allows the buildings to receive natural light and air, while also preventing obstruction of each other's views. The ground floor walls are designed as high walls with few openings, serving both functional and privacy purposes. In houses, the ground floor is used for service areas, while the upper floors are allocated for living spaces. Access to the garden and the ground floor is provided from the street through garden gates. Access to the auxiliary units located within the garden is also provided from inside the garden.

Figure 11. Number of Floors Analysis Map

The village's location in a harsh climate plays a decisive role in the shape and roofing material choices of the buildings' roofs. Accordingly, in the settlement, hipped (kırma) or gable (beşik) roofs are commonly used, while shed roofs (sundurma çatı) are observed in the outbuildings. As for roofing materials, tiles (kiremit) are predominantly used, although one building was found to have a metal (sheet) roof (Figure 12.).

Figure 12. Roof Material and Type Analysis Map

3.2.5. Quality and Conservation Status Analysis

There are no officially registered or protected buildings in Topçu Village. However, due to the importance and value these buildings carry as part of the rural architectural heritage, they are considered worthy of preservation. Within this scope, buildings that stand out in terms of plan layout, construction system, material usage, façade character, and decorative details have been evaluated and documented as qualified structures.

Buildings constructed with reinforced concrete or prefabricated materials have been classified as unqualified, as they lack rural characteristics. According to the Quality Analysis Map, nearly half of the buildings are classified as qualified structures. This situation highlights the importance of emphasizing the rural architectural value of the settlement (Figure 14.).

Figure 13. Garden Gates

One of the characteristic features of the settlement is the presence of garden gates at almost every house. These gates vary in size depending on the user. The number of gate leaves changes according to the intended use—single-leaf gates for people and double-leaf gates for animals. The gates are designed quite simply, featuring metal studs on their surfaces (Figure 13).

Figure 14. Qualitative Analysis Map

Figure 15. Conservation Status Analysis Map

In the Conservation Status Analysis prepared to determine the protection status of village houses, it was found that structures identified as qualified should be preserved due to their rural heritage value. Additionally, newly constructed buildings that are still in use and do not contradict the fabric of the settlement were also deemed necessary to be protected (Figure 15). Buildings for which it is considered possible to harmonize with the fabric through certain interventions were classified as “can be preserved and continue to be used.” Thus, it will be possible to achieve harmony with the settlement fabric by removing additions, making changes in facade openings and details, and using different materials.

3.2.6. Building Damage Status and Usage Analysis

Compared to many rural settlements in Anatolia, Topçu Village is in an advantageous position regarding the continued use of its buildings. Its proximity to the city center allows most residential buildings to be used seasonally. Users often have second homes in the city center to meet their educational, health, and comfort needs, which shortens the duration of use of the village houses. Those with second homes in the city center use their village houses during different periods of the year, especially when climatic conditions are suitable, such as summer, school holidays, summer vacations, official holidays, etc. They also use the house gardens for winter preparations and planting activities. While a small number of residential and other functional buildings are actively used, there are also some buildings that are unused or in ruins due to migration or neglect (Figure 16).

Figure 16. Usage Status Analysis Map

Figure 17. Damage Status Analysis Map

In the damage status analysis, buildings were evaluated structurally as 'ruined, damaged, moderately damaged, and undamaged.' Buildings that are structurally standing were classified as 'undamaged,' those with structural problems but still usable as 'moderately damaged,' buildings physically standing but with some elements damaged or unusable as 'damaged,' and buildings that are unusable as 'ruined.' The high number of undamaged or moderately damaged buildings is quite promising for the settlement (Figure 17.).

3.3. Documentation Study of Topçu Village

To identify the plan schemes of the houses in Topçu Village and determine the units within the parcels and the typological group they belong to, 15 buildings were accessed and their plan schemes and parcel usages were prepared (Figure 18.). Although the houses face the street in the parcels, access to the houses is always through the garden. Within the parcel, there are annex units such as wood storage, tandır (traditional oven), WC, poultry house, and barn. In single-story houses, annexes are located freely or attached to the building within the parcel, while in two-story houses, the ground floor is used as barn, hayloft, and wood storage. All houses and other annex units are accessed and used through the garden.

The house plan schemes conform to the internal sofa (inner courtyard) plan typologies defined by Sedad Hakkı Eldem. In single-story houses, there is direct access to the building. In the plan scheme where the entrance area is the sofa, rooms are accessed from the sofa. In two-story houses, the sofa is reached from a semi-open area accessed by stairs, and the rooms are again accessed from the sofa. Both single- and two-story houses typically have two or four rooms accessible from the sofa. The third plan scheme has been included in the internal sofa type, considering the village's climate. Due to parcel size or the position of adjacent buildings, it is thought that the rooms are attached only to one side of the sofa. Accordingly, it was determined that Topçu Village's plan schemes are internal sofa types. The internal sofa plans are shaped by the use of two or four rooms attached on one or two sides of the sofa.

Over time, the houses have undergone changes due to user interventions for comfort and needs. In addition to the used plan schemes without any modification to the sofa, there are also house plans where WC or kitchen has been added to continue use. In plan schemes where both WC and kitchen are added, one unit is located in the sofa, and the other is added in the area where rooms meet.

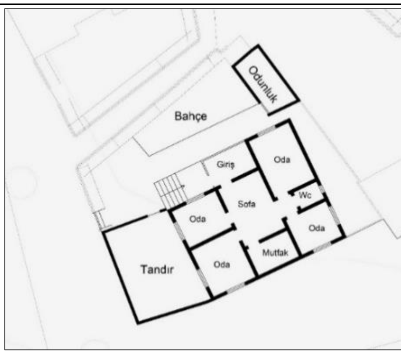
Figure 18. Houses Documented in the Study

In Figure 18, the houses for which plan schemes were prepared are numbered and identified. Among these structures, numbers 1 and 6 correspond to Plan Scheme 1. Houses numbered 11, 12, 14, and 15 align with Plan Scheme 4. Additionally, house number 7 matches Plan Scheme

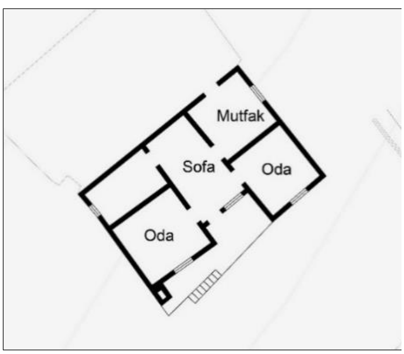
2, number 8 matches Plan Scheme 5, number 9 corresponds to Plan Scheme 6, number 10 to Plan Scheme 3, and number 13 matches Plan Scheme 7.

The differences among the seven prepared plan schemes do not affect their typological group; however, they were drawn separately and prepared due to additions made and variations in the ancillary units located within the parcels (Table 1).

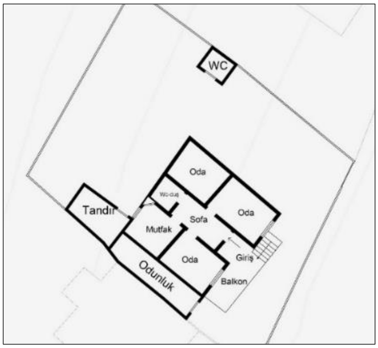
Table 1. Plan Type Examples



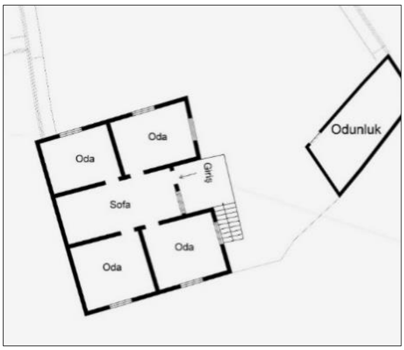
Plan 1



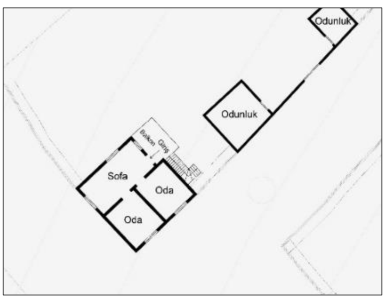
Plan 2



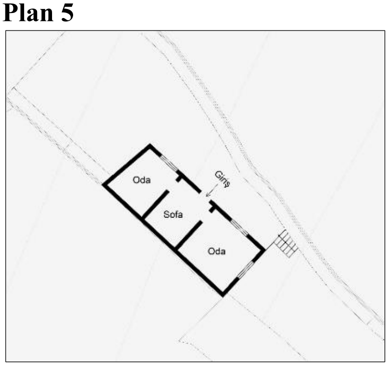
Plan 3



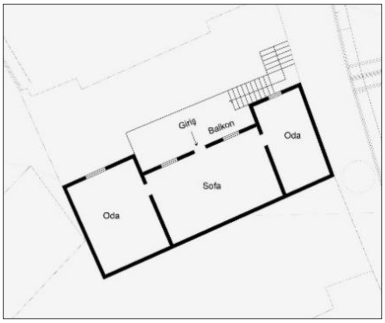
Plan 4



Plan 5



Plan 6



Plan 7

4. Conservatıon Problems of Topçu Vıllage

The rural houses of Topçu Village, which hold significant value due to their rural architectural heritage characteristics, face various challenges in terms of preservation. These challenges can be categorized as socio-cultural and socio-economic. Under these main headings, it is also possible to mention certain issues caused by natural conditions and user-related factors. Due to the aforementioned problems, buildings are sustaining damage, and over time, irreversible consequences may arise (Figure 19).

Figure 19. Collapsed Adobe Structures

As in many rural settlements across Anatolia, migration must be mentioned as the most significant conservation issue for Topçu Village. Due to users' needs for improved education, healthcare, comfort conditions, greater social activity, and employment opportunities, many choose urban life over rural living. This shift results in the abandonment of rural settlements. The annual maintenance needs of adobe houses and the desire for improved comfort conditions further lead users to prefer modern structures. Consequently, rural homes are often left unused based on user preferences.

Topçu Village can be considered relatively advantageous in this regard. Its proximity to the city center enables at least seasonal usage of homes rather than complete abandonment. Additionally, the traditional rural values of neighborly relations, kinship, and collective labor (imece)—once widespread—are also deteriorating due to heavy migration and the infrequent use of rural properties.

The lack of employment opportunities in the village results in economic weakness, making it difficult for users to afford the maintenance and repair costs of rural homes. This situation leads to abandonment or to low-quality, temporary repairs that ultimately damage the authenticity of the structures. Economically better-off users tend to build modern houses using contemporary materials and systems instead of traditional adobe construction. The increase in such modern buildings within the village harms the rural character of the settlement (Figure 20).

Figure 20. Reinforced Concrete Structures

Due to natural disasters or abandonment, the collapse of adobe structures (Figure 19) harms the physical fabric of the settlement. In addition to the risk they pose to the safety of residents, they also negatively affect the identity of the settlement.

Among the preservation issues encountered in village houses, several user-induced interventions have been identified. These issues primarily stem from the inclusion of formerly auxiliary units such as WC-bathrooms and kitchens—originally located in the garden—into the main building. The integration of these units into spaces like the sofa (hall) or rooms, along with their plumbing and electrical installations, poses significant problems for the structures. It leads to the deterioration of the original floor plan and causes damage to walls and flooring.

Another frequently observed issue is the addition of new functions to the parcel alongside the auxiliary structures, which alters the spatial organization.

To ease the maintenance burden of adobe houses, users often make material-based interventions. The most common is plastering the surface of adobe or stone masonry walls with concrete plaster. Though this is done to reduce the need for annual plaster renewal, it is considered a harmful intervention to adobe materials. Due to the material incompatibility, salinization occurs, which damages the adobe or stone structure. While regularly renewing earthen plaster applied to adobe walls is a maintenance challenge in terms of practicality, interventions that do not align with the original material detailing harm the building's authenticity.

Materials such as concrete blocks, aerated concrete, and modern bricks, which are used to repair damaged walls, roofs, and other architectural elements, prevent the preservation of the original material character. Another preservation issue is the replacement of original wooden door and window joinery with PVC, along with changes in their dimensions, which disrupts the solid-void balance of the facade and damages its character. Additionally, the closing or relocation of window and door openings during renovation and repair processes is another factor that deteriorates the facade character (Figure 21).

Figure 21. Façade Interventions

Examples have been observed where the semi-open spaces located at the entrance of houses have been enclosed and used as entrance halls. These interventions, made to adapt to climatic conditions and improve comfort, disrupt the relationship between closed and semi-open space use in the dwelling.

In cases where a house is divided due to inheritance or where usage patterns change over time, entrances to the building are often modified, rendering the original staircase unusable. This situation not only constitutes an intervention in the original façade design but also leads to changes in user habits, which is considered a negative outcome (Figure 22).

Figure 22. Façade Interventions

It is possible to consider the lack of sufficient awareness regarding the need to preserve these structures bearing rural heritage value as a major conservation issue. In this context, raising awareness during compulsory education on topics such as cultural heritage, cultural assets worth preserving, and rural heritage becomes increasingly important. The lack of practical implementation concerning the preservation of rural heritage by local authorities, NGOs, universities, and institutions with a say in urban matters can also be regarded as a negative aspect under conservation problems.

5. Conclusion and Suggestions

Topçu Village, as an example of rural architectural settlement, presents features worth preserving with its rural housing units. Primarily, for the city of Yozgat, to which the village is affiliated, it is necessary to adopt a holistic conservation approach that includes rural settlements in future preservation strategies.

Efforts must be made to eliminate the negative conditions the village has experienced during its development process, and proactive measures should be taken. In this context, as seen in many rural settlements across Anatolia, intensive migration must be prevented, and employment opportunities in rural areas must be enhanced. Initiatives to promote agriculture and livestock farming, which are the primary sources of livelihood in rural areas, must be undertaken. It is considered important that the state provides incentive-based investment support to encourage the younger generation to work in these sectors. Moreover, improving the conditions of current support programs already in place is also deemed essential.

By supporting the continuity of agriculture and livestock — the fundamental components of rural production — it is anticipated that rural development can be achieved, and economic sustainability ensured. Improving local economic conditions is expected to significantly reduce migration, and residents' decision to remain in their homes will greatly contribute to the preservation of the village's physical fabric.

The seasonal use of houses in the village is seen as an advantage, and there is a need to develop strategies to prevent these users from abandoning their rural homes. Facilitating the production and marketing of local products could help increase the village's visibility and awareness. Within this scope, promotional and marketing strategies by social media, local authorities, and university-related institutions could improve sustainability and generate economic benefits.

Some interventions carried out in buildings due to a lack of sufficient awareness about rural architectural heritage have been identified. Thus, it is suggested that the curriculum include content focusing on cultural and rural heritage values. These topics should not only be part of the compulsory education program but also communicated to local residents to ensure they gain awareness. This way, residents will understand the importance of preserving the buildings they inhabit and recognize the need to consult professionals when undertaking any interventions.

Such awareness can help eliminate unintentional architectural changes and inappropriate modifications. Raising awareness about the cultural value of these structures can also help prevent harmful practices such as low-quality additions, alterations to original plans, and the use of incompatible materials.

The abandonment of these homes and their gradual disappearance over time would prevent current and future generations from understanding the period and cultural structure they represent. Completely abandoning these houses poses a major obstacle to their preservation. To prevent their loss, it is essential to propose their registration or inclusion under heritage protection.

In conclusion, it is necessary for local governments, NGOs, universities, and other relevant institutions to carry out awareness-raising activities and initiatives regarding the preservation of rural settlements. This way, it is believed that contributions can be made to safeguard rural cultural values and ensure the continuity of cultural heritage footprints.

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The article complies with national and international research and publication ethics.

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Author Contribution and Conflict of Interest Declaration Information

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Criteria and Practices for Resilience at the Neighbourhood Level

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1. Introduction

In today's context, where multidimensional urban risks such as climate change, disasters, and social inequalities are increasing, the idea of resilient cities is viewed as a complex system that includes not only physical infrastructure but also social, economic, and governance elements (Meerow, Newell & Stults, 2016; Sharifi, 2016). Resilience refers to a system's ability to withstand, adapt to, and recover from external shocks (Cutter, Ash & Emrich, 2014). In this setting, resilient cities are not just urban systems that "respond" to disasters and crises, but also those that can develop proactive, transformative, and inclusive solutions (Vale, 2014).

The neighbourhood level is a vital scale in spatial planning for creating resilient cities. Neighbourhoods are units where local communities interact directly, where social capital is concentrated, and where daily practices are maintained. Physically, neighbourhoods include various spatial elements such as the road network layout, distribution of open and green spaces, building density, types of buildings, quality of public spaces, and infrastructure systems. Assessing these components collectively at the neighbourhood level is essential for the success of both pre-disaster risk reduction and post-disaster recovery. For example, the proportion of permeable surfaces plays a key role in managing rainwater and reducing the urban heat island effect, while green corridors and parks support ecological balance and foster social interaction (Mueller et al., 2023; Henning Larsen Architects, 2024).

Moreover, morphological factors such as street widths, building heights, and development patterns should be evaluated in terms of emergency response capacity, accessibility, and the availability of safe gathering areas. In this regard, neighbourhoods are multidimensional spaces that influence both physical and social resilience. Therefore, urban design practices implemented at the neighbourhood scale in resilience planning should be considered not only as technical solutions but also as spatial strategies integrated with communities (Sajjad et al., 2021; Bixler et al., 2022).

However, the practical application of resilience strategies at the socio-spatial level is most clearly tested in neighborhoods (Bixler et al., 2022; Sajjad et al., 2021). In urban design, neighborhoods especially offer strategic opportunities for open space systems, microclimate control, disaster shelter solutions, and community-driven planning practices (Henning Larsen Architects, 2024; Mueller et al., 2023).

This study aims to compile the criteria identified in the literature for resilient neighborhood design. By analyzing disasters caused by climate change and natural hazards, the research demonstrates how theoretical debates are reflected in practical applications through a review of literature and real-world projects.

2. Material and Methods

In academic research, a *scoping review* is a systematic yet flexible form of literature review conducted to broadly map the existing body of knowledge on a particular topic, identify key themes, conceptual frameworks, and knowledge gaps (Arksey & O'Malley, 2005; Munn et al., 2018). Compared to systematic reviews, scoping reviews offer a broader scope for exploration and conceptual categorisation (Peters et al., 2020).

In this study, the topic of resilient neighbourhood design is addressed from a multidisciplinary perspective. In particular, resilience practices and urban design approaches developed at the neighbourhood scale in the face of multidimensional urban risks, such as climate change and natural disasters have been examined in light of literature and best practice examples.

This study aims to identify key principles, priority strategies, and implementation scales related to resilient neighborhood design by analyzing current case studies and academic debates. It clarifies the scope of the subject within its conceptual diversity and highlights the common features and different approaches of models developed in various regions. Using this scoping method, broad trends in the literature concerning both the theoretical framework and implementation strategies for resilient neighborhood design are uncovered.

In this study, a comprehensive literature review was conducted to identify existing indicators for measuring and evaluating neighborhood-level resilience to disasters. A search using the keywords "resilience," "neighborhood," "disaster," and "indicators" in the Web of Science (WOS) and Scopus indexes yielded a total of 40 articles. Additionally, this research was conducted from 2020 to 2025. Similarly, to identify indicators for climate resilience at the neighborhood level, the keyword "climate" was searched together with "resilience," "neighborhood," and "indicators" in the Web of Science (WOS) and Scopus indexes. In total, 37 documents in Scopus and 53 in WOS were listed. These identified studies were examined, and publications that fell outside the scope of the research in terms of subject matter and scale or were duplicative were eliminated. Publications found in both searches are only included in one research field; for example, publications about flooding are only included under the disaster topic. The keywords used in the searches and the number of publications selected from the indexes are shown in Table 1.

Table 1. WoS and SCOPUS literature search results from 2020 to 2025

Article	SCOPUS	WoS
Indicators for neighbourhood disaster resilience	10	6
Indicators for neighbourhood climate change	5	12
Disaster-resilient neighbourhood implementation	18	9

2.1. Data Extraction and Coding Process

The following information was systematically extracted from the selected articles:

• Year of study and geographical context

• Resilience dimensions used (social, physical, economic, environmental, governance, technological)

• Proposed or tested indicators

• Analysis methods used (e.g., survey, statistical analysis, case study, modeling, etc.)

These data were thematically coded, and common indicators were categorized in a table. The coding process was conducted independently by two researchers, and the results were compared to ensure consistency.

2.2. Analysis Method

The study used a qualitative content analysis approach, not a quantitative meta-analysis. The findings were interpreted within a thematic framework, including the areas where indicators are concentrated, which indicators are prominent in specific regions, and where gaps exist.

3. Findings and Discussion

This section initially presents a conceptual framework grounded in interdisciplinary studies of disaster risk reduction and climate resilience, forming a basis for resilient neighbourhood design. It also describes practical applications across urban and architectural fields, highlighting adaptive strategies, risk-informed planning, and design innovations aimed at improving neighbourhood-level resilience.

3.1. Indicators for Neighbourhood Disaster Resilience

Disasters not only cause severe damage to physical infrastructure but also have complex and profound effects on social, economic, and administrative systems. In this context, the ability of communities to prepare for, mitigate, adapt to, and recover from disasters is called resilience (Meerow et al., 2016). Resilience provides a comprehensive approach to disaster risk management, covering not only physical recovery but also aspects like social capital, economic strength, institutional cooperation, and environmental sustainability (Cutter et al., 2014; Twigg, 2009).

Recent research emphasises the importance of indicator-based approaches in assessing resilience. Indicator sets ensure that spatial planning and disaster risk reduction strategies are based on measurable and comparable data (Cutter et al., 2010; Joerin & Shaw, 2011). The neighbourhood scale is particularly significant because it is where local characteristics and community capacity can be observed in the most detailed way (Sharifi, 2016; Vale, 2014). This scale is vital for decision-making regarding pre-disaster preparedness as well as post-disaster response and recovery efforts.

In this study, a comprehensive literature review was conducted to identify existing indicators for measuring and evaluating neighbourhood-level resilience to disasters. The 16 articles were systematically analysed in terms of the dimensions and indicators used in measuring resilience to disasters at the neighbourhood level. The findings, which evaluate approaches from different disciplines within a holistic framework, are presented in Table 2.

Table 2. Indicators for neighbourhood disaster resilience

Article	Dimension	Identified Indicators
Barroca et al., 2023	Social	Social ties, level of participation
	Governance	Local governance capacity, inter-institutional cooperation
	Physical	Building density, infrastructure condition
	Economic	Income level, economic resilience
Bixler et al., 2021	Social	Social networks, mutual trust, and information sharing
	Institutional	Resource sharing, support mechanisms
Buck et al., 2023	Social	Micro-scale measures, level of organization
	Institutional	Meso-scale neighborhood organizations, governance structures
	Physical	Macro-scale infrastructure investments, physical planning
Saijad et al., 2021	Information/ Data	Real-time disaster data, historical records
	Institutional	Governance structures, collaboration networks
	Process	Learning and feedback loops, social learning
Adrobo et al., 2023	Physical	Building age, building type, and infrastructure condition
	Social	Population density, dependent population, and education level
	Economic	Income, ownership status, job security
Meshkini et al.,2021	Physical	Land-use diversity, green spaces, accessibility
	Social	Social resilience, mixed-use advantages
Pazhunan & Amirzadeh (2023).	Social	Social ties, participation
	Economic	Income level, livelihoods
	Physical	Building condition, infrastructure
	Institutional	Inter-institutional coordination, local governance
	Environmental	Natural environmental conditions

Chakraborty et al., 2024	Social	Elderly ratio, low income, single-parent households, ethnic minority ratio, and education level
	Physical	Spatial overlap with seismic risk zones
Li et al., 2021	Social	Community organization, social indicators
	Economic	Income sources, economic security
	Physical	Infrastructure condition, building quality
	Environmental	Green space, environmental quality
	Institutional	Local government capacity, decision-making mechanisms
Zebardast, 2022	Social Capital	Trust, participation, relationships
	Infrastructure	Access and quality
	Economic Security	Livelihoods, income stability
	Governance	Participation in local decision-making
	Environmental Awareness	Environmental sensitivity, sustainability behaviors
Alam & Haque (2022).	Physical	Building density, building type, number of floors, building quality
	Social	Population density, dependent population ratio, and education level
	Economic	Income level, ownership status (tenant/homeowner)
	Environmental	Soil type, green space ratio
Bixler et al., 2022	Social/Process	Trust among stakeholders, transparency of communication, sensitivity to local context, diversity of information, and continuous learning
	Institutional	Institutional resilience and management of resource constraints
Sogabe & Maki (2021).	Social/ Demography	Population change, age distribution, proportion of returning young population
	Economic	Employment types, recovery of small businesses, and public investments
	Spatial	Housing policies, socio-spatial segregation, and port functions
Amirzadeh & Barakpour (2021).	Institutional	Multi-level governance, institutional capacity, and coordination
	Local Knowledge	Local knowledge and learning systems, information sharing
	Community	Participation of women/young/and elderly, social networks, organizations
	Nature-Based	Water management, diversification of livelihoods
Moradi et al., 2021	Physical-Environmental	Building age, building type, road width, plot layout, and infrastructure condition
	Socio-Cultural	Public awareness, level of participation, and health infrastructure

	Economic	Income level, economic infrastructure
	Key Criteria	Resistance, adaptation capacity, redundancy, recovery
Singh-Peterson et al., 2025	Social	Social capital, local participation
	Economic	Economic resources
	Infrastructure	Infrastructure services
	General	Spatial variability indicators, neighborhood-level analysis

An examination of Table 2 reveals that the most prominent indicators are physical, social, economic, corporate-governance and scale-related indicators. Social, physical, economic, and institutional indicators are the primary ones. Environmental and governance factors are also significant but serve as supporting elements. Among physical indicators,

Building density, infrastructure, land use diversity, and green spaces are the most emphasized factors for both earthquake and flood resilience. Social indicators, including social networks, community trust, participation, and social capital, are key elements that enhance resilience in nearly all studies. Economic indicators focus on livelihood diversity, income stability, and economic infrastructure, and are seen as directly linked to post-disaster recovery capacity. The importance of institutional and governance aspects, such as multi-level governance, information sharing, and local government capacity, is vital in addressing slow-moving hazards and complex urban systems. When analyzing the studies by scale, most are conducted directly at neighborhood or similar sub-local levels (e.g., Mymensingh, Lyon City, Shanghai, Shiraz).

Character of Indicators:

- Physical: Concrete spatial factors such as building density, building type, road width, and infrastructure are at the forefront.

- Social: Emphasises local participation, social networks, and community connections.
- Economic: The variety of economic resources and ownership structures at the neighbourhood level is vital for post-disaster recovery.
- Institutional/Governance: Local governance capacity and inter-institutional coordination are critical to neighbourhood-based planning.

The benefits of neighbourhood-level studies are thought to be enhanced spatial awareness in disaster management, offering a solid foundation for prioritisation and targeted actions.

The indicators summarized in Table 2 reveal common themes from various disciplines used to measure disaster resilience at the neighborhood level. However, simply listing these indicators is not enough; a critical and contextual evaluation is also essential. Studies conducted over the past five years have identified three distinct trends in disaster resilience indicators.

Initially, physical infrastructure indicators remain dominant, but they are not sufficient alone. While indicators such as building density, road width, infrastructure quality, and green space availability are prominent because they can be measured quickly (Li et al., 2021; Alam & Haque, 2022), the literature warns about the risk of neglecting the social aspect.

Then, social and governance indicators are gaining importance. Participation levels, social trust, the strength of social networks, and the representation of vulnerable groups (elderly, migrants, low-income communities) are seen as critical for sustainable resilience (Bixler et al., 2022; Chakraborty et al., 2024). In terms of governance, multi-level coordination, transparent information sharing, and local government capacity have been prominent indicators, particularly in managing slow-developing risks (Amirzadeh & Barakpour, 2021).

The third theme, technological and environmental indicators, adds a new dimension to the topic. Recent studies demonstrate that IoT-based early warning systems, big data analysis, and AI-supported decision-making mechanisms can be used at the neighborhood scale (Yang et al., 2025; OECD, 2025). Furthermore, nature-based solutions (permeable surfaces, ecosystem services, greenways) not only provide ecological benefits but also strengthen social interaction and support social capital (Mueller et al., 2023).

Differences in geographical contexts also shape the choice of indicators. While Asian examples focus on engineering-based infrastructure solutions, European literature emphasizes nature-based approaches and participatory governance. In the US, technology integration and multi-actor governance are combined (Boston Climate Ready, Barcelona Eixos Verds, China's Sponge City program). This shows that indicators must be adaptable to specific settings but also standardized to support international comparison (Sharifi, 2016; Wang & Liu, 2023).

Consequently, indicators used to measure disaster resilience at the neighborhood level are not limited to physical parameters; they offer a multidimensional framework encompassing social justice, economic diversity, governance capacity, environmental sustainability, and technological innovation. This multidimensional approach necessitates the development of context-specific yet comparable hybrid indicator sets in the future.

3.2. Indicators for Neighbourhood Climate Change Resilience

Climate change refers to long-term alterations in temperature and weather patterns, which can occur due to natural phenomena such as solar variability or significant volcanic activity (UN, n.d). However, mounting scientific evidence confirms that human factors particularly the combustion of fossil fuels, intensive urban development, deforestation, large-scale agricultural practices, and many other activities harming the environment have become the predominant drivers of climate change today (UN, 2024; EC, n.d.). Climate change-related factors damage the physical infrastructure and create negative impacts on the social, economic, and administrative systems. There is a need for comprehensive and reliable statistics to assess the impacts of climate change and urban shocks at the neighbourhood scale, monitor the effectiveness of interventions, and develop plans (Figueiredo et al., 2018).

Current climate actions remain insufficient to achieve global climate targets, and bridging this gap requires action at all levels. The provision of accurate and adequate data is essential for the effective use of indicators. Therefore, it is crucial to implement policies that are tailored or adapted to the conditions of specific locations through local markets and municipal funding mechanisms. In doing so, local communities can be mobilised to realise place-based climate action (OECD, 2025).

The Global Set of Climate Change Statistics and Indicators (Global Set), developed by the United Nations, serves as a statistical framework for monitoring and reporting climate action and guides countries to prepare their own statistical sets (UN, 2024). This set is connected to international goals such as the Sustainable Development Goals (SDGs) and the Sendai

Framework for Disaster Risk Reduction. SDG 11 aims explicitly to "Make cities and human settlements inclusive, safe, resilient and sustainable".

Statistical indicators are employed to identify vulnerable areas and population groups in contexts such as heat vulnerability, urban flood vulnerability, and climate change vulnerability (Cangüzel & Coşkun Hepcan, 2024). This helps target interventions and reduce health inequalities. Systems like Neighbourhood Sustainability Assessment Tools (NSATs) utilise statistical data through criteria, indicators, and metrics to evaluate neighbourhood development performance, supporting urban planning and design decisions (Luna-Galvan et al., 2018; Buck et al., 2022).

In this part of the research, climate-related indicators were identified through the retrieved publications in the Web of Science (WoS) and Scopus indexes. After the elimination process mentioned, the number of publications was reduced to 17. These publications were systematically analysed based on the dimensions and indicators used to measure resilience to climate and climate change at the neighbourhood level. The findings, which assess approaches from different disciplines within a holistic framework, are presented in Table 3.

Table 3. Climate resilient neighbourhood indicators

Article	Dimension	Identified Indicators
Anas & Sallay, 2025	Thermal/ Environmental	Capacity to adapt, withstand, and recover, spatial designs that modulate microclimates and reduce heat
	Socio-economic	People-centred urban designs: courtyard blocks, semi-superblocks
	Ecological	Balancing thermal and ecological objectives, supporting biota and biodiversity, reduction in air temperature, green pockets/land pockets
Baldauf, et al., 2025	Economic	Socioeconomic justice, potential, and classification of initiatives

	Social	Social justice, equality, and participation, local technical and human aspects
	Environmental	Creativity towards change, adaptation, or transformation, level of knowledge, and interest
	Cultural	Community's cultural vitality and respect
Cangüzel & Coşkun Hepcan, 2024	*Vulnerability of urban areas to climate change:*	
	Exposure	Neighbourhoods have already experienced climate-based hazards.
	Sensitivity	Vulnerable population in coastal and inner city areas, health and transportation conditions
	Adaptive Capacity	Institutional, social, grey infrastructure, and blue-green infrastructure capacities
Cole, et al., 2024	Natural	Environmental hazards; ecosystem stability; green infrastructure effectiveness (e.g., green roofs, ecological corridors)
	Economic	Employment rate and diversity, poverty levels, and economic participation (e.g., women's participation, insurance coverage)
	Social	Social equality, literacy and awareness; social vulnerability; access to transport and health services; community participation
	Physical	Land use characteristics, urban form and texture, building resilience, neighbourhood cohesion, protective infrastructure
	Institutional	Integrated management across urban organisations: public safety, urban development planning and technology, disaster governance structures
Cooper, et al. (2024).	Socioeconomic Vulnerability:	Poverty rate, concentration of ethnic minorities, proportion of elderly population
	Spatial Justice	Level of access to green spaces, distribution of Nature-Based Solutions (NBS) projects
	Policy Implementation	Proportion of strategies targeted at the neighbourhood level (less than 25%)
	Equity-Oriented Planning	Whether NBS policies are directed toward low-income and vulnerable
Dutta, et al., 2025	Mitigation and Adaptation	Resilience to extreme heat, disaster risk management activities
	Environmental Justice and Equity	Disproportionately affected low-income communities, with lower access to Urban Green Infrastructure (UGI)
	Anticipatory and Co-	Integrative, anticipatory approach, Scenario planning, and co-production involving stakeholders

	produced Planning	
Gallez, et al., 2024	Climate Change Adaptation	Green and blue land cover, tree canopy cover, and nature-based solutions
	Social/ Environmental	Median income level, educational attainment
	Institutional	Monitoring Green and Blue Land Cover, tree canopy cover indications, and providing recovery, promoting nature-based solutions
Gorenc (2025).	Attitude	Trust in heat mitigation methods, risk perception
	Practice	Seeking shade, drinking ample water, avoiding outdoor activities, and ventilating
	Spatial	Access to shade, proximity to green spaces
	Social	Community organisation, social indicators
Lobaccaro et al. 2015	Thermal Comfort	Ground Surface Material, Surface Temperature, PET (Physiological Equivalent Temperature)
	Green Actions	Combining trees and grass surfaces, green roofs/walls, urban geometry, surface materials, permeability, and reflectiveness rate
Naji & Gwilliam (2022).	*Institutional Dimension Extension of Climate Resilience and Indicators*	
	Adaptive Governance	Collaboration, participation, building knowledge, monitoring, and adapting
	Institutional: BREEAM Communities	Building Participation: Consultation plan, inclusion of community needs, knowledge, and ideas, and Design review.
Nematchoua, et al., 2025	Natural Disasters	Adapting and designing to climate change, the use of solar energy,
	Carbon Reduction	Efficient insulation and ventilation systems, local materials, green walls, and roof tops
	Energy Systems & Consumption	Natural lighting and cooling systems, Photovoltaic panels, and smart building design
	Transportation and Mobility	Compact city, pedestrian and cycling infrastructure, urban morphology,
	Policy and Societal	Low-carbon policies, Negative emission Technologies, Carbon capture and storage, Strategic and well-informed planning
Orozco-Messana, et al., 2022	Environmental	Climate adaptation, ecosystem services, carbon sinks
	Social	Equitable access, social inclusion, and community participation
	Economic	Low-cost solutions, economic diversification

	Governance/ Planning	Participatory planning, cross-sectoral integration, and strategic goal setting
	Spatial Justice	Equity in green space distribution, urban–rural balance
	Institutional	Institutional resilience and management of resource constraints
Priya & Senthil, et al. 2025	Urban planning	Mitigation of Urban Heat Island: climate-responsive green solutions, Urban trees, green roofs, and local parks
	Ecological	Support for biodiversity and ecological resilience, small or medium-scale urban green spaces, local plants, and spontaneous vegetation
	Environmental	Improvement of air and water quality by filtering pollutants, stormwater management by green roofs and street trees, permeable surfaces, and collecting drained water
	Community health and safety	Physical and mental health, dynamic environmental exposures, modular green walls and biofaçades, age-friendly natural area designs
	Community participation	Social interaction and community bonds, community gardens, guidelines for sustainable UGS maintenance, community participation, and education
Sifuentes-Muñoz et al. 2024	Urban morphology	Population density, building arrangement, public and private space ratio, open space percentage,
	Vegetation	Quantity and quality of vegetation, percentage of green space (above and below ground), vegetation distribution,
	Physical	Permeable/ impermeable surface ratio, surface reflectivity (Albedo)
	Thermal comfort	Land surface temperature, air temperature
Suárez, et al. 2024	Socio-Cultural	Diversity, social justice, equity, and social cohesion in education
	Economic	Income level, economic infrastructure
	Ecological	Biodiversity, green elements, and the city's metabolism
	Physical and Technological	Human-made 'grey infrastructure', self-sufficiency, and autonomy.
	Governance	Polycentric governance, learning, and innovation
Wang & Liu (2023).	*Conceptual framework for climate gentrification*	
	Social Environment	Occupation rate, qualification rate, family composition, household income, rental, and land value change

	Built Environment	Distance to other cities/towns, distance to public transport, green space coverage, housing density, road density, land use diversity, housing diversity
	Natural Environment	Topography, distance to water bodies, distance to coastlines,
Yang, et al., 2025	Multi-Scale Mechanisms	Micro, meso, and urban scale: Street level, neighbourhood, and urban cooling through mechanisms, green roofs, parks, forests, and wetlands. landscape connectivity
	Ecology and Environment	Trees/forests, parks/open spaces, green roofs/facades, blue infrastructure, permeable pavements, green-blue integration
	Evaluation and Decision Support Systems	Thermal comfort, microclimate, landscape structure,
	Technological Integration and Governance	(AI), Internet of Things (IoT) sensors, cloud analytics, and decision support systems to aid UGBI evaluation and planning

An examination of Table 3 reveals that, while the dimensions associated with disaster resilience, such as physical, social, economic, and others, tend to be more structured and consistent across studies, those related to climate resilience are often more site-specific and vary considerably in scope and emphasis. In the context of climate resilience research literature, three major thematic domains stand out. The first focuses on mitigation-oriented approaches that aim to address global warming driven by rising atmospheric CO_2 concentrations. The primary focus is on reducing greenhouse gas emissions and enhancing carbon sequestration. The second approach focuses on sustainability-driven strategies that aim to mitigate ecological degradation caused by urban sprawl and excessive resource use, particularly in response to the increasing risks of drought and biodiversity loss. The third thematic focus addresses the mitigation of flood risks resulting from climate-induced sea level rise and changing precipitation patterns, which is analyzed within the disaster resilience framework adopted in this research.

The primary concern in all of these research areas is collecting statistical data, since all aspects of climate issues are entirely site-specific and unique. Therefore, indicators also vary depending on geographical location, local population, urban density, industrial plants, agricultural activities, and other factors. This fact also highlights the advantages of neighbourhood-level studies.

In this research area, although the main dimensions resemble those found in disaster resilience publications (Priya & Senthil, et al., 2025; Suárez, et al., 2024; Cole, et al., 2024), such as the Institutional Dimension of Climate Resilience and Indicators (Naji & Gwilliam, 2022), and the Vulnerability of urban areas to climate change (Cangüzel & Coşkun Hepcan, 2024), these studies have their own distinctive approaches toward indicators and resilience dimensions. One recent study highlights a specific concern, as it employs a framework to examine the phenomenon of "climate gentrification," which involves the demographic and socioeconomic upgrading of neighborhoods linked to SLR, potentially displacing lower socioeconomic groups by the higher classes (Wang & Liu, 2023). Nonetheless, the most common indicators mentioned in these studies include increasing green and blue surfaces, creating greener patches, and developing more permeable and less reflective surfaces. Additionally, the most frequently cited indicators encompass community participation, spatial awareness, and spatial justice within the social dimension.

Indicators for measuring disaster and climate resilience at the neighborhood level are organized and analyzed within a thematic framework. The findings show that resilience indicators mainly focus on social, physical, economic, governance, and environmental aspects. Additionally, technological and process-oriented dimensions have become increasingly important in recent years.

Analyzed studies indicate that the most frequently used indicators for disaster resilience are building density, infrastructure quality, green space availability, social networks, social trust, income level, and governance capacity. These indicators play a critical role in both pre-disaster preparedness and post-disaster recovery processes. Social capital and local participation, in particular, stand out as determining factors, alongside physical infrastructure (Cutter et al., 2014; Bixler et al., 2022).

Studies reveal that physical indicators are frequently preferred due to their measurability and direct applicability, while social and governance indicators are often considered secondary. This situation leads to a prioritization of "technically focused" solutions in practice, whereas community participation and local knowledge systems are indispensable for the sustainability of resilience.

Climate change adaptation indicators are more diverse. Studies focus on physical-environmental measures such as reducing the heat island effect, increasing green and blue infrastructure, promoting permeable surfaces, and protecting ecosystem services. Furthermore, climate justice, protection of vulnerable groups, equity, and spatial justice have gained prominence as key social indicators in recent years (Suárez et al., 2024; OECD, 2025).

While studies in Europe and North America highlight nature-based solutions and participatory governance models, examples in Asia (e.g., the

Sponge City program in China) emphasize infrastructure and water management solutions more. This difference shows that indicators are sensitive to context and that a single set of criteria will not be enough.

Comparative analysis of studies reveals three key trends:

1. While physical indicators (building density, infrastructure status, green space ratio) still dominate, these indicators alone are not sufficient.

2. Social indicators (participation, social networks, trust) and governance indicators (multi-level governance, institutional capacity) are becoming increasingly important.

3. Technology integration (IoT-based early warning systems, real-time climate data monitoring, AI-supported decision-making mechanisms) adds a new dimension to resilience indicators.

Existing literature shows that neighborhood-scale resilience studies mainly rely on conceptual frameworks but lack standardized measurement methods (Sharifi, 2016; Wang & Liu, 2023). This makes it difficult to compare data from different regions. Additionally, many studies only examine the effects of local context and social inequalities on indicators.

Therefore, future research should develop context-sensitive yet comparable indicator sets, increase interdisciplinary collaborations, and test the applicability of indicators in the field.

The findings reveal that neighborhood resilience involves more than just physical infrastructure; it is a complex concept that encompasses social capital, economic diversity, governance capability, and environmental solutions. The most common indicators identified in the research (such as social participation, building density, infrastructure quality, and green spaces) are also the easiest to incorporate into policy and planning.

Furthermore, the variety of models developed in different locations highlights the need for indicator sets that are both sensitive to context and adaptable.

In this context, the findings align closely with the recommendations in the study's conclusion: standardizing indicators, ensuring transparency of data sources, conducting long-term monitoring studies, and fostering greater interdisciplinary collaboration. Additionally, approaches that leverage smart technologies and emphasize community participation seem to play a crucial role in strengthening neighborhood resilience in the future.

3.3. Examples of Resilient Neighbourhood Implementations

In the review, which focused on “resilient neighbourhood practices and disasters” (including geological disasters and climate change), it was observed that projects developed within the context of climate change gained prominence. Regarding climate change, the spatial arrangements of cities have emphasised solutions centred on floodwater or rainwater management, energy management, disaster-related technologies, as well as smart urbanism and architectural practices.

The practices are classified as those covering the entire city and architectural scale practices that provide detail at the trim neighbourhood group level. In this section, the practices examined are presented in two categories: urban-scale and architectural-scale topics.

3.3.1. Urban design scale

The sponge city concept, which involves urban and regional-scale water management strategies to address climate change, is gaining prominence. Sponge City practices, a China-based initiative launched as a pilot programme in 2013 for floodwater management, represent a significant topic in climate change governance. In response to China's ongoing population growth and the rising risk of water inundation caused by global climate change, sponge city measures have been implemented at the neighbourhood level. In this context, two examples are provided from the Chinese cities of Xiamen and Wuhan.

The project in Xiamen was actively implemented in 2014. The LID (Low-Impact Development) projects, which began in Xiamen in 2014, were primarily completed between 2015 and 2017, featuring green roofs, rain gardens, water channels, and storage systems (Figure 1). In the 6.2-hectare pilot area, design solutions were developed, including 1,401 m^2 of green roofs, 5,325 m^2 of bioretention areas (rain gardens), 1,880 m^2 of vegetated swales, and a 15 m^3 rainwater storage tank (Xiang et al., 2017). These solutions made significant contributions in reducing the impact of heavy rainfall, decreasing the volume of water discharged to the sewer system, and lowering carbon emissions. Its resistance to Typhoon Nepartak in 2016 has been a strong indicator of the system's effective operation (New Security Beat, 2017).

In the case of Wuhan, efforts under the sponge city strategy began in 2015, and a comprehensive system was implemented, consisting of two main demonstration areas and 288 sub-projects (GrowGreen, 2021). Similarly, in the Wuhan example, rain gardens, green roofs, permeable asphalt, on-site infiltration ditches, and water storage systems were utilized (Reason to be Cheerful, 2020).

In this project, too, the development of resilience against climate change was demonstrated by the fact that despite a daily rainfall of 472 mm in 2020, the city did not experience significant inundation, and the number of flood-prone locations decreased by more than 50% (GrowGreen, 2021; Reason to be Cheerful, 2020).

Figure 1. A: Tianjin Wetland Park, B: Qnuli Rainwater Park, C: Haikou Meishe River before the project, D: Haikou Meishe River after the project (Edited with images from Arkitera, 2023).

Increasing the amount of green space at the urban scale is one of the key practices in resilient neighbourhood design for temperature management. An important example in this regard is the Eixos Verds plan implemented in Barcelona. Eixos Verds refers to the network of green streets with high vegetation cover that connect neighbourhoods in the city of Barcelona (URBAG, 2023) (Figure 2). A total of over 750 km of potential green routes has been planned. Among the objectives of the practice, also referred to as a green corridor, are strengthening socio-ecological connectivity, supporting habitat, improving the microclimate, managing rainwater, and increasing the amount of recreational space (URBAG, 2021). In the project, which was carried out through co-creation workshop processes, the top priorities include multifunctionality, reducing heat stress, and supporting biodiversity (URBAG, 2023).

The planning process for Eixos Verds is based on the Superblock pilot studies conducted in Barcelona between 2013 and 2016. This design approach has been demonstrated to provide advantages in terms of climate management and accessibility (Anguelovski et al., 2023).

These pilot applications demonstrated the effects of transformation on promoting equity (Anguelovski et al., 2023). In 2021, the Superblock pilot projects were expanded across the entire city and developed into Eixos Verds (URBAG, 2021; Anguelovski et al., 2023).

In the Eixample district, one in every three streets has been designated as a green corridor (López-Bueno et al., 2023). Streets such as Consell de Cent, Carrer de Bolívia, and Carrer de Cristóbal de Moura have incorporated vegetation, water features, and social spaces.

As of 2023, 2.8 km of the main corridor of the plan, which is still under implementation, has been completed, and expansion continues into surrounding neighbourhoods such as Sant Martí (Barcelona City Council, 2022).

According to Mueller et al. (2023), the corridor can increase the green area ratio by 3.6% and reduce temperatures by 0.05–0.42 °C. The project, which increases access to green space for children and low-income groups, is estimated to have positive mental health effects for 31,353 people and a 13% reduction in medication use (Mueller et al., 2023; Opbroek, 2024). According to the analysis by the Barcelona Institute for Global Health

(ISGlobal) (2023), which evaluates the potential health impacts of the Eixos Verds plan, the green corridor intervention covering one out of every three streets may contribute to the reduction of preterm birth risks annually (ISGlobal, 2023; Mueller et al., 2023).

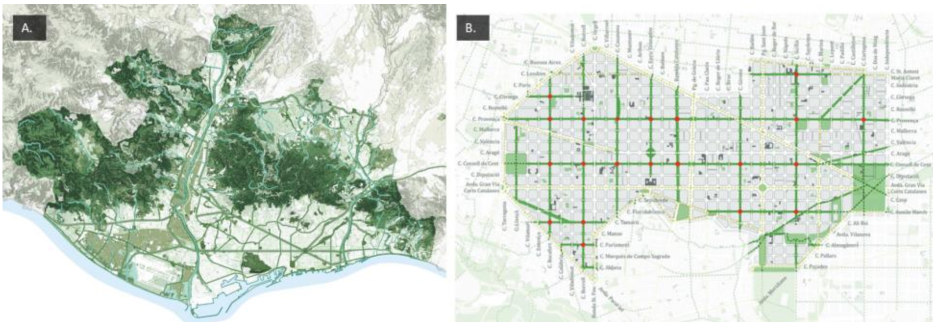

Figure 2. A: Eixos Verds plan (taken from URBAG, 2021). B: Distribution of the green corridor at neighbourhood level in the Example case (edited with images from Anguelovski et al., 2023).

Another key factor guiding citywide implementations is the use of technological solutions. Innovative urban solutions are employed across the city to address various types of disasters. While smart city technologies aim to improve urban efficiency through data-driven management and infrastructure solutions, resilient neighbourhood design emphasises physical, social, and infrastructural resilience to climate change and disaster risks.

The city of Boston integrates these two approaches, setting an example with pioneering applications in both technological and ecological fields.

Launched in 2016 by the Boston Planning and Development Agency, the Climate Ready Boston program is a comprehensive plan for climate adaptation throughout the entire city. It includes risk analyses for the 47-mile-long coastline, adaptation strategies against heat stress, and flood projections. Resilient infrastructure solutions have been developed particularly in coastal residential areas of neighbourhoods such as East Boston, Charlestown, South Boston, and Roxbury (City of Boston, 2023; Boston Planning & Development Agency, 2022).

In the East Boston area, nature-based solutions such as elevated park areas, deployable floodwalls, and flood defence systems integrated with natural landscapes have been implemented. These solutions are supported by sensors and early warning systems, creating a 'smart + resilient' structure at the neighbourhood level. The projects were shaped through community participation, and pilot implementations began in 2021 (ASLA, 2022).

The Waterfront Innovation District transformation project, launched in 2010, aims to convert the industrial waterfront area of South Boston into a centre for knowledge, clean technology, and innovation. The project features smart transportation systems, energy efficiency measures, IoT-based infrastructure solutions, and sustainable building standards. The area has been designed as a “living lab,” meaning a real-life testing ground for innovation (City of Boston, 2023; Boston Planning & Development Agency, 2022).

Resilient solutions such as elevated building foundations, permeable surfaces, bioswales for stormwater management, and smart energy infrastructure enhance the area's resilience to climate change. Additionally, the Climate Resiliency Infrastructure Contribution model allows for financial contributions from the private sector to public infrastructure projects (Kim, 2024).

The Boston cases demonstrate that strong integration between technology and resilience is possible. Both projects use early warning systems, data analytics, nature-based design solutions, participatory planning approaches, and multi-stakeholder governance models.

Thanks to this integration, both infrastructural resilience and social inclusion are prioritised (City of Boston, 2023; Boston Planning, 2023). By integrating smart city technologies with resilient neighbourhood design at both neighbourhood and district scales, Boston presents a model urban framework. This structure highlights the importance of a multidimensional approach to urban planning in the age of the climate crisis.

3.3.2. Architectural design scale

The example of Moakley Park in Boston, Massachusetts, illustrates a significant approach to managing potential coastal flooding caused by sea level rise (Figure 3A). According to Whiteside (2022), Moakley Park, originally established in 1916 for multi-purpose recreational use, has been incorporated into various climate adaptation strategies since 2018. These measures, mainly aimed at preventing sea level rise along the coast and managing stormwater, are expected to provide notable benefits both in the short and long term. A boundary was outlined along the coastline to indicate the potential sea level rise, and landscape features such as barriers, vegetation, and similar elements were developed between this boundary and the waterfront to hold back water (Figure 3 B). The design of these interventions, created through community collaboration for disaster risk reduction, highlights Moakley Park’s role in strengthening community resilience (Boston Parks and Recreation Department, 2025).

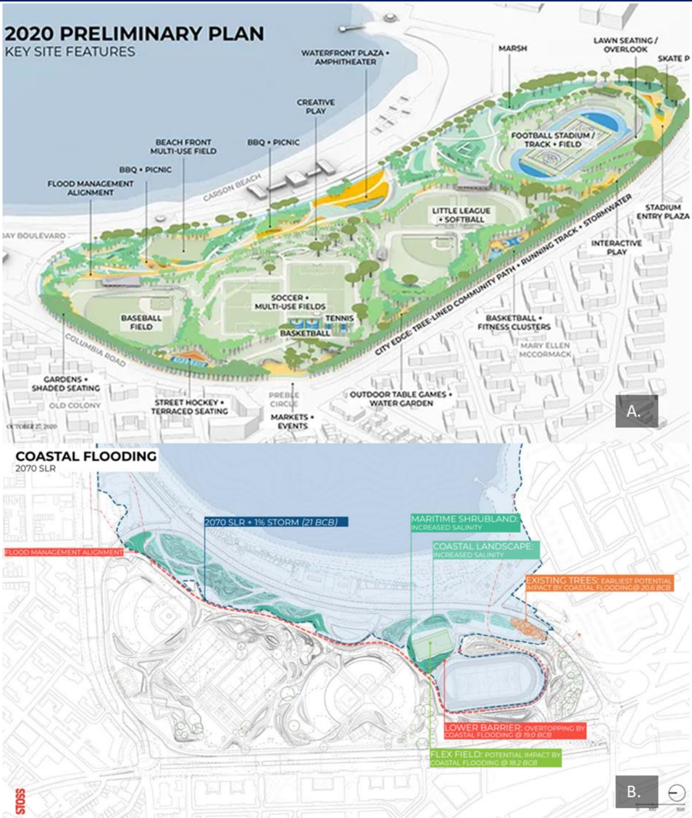

Figure 3. A: Functional distribution of Moakley Park. B: Moakley Park coastal flood management plan (edited with images from the City of Boston, 2025).

Among the examined examples of climate-resilient neighborhood designs is the Climate-Resilient Block from Copenhagen. Developed between 2013 and 2024 as a model in collaboration with local authorities, the project aims to improve energy efficiency, preserve biodiversity, and manage stormwater (Henning Larsen Architects, 2024). The project envisions modifications to Copenhagen's characteristic block typology in line with these goals and provides model solutions that can be implemented citywide (Henning Larsen Architects, 2024) (Figure 4).

Accordingly, the project transformed the backyards of 13 separate properties into a shared courtyard covering 5,000 square meters, where old buildings were renovated, sidewalks and courtyards upgraded (Henning Larsen Architects, 2024). Through this renovation, solutions focusing on energy optimization and sustainable water management were implemented (Henning Larsen Architects, 2024). Rainwater flowing through the courtyard was directed into rain gardens and stored in pools with a capacity of 40 m³ in each garden (Henning Larsen Architects, 2024) (Figure 4D). The stored water is reused as greywater. It is also noted that the synergy between the local community and the natural environment has been strengthened (Henning Larsen Architects, 2024).

Figure 4. A: St. Kjelds Quarter, Osterbro, Copenhagen, settlement pattern and project area (Google Earth, 2022). B: Project area perspective photo

(Henning Larsen Architects, 2024). C: Architectural project of the courtyard arrangement of the project area (Henning Larsen Architects, 2024). D: Project area water storage tank sample photo (Henning Larsen Architects, 2024).

An example that can be detailed at the architectural scale in line with the sponge city concept is the Leibniz University campus (Figure 5). Leibniz University (Hannover) applies a stormwater management system throughout its extensive university park, where the stored water is used for irrigation or to meet various public water needs during extreme droughts and heatwaves (Köster et al., 2023). Figure 5 presents the stormwater management details implemented in the University Park.

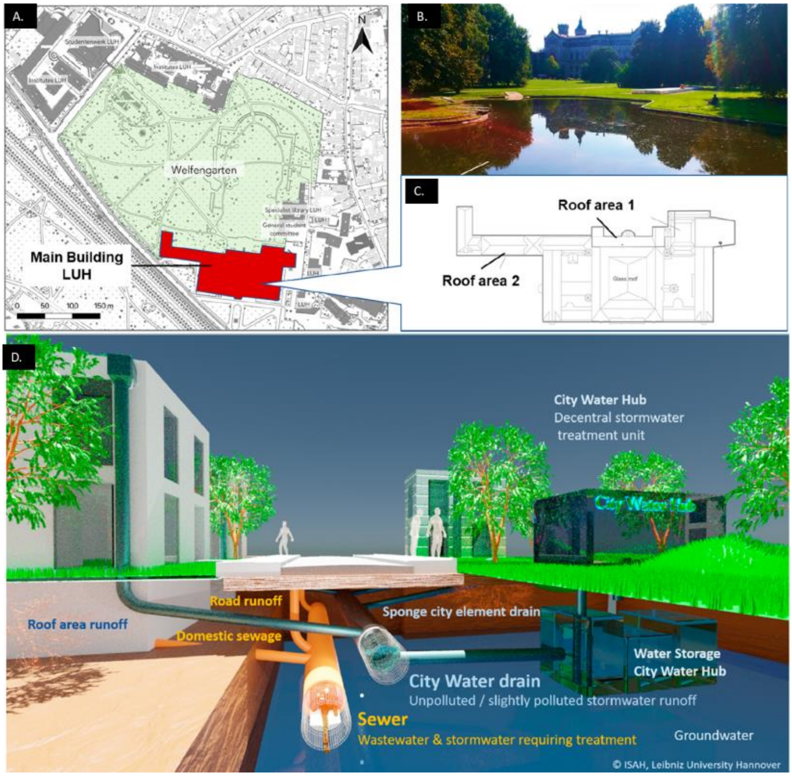

Figure 5. Leibniz University Stormwater management model (edited with images from Köster et al. 2023).

Another example of stormwater management is the multifunctional square project in Rotterdam, initiated in 2013. Known as the Water Square, the square is usually dry and is used for recreational purposes such as resting, skateboarding, and playing basketball or football during dry periods (Figure 6). The square is designed like a basin to collect rainwater and features a system that channels the water through canals into a storage area (Urbanisten, 2013). The square, which collects and redirects stormwater in the neighbourhood, also helps give the neighbourhood a distinct identity.

Figure 6. Water Square in Rotterdam (edited with images from the Urbanisten (2013).

Developed through a collaboration between the Norman Foster Foundation and Holcim, the "Essential Homes" project offers an innovative architectural solution for designing shelters that provide long-term habitability in disaster, crisis, or forced migration conditions (Norman Foster Foundation, 2023). The project aims to create long-lasting, dignified, and human-centered living spaces as alternatives to temporary tents (Figure 7). Such solutions are crucial for sustainable living (Treehugger, 2023). Essential Homes are quickly deployable and climate-resilient structures, thanks to an outer shell made from low-carbon concrete canvas (Holcim, 2023).

Figure 7. Essential Homes (edited with images from Wallpaper*, 2023)

The main body of the structure is coated with a concrete surface that solidifies within 24 hours when sprayed with water. Concrete canvas offers significant advantages in terms of environmental sustainability, providing up to a 70% reduction in carbon emissions (Holcim, 2023) (Figure 7). The interior features wooden surfaces, skylights that let in natural light, sliding doors, bathroom areas, and sleeping units, creating a comfortable living space (Wallpaper*, 2023) (Figure 7). The structure is water-resistant and provides thermal insulation, making it suitable for a wide range of climatic conditions. With a lifespan of up to 20 years, it offers a longer-term solution compared to traditional disaster shelters (Norman Foster Foundation, 2023). The Essential Homes project presents a building model that extends beyond quick assembly and temporary accommodation, aiming to improve quality of life and social cohesion. Through resilient, sustainable, and user-centred architecture, it seeks to redefine the concept of temporary post-disaster shelter (Treehugger, 2023).

3.2.3. Conclusion and evaluation

This section has explored various international examples at both urban and architectural levels to improve resilience against natural disasters, climate change, and related challenges. The projects reviewed include diverse objectives such as water management, reducing the urban heat island effect, enhancing green infrastructure, promoting social inclusion, and integrating technological systems. Examples like China's sponge city initiatives, Barcelona's Eixos Verds green corridors, Boston's smart and resilient neighborhood programs, and Norman Foster's disaster shelter solutions illustrate different approaches to resilient neighborhood design in various contexts.

Common themes that emerged across the projects are:

Nature-based solutions not only support environmental sustainability but also improve neighborhood aesthetics and encourage social interaction.

Community participation and local stakeholder collaboration play a critical role in the success of implementations.

Data-driven technological infrastructure and smart systems contribute significantly to early warning, crisis management, and resource efficiency. Diversity in spatial scale requires the integration of architectural details with urban strategies.

In this context, resilient neighbourhood design necessitates a holistic approach that encompasses not only physical infrastructure but also social, economic, and governance dimensions. For future practices, it is crucial to promote interdisciplinary collaboration, data-informed decision-making, and community-centred models.

4. Conclusion and Suggestions

This study provides a thorough interdisciplinary analysis of indicators used to evaluate disaster and climate change resilience at the neighborhood level. The findings reveal that resilience extends beyond physical infrastructure to include a multidimensional framework comprising social capital, economic diversity, governance capacity, environmental sustainability, and technological innovation (Cutter et al., 2014; Sharifi, 2016; Bixler et al., 2022).

However, social capital, community involvement, building density, infrastructure quality, and governance capacity are key indicators; these elements are also essential for both pre-disaster preparedness and post-disaster recovery at the neighborhood level. Meanwhile, nature-based solutions, climate justice strategies, and emerging technological innovations have become prominent trends in recent years.

Indicators are grouped as seen in Table 4. The first key observation is that social and physical indicators are the most reported (e.g., population density, social capital, building density, infrastructure status) and dominate other indicators. In the context of disaster resilience, the most frequently cited indicators include building density, infrastructure quality, green space availability, social networks, community trust, income level, and governance capacity (Li et al., 2021; Alam & Haque, 2022; Zebardast, 2022).

Table 4. Key common indicators

Dimension	Key Common Indicators
Social	- Social capital (trust, community ties, social networks) - Level of participation (involvement in decision-making and solidarity activities) - Population density, proportion of elderly/dependent population - Education level and awareness - Social equality, social justice, and inclusiveness
Economic	- Income level and income stability - Diversification of livelihoods and economic security - Types of employment, recovery of small businesses - Poverty rate, economic infrastructure, and resilience
Physical / Infrastructure	- Building density, building type, building quality - Infrastructure condition (roads, water, energy, etc.) - Land use diversity and spatial integration - Green spaces and accessibility - Urban morphology, open space ratio, and urban heat island effect
Institutional / Governance	- Local governance capacity and multi-level governance - Inter-institutional cooperation and coordination - Resource sharing and support mechanisms - Transparency, information sharing, learning and feedback loops
Environmental / Ecological	- Natural environmental conditions, ecosystem services - Green and blue infrastructure (parks, forests, wetlands, water management) - Biodiversity and ecological resilience - Reduction of heat island effect, microclimate regulation capacity
Process / Technological	- Long-term monitoring and use of longitudinal data - Use of real-time disaster and risk data - Learning and innovation capacity - Technological integration (IoT sensors, AI-supported decision support systems)

These indicators play a critical role in both pre-disaster preparedness and post-disaster recovery. However, due to their measurability, physical indicators tend to be prioritized, while social and governance indicators are often considered secondary (Buck et al., 2023; Chakraborty et al., 2024). This leads to a dominance of technically focused solutions, whereas community participation, local knowledge systems, and institutional collaboration are essential for sustainable resilience (Amirzadeh & Barakpour, 2021; Sogabe & Maki, 2021).

Climate change resilience, on the other hand, is addressed through more diverse and context-specific indicators. Physical-environmental measures such as reducing the urban heat island effect, increasing green and blue infrastructure, promoting permeable surfaces, and protecting ecosystem services are emphasized (Priya & Senthil, 2025; Yang et al., 2025). Additionally, social indicators such as climate justice, protection of vulnerable groups, equity, and spatial justice have gained prominence in recent years (Suárez et al., 2024; OECD, 2025). For these reasons, the second key observation is the growing emphasis on institutional and governance indicators such as multi-level governance and coordination mechanisms as well as the promotion of sustainability-oriented behaviors. The third key observation emerging from this study is the critical importance of spatial scale, particularly the role of neighbourhoods as foundational units in resilience planning. Neighbourhoods are not only social constructs but also spatial entities composed of diverse physical, infrastructural, and environmental components. These include residential fabric, open and green spaces, transportation networks, public service infrastructure, and social amenities. Such multidimensional characteristics directly influence a neighbourhood's capacity to withstand and recover from disasters (Cutter et al., 2014; Sajjad et al., 2021; Sharifi, 2016).

This perspective is reinforced by implementation examples such as the Sponge City projects in Xiamen and Wuhan, which demonstrate how neighbourhood-level interventions like rain gardens, green roofs, and permeable surfaces can effectively reduce flood risks and enhance climate resilience (Xiang et al., 2017; GrowGreen, 2021).

Similarly, the Eixos Verds plan in Barcelona illustrates how spatial scale can be leveraged to integrate ecological, social, and health-related indicators. By transforming one in every three streets into green corridors, the city has not only improved microclimatic conditions but also enhanced access to green spaces for vulnerable populations, contributing to public health and social equity (Mueller et al., 2023; ISGlobal, 2023).

From a design perspective, addressing the physical features of neighborhoods through integrated urban planning allows for the coordination of infrastructure systems, expansion of green spaces, creation of multifunctional areas, and development of flexible solutions to disaster risks. Projects such as Moakley Park in Boston and the Climate-Resilient Block in Copenhagen demonstrate how architectural-scale interventions can support stormwater management, energy efficiency, and biodiversity preservation while encouraging community engagement (Henning Larsen Architects, 2024; Boston Parks and Recreation Department, 2025).

These examples affirm that the spatial scale of neighbourhoods is not merely a technical consideration but a strategic dimension in resilience planning. It allows for the contextualization of indicators, the mobilization of local knowledge, and the implementation of tailored solutions that reflect the unique needs and capacities of communities. As emphasized in recent literature, neighbourhood-level approaches enhance spatial awareness, support participatory governance, and provide a robust foundation for prioritizing and targeting resilience actions (Sharifi, 2016; Wang & Liu, 2023; Amirzadeh & Barakpour, 2021).

In this context, the third key observation of the study is the growing recognition that neighbourhoods, as spatially and socially integrated units, offer a unique opportunity to operationalize resilience strategies in a way that is both locally grounded and scalable.

The fourth key observation of this study is the growing role of technological integration in enhancing neighbourhood resilience. Recent literature highlights that trend technologies based early warning systems, real-time climate data monitoring, and AI-supported decision-making mechanisms are increasingly being adopted as part of resilience indicator frameworks (Yang et al., 2025; Naji & Gwilliam, 2022). These tools not only improve the accuracy and responsiveness of disaster risk management but also enable predictive modelling and scenario planning at the neighbourhood scale.

Technological indicators are no longer peripheral; they are becoming central to resilience strategies. For example, Yang et al. (2025) emphasize the use of multi-scale mechanisms—ranging from street-level sensors to urban-scale landscape connectivity—supported by cloud analytics and smart infrastructure. Similarly, OECD (2025) and Mueller et al. (2023) highlight the importance of digital tools in monitoring green-blue infrastructure and assessing the effectiveness of nature-based solutions.

This trend is clearly reflected in implementation examples such as Boston's Climate Ready Boston and the Waterfront Innovation District. These projects integrate smart city technologies with neighbourhood-scale resilience strategies, combining sensor-based flood monitoring, IoT-enabled infrastructure, and data-driven planning to address climate-related risks (City of Boston, 2023; ASLA, 2022). In East Boston, for instance, deployable floodwalls and elevated parks are supported by early warning systems, while the Innovation District functions as a "living lab" for testing smart energy and transportation solutions (Boston Planning & Development Agency, 2022; Kim, 2024).

These examples demonstrate that technological integration is not limited to infrastructure efficiency but also enhances community engagement, governance transparency, and adaptive capacity. Projects are increasingly designed through participatory processes, where digital platforms facilitate stakeholder collaboration and feedback loops (Amirzadeh & Barakpour, 2021; Bixler et al., 2022).

In this context, the fourth key observation is that technological indicators and applications are transforming how resilience is understood and put into action. They provide scalable, data-driven, and context-aware solutions that enhance physical, social, and institutional aspects of resilience. As cities confront increasingly complex and slow-onset hazards, integrating smart technologies into neighborhood planning becomes a crucial pathway for developing future-ready urban environments.

The findings confirm that disaster resilience at the neighborhood level is fundamentally multidimensional. While physical indicators such as building density and infrastructure quality are well-known metrics, they should be considered alongside social networks, participation levels, and economic resources (Cutter et al., 2014). Additionally, governance indicators like institutional capacity and coordination have become critical factors in the success of resilience strategies (Sharifi, 2016).

The scoping review also highlights several gaps: Few studies provide detailed data or utilize standardized measurement frameworks. The variation of indicators across different contexts emphasizes the need for context-specific indicator sets that reflect local vulnerabilities and capacities. In conclusion, to effectively achieve the vision of a resilient city, decision-making must occur at the neighborhood level. The neighborhood scale serves not only as a foundation for physical design but also as a means to address social factors such as governance, inequality, accessibility, and social cohesion. Therefore, urban planning and design strategies should be reorganized with an emphasis on developing resilient neighborhoods.

General Conclusions

1. While physical indicators are still dominant, they are not sufficient on their own; they need to be considered in conjunction with social and governance indicators.

2. Local participation and community networks are as critical to the sustainability of resilience as infrastructure investments.

3. Climate justice and spatial equity are increasingly important, particularly in climate change adaptation policies.

4. Resilience indicators should be context-sensitive yet comparable; this ensures that local needs are met and international comparisons remain possible.

Recommendations

Develop standardized yet flexible indicator sets. These sets should adapt to various geographic and socio-economic contexts while maintaining comparability. Conduct historical process studies to track resilience over time.

Methodological transparency should be improved. Future studies must clearly specify data sources, measurement scales, and validation methods. Long-term monitoring needs to be established. Indicators of neighborhood resilience should demonstrate changes over time, not just cross-sectional data.

Interdisciplinary collaboration needs to be strengthened. Architecture, urban planning, sociology, economics, environmental sciences, and information technology should work together to develop more inclusive models. Policy and practice should be seamlessly integrated. The indicators highlighted in the study should be directly incorporated into municipalities' urban planning strategies and disaster management policies.

Encourage community participation. Resilience efforts at the neighborhood level should include residents' knowledge and experience, supported by participatory governance models.

Smart technologies and nature-based solutions should be used together. Resilience can be enhanced by integrating early warning systems, data analytics, and artificial intelligence with green infrastructure and water management solutions.

This study has limitations in that it only searched the WoS and Scopus databases, excluding local reports. Direct comparisons were challenging because of the diverse methods used in the analyzed studies.

The findings were mainly based on literature and not backed by on-site field data.

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The article complies with national and international research and publication ethics.

Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article.

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Social Sustainability Through Digital Tools for Participatory Public Space Design

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1. Introduction

Today, rapidly increasing urbanization necessitates the re-evaluation of public spaces not only in terms of their physical life but also in relation to social sustainability policies such as social solidarity, cooperation, and inclusiveness (United Nations, 2015). In fact, the critical role of such components in a democratic and sustainable city can be seen more clearly in examples where the design and planning encompass different social segments is comprehensive (Arnstein, 1969). Nevertheless, traditional methods often fail to fully integrate achieve the expected effect due to time and cost constraints (Innes & Booher, 2004).

In recent years, digital technologies have significantly transformed this . Tools such as Geographic Information Systems (GIS), social media, augmented reality (AR), online surveys, and participatory digital mapping enable diverse stakeholders to participate more easily and directly in spatial decision-making processes (Nurminen et al., 2024; Tappert et al., 2024). Numerous studies published between 2015 and 2025 demonstrate that digital participation methods positively contribute to design quality, increase user satisfaction, and strengthen social inclusion. This will examine the function of these tools in the context of social sustainability and focus on their potential impact in practice.

1.1.Purpose of the Study

Within the framework of social sustainability and Sustainable Development Goals (SDGs) worldwide, the participation of urban individuals in decision-making and design processes related to their living environment is becoming increasingly important. In this context, the primary objective of this study is to examine how digital participation methods are applied in the design of urban public spaces, evaluate the effectiveness of these methods, and contribute to participatory design approaches that prioritize social sustainability. To this end, trends, focal points, and challenges encountered in national and international studies published between 2015 and 2025 were examined. The data obtained through a repetitive and thematic screening process was classified under the and authors, year, scope, and method, and presented in tabular form, thereby proposing a comprehensive framework that could serve as a resource for future studies.

1.2.Importance of the Study

With the COVID-19 pandemic, digitalization processes in urban life have accelerated, and at the same time, the importance of open and accessible public spaces in terms of social solidarity, mental health, and spatial justice has become more apparent. This transformation has led to a redefinition of the relationship between urban individuals and public spaces; in particular, the question of how participation in spatial decision-making processes can be supported through digital tools has begun to be discussed more extensively in the context of social sustainability. This study systematically examines how digital participation methods are integrated into public space design, highlighting existing gaps in the literature and evaluating current trends, application patterns, and challenges in a holistic approach. This assessment, which points to the possibility of a more inclusive, transparent, and interaction-based design process by leveraging the potential of digital tools, not only contributes to theoretical knowledge production but also generates insights for local governments, design professionals, and policymakers.

1.3. General Information

1.3.1. Participation – Concepts of Participation

The concepts of participation and engagement are closely linked to the democratization of social decision-making processes and have their origins in the agora tradition of Ancient Greece(Habermas, 2004). Conceptually, participation refers to the direct involvement of individuals or communities in administrative or spatial processes, while participatory participation is seen as an approach that defines the implementation of this process through planned, inclusive, and egalitarian mechanisms (Sanoff, 2000).In this context, Arnstein's (1969) “ladder of participation” model provides a groundbreaking framework for questioning the quality of participation by presenting a hierarchy ranging from superficial forms of participation to stages where decision-making power is genuinely transferred to citizens. Today, it is increasingly clear that participation is not only a democratic right but also a cornerstone of social sustainability, as social sustainability is based on the principle of meaningful participation of individuals in decision-making processes, alongside the establishment of social justice, for the long-term well-being of communities (Nabatchi & Leighninger, 2015). In this context, increasing the scope and accessibility of participation is of critical importance for achieving social sustainability goals. Therefore, with the development of digital technologies, participatory processes have become independent of time and place; Online platforms, interactive maps, digital survey tools, and social media-based applications have enabled broader and more diverse user groups to be included in the process, thereby facilitating the emergence of new forms of participation that support social sustainability (Nabatchi & Leighninger, 2015).

1.3.2.Participation in Planning and Design

The concept of participation in planning and design disciplines has gained importance throughout history, particularly with the emergence of social inequalities and spatial injustices in cities. In the early 20th century, Patrick Geddes emphasized that the public should not merely be observers but active participants in urban planning, and he proposed the establishment of public forums to enable local governments to work in collaboration with the public (Turner, 1978, cited in Baba, 2009). Geddes' approach represents a significant turning point in modern planning theory, aiming to transform the public from a passive role into a representable and influential actor. Although these ideas first emerged in England, practices related to public participation in urban decision-making processes began to appear in various local government examples in the United States in the 1870s (Wulz, 1985). With the rise of social awareness in the 1960s, user participation in planning and urban design processes began to take concrete form through practical examples; this period marked a threshold where participation moved from the level of discourse to the practical level (Sanoff, 2006). Particularly with the 1968 Paris student movement, the rise of social demands based on freedom, equality, and peace in Europe paved the way for participatory approaches to be discussed more strongly not only in urban planning but also in all areas of social life (Yoldaş, 2012). This process revealed that design is not only a technical activity but also a tool for social consensus and representation.

1.3.3. Integration of Digital Technologies into Participatory Design Processes

The use of digital technologies in participatory design processes is not a new phenomenon, but rather the product of a development process that dates back to the early 1990s. During this period, geographic information systems and digital mapping technologies, particularly through approaches such as Public Participation Geographic Information Systems (PPGIS), began to be used to involve the public in spatial planning processes (Sieber, 2006). With the spread of the internet in the 2000s, web-based surveys, online forums, and interactive maps strengthened the digital dimension of participation (Kingston et al., 2000). However, these digitalization efforts were long limited due to technical limitations and low digital literacy. However, the COVID-19 pandemic has radically changed the situation; digital technologies have become indispensable tools not only in individual living spaces but also in public decision-making and spatial design processes. This development has been a significant turning point that has accelerated the digital transformation process in the field. In this period where physical interactions are limited, digital participation methods have become both more diverse and more effective. Consequently, different digital tools that facilitate individual participation have become more widely used. For example, online survey and voting systems enable rapid and data-driven feedback from large audiences; PPGIS-based mapping techniques allow users to directly transfer spatial data about their environment into the digital environment (Simon, 2024).

In addition, interactive digital platforms and collaborative design tools enable users to contribute directly to idea generation, while participatory methods such as social media applications, gamification techniques, and digital storytelling are effective in involving young people and those who actively use technology in the process. The widespread use of these tools demonstrates that digitalization is not merely a technical transformation but also a structural change that makes public participation more inclusive, diverse, and sustainable (De Siqueira et al., 2022).

2. Material and Method

Within the scope of the research, publications including articles, book chapters, master's, and doctoral were retrieved from the Google Scholar, Academia, YÖK Thesis, Web of Science, SpringerLink, and Semantic Scholar databases. A systematic literature review was conducted with the aim of classifying the studies according to their year of publication, scope, and research methods. First, plans were made to develop the research objective, research question, keyword list, and criteria for inclusion and exclusion of articles. Within the framework of the inclusion criteria, publications written in English and accessible online were preferred. The search was conducted by searching titles and existing article abstracts using the query phrase ((“Use of digital tools in participatory design of public spaces”)). Through a preliminary evaluation based on the abstracts, those not suitable for the scope of the research were excluded, and the publications were classified according to the specified criteria and tabulated.

The distribution of publications by year, field of study, and publication type is presented in Tables 1, 2, and 3 below.

According to the data, there were 5 publications in 2025, 5 in 2024, 10 in 2023, 4 in 2022, 3 in 2021, 2 in 2020, 3 in 2019, 2 in 2018, 2 in 2017, 2 in 2016, and 2 in 2015, totaling 40 publications (Table 1).

Table 1. Distribution of Publications by Year (Author, 2025)

Year Of Publication	Number Of Publications	Year Of Publication	Number Of Publications
2025	5	**2019**	3
2024	5	**2018**	2
2023	10	**2017**	2
2022	4	**2016**	2
2021	3	**2015**	2
2020	2	**TOTAL**	40

The distribution of publications according to their fields of study is shown in Table 2. According to the data, 13 studies were examined in the field of Urban Design, 11 in Architecture, 10 in Urban Planning, and 6 in Sustainable Development and Environmental Studies (Table 2).

Table 2. Distribution of Publications by Field of Study (Author, 2025)

Field of study	Number Of Publications
Urban Design	13
Architecture	11
Urban Planning	10
Sustainable Development and Environmental Studies	6

According to Table 3, 30 articles, 3 master's theses, 2 doctoral theses, and 5 book chapters were examined (Table 3).

Table 3. Distribution by Publication Type (Author, 2025)

Type Of Publication	Number Of Publications
Article	30
Master's Thesis	3
Doctoral Thesis	2
Book Section	5

3. Findings and Discussion

In the literature review, not only the distribution of the studies examined by year and discipline was analyzed, but also their content depth, methodological diversity, and thematic focus points were comprehensively analyzed. During this analysis process, criteria such as how digital participation tools are used in the context of public space design, which participation strategies are adopted, and the extent to which access to user profiles is provided were taken into consideration. Thus, the contribution of digital tools to participatory design processes that prioritize social sustainability was evaluated in both qualitative and methodological dimensions. In this regard, the types of methods used in the studies, their content scope, and publication details are presented in a systematic table.

A portion of the content and methodological findings of the publications is provided in Table 5. In the "Method" section of the table, the types of digital tools used in participatory public space design in the studies examined are indicated with letter codes to create a clear and comparable structure. These codes indicate how the relevant technologies were used in the design process and enable the interpretation of the levels of digital participation in the studies. The explanations of the codes are provided below:

Method Section Letter Codes:

AR: Augmented Reality **3D:** 3D Visualization
AI: Artificial Intelligence **E-:** E-Participation, Online Participation
VR: Virtual Reality **Y**: Software Use
W: Social Media, Websites

Table 5. Literature Review on the Use of Digital Tools in Participatory Design of Public Spaces (Author, 2025)

Author/Year	Study Scale	Digital Methods Used	Brief Description
Quan, SJ ve Lee, S. (2025).	Street/Park	VR / W	Use of a digital platform that integrates ChatGPT-based dialogues and generative design tools
Fessler, Flora, et al(2024).	Public Open Space / Square	3D / E / W	Integrated use of digital tools such as online surveys, map-based platforms, pedestrian simulations, and 3D visualization
Marshall, Stephen, et al(2024).	Neighborhood Scale	3D / E / Y / W	Examining the implementation of an experimental online participatory platform in the regeneration of a residential area in London
Ng, P., et al. (2023).	Settlement / Site Scale	3D	Gamification in decision-making processes for the planning of public facilities in high-density public housing in Hong Kong
Singh, Ajit Christmann, Gabriela. (2020).	City Scale	E / 3D	The contribution of Berlin residents' digitized and visualized communicative actions to the social construction of urban spaces is being investigated.
Alvarado Vazquez et al. (2023).	Neighborhood Scale	E / W	In Latin America, research is being conducted on how information and communication technologies (ICT) can support social participation in the planning, design, and maintenance of public spaces.

M. Shareef, O. S., & Galal Ahmed, K. (2024)	Building Scale	3D / E / VR	In social housing design, integrating users' opinions and needs into the process for semi-public and shared use areas through digital participation tools.
Drechsel, M., et al. (2023)	Neighborhood Scale	3D / E / W	Using the example of the Ehringsdorf district in Germany, digital participation tools mobilize the public and encourage cocreation.süreçlerine entegre edilmesi
Timmerman, R., et al. (2019).	Street/Park	3D / E / W	The contribution of digital participation tools to socially sustainable urban design was examined in the renovation of a series of courtyards associated with social housing blocks.
Guridi, J. A., et al. (2025)	Park Scale	Aİ / 3D	The study examines the impact of image-generating artificial intelligence (IGAI) on the co-design of public parks by translating public demands into design features.
Bouzguenda, I., Fava, N. ve Alalouch, C. (2021)	Neighborhood Scale	3D / W	3D Digital Planning Tools and Their Potential to Enhance Community Participation
Sou, K., Shiokawa, H., Yoh, K., & Doi, K. (2021)	Street Scale	Aİ / E / W	It presents an evaluation model based on human–AI collaboration to enhance participation in street design.
Smaniotto Costa, C., et al. (2017)	Park Scale	Y/ W	A new digital tool, WAY Cyberparks, is introduced and discussed to enhance the understanding of the relationship between users and social practices.
Hilmer, L. (2024)	City Scale	AR / VR	The impact of Information and Communication Technologies (ICT) on participatory planning is examined during a workshop conducted for an urban public space in Hamburg.
Geropanta, V., et al. (2022)	City Scale	Y / W	An Examination of the BIT-Based Digital Platform Her City in Promoting Women's Participation in Urban Public Space Redesign

Deon, L. F. N., et al. (2021)	Park Scale	3D / Y / W	Digital tools and co-design methods can effectively engage children in participatory design processes for public spaces such as playgrounds.

Literature reviews indicate that, particularly after the 2020 COVID-19 pandemic, face-to-face participation methods began to give way to digital tools. This paved the way for the widespread use of digital technologies in public space design at different scales and for various purposes (Geropanta et al., 2022). The pandemic has made the importance of public open spaces more visible for social integration, health, and psychological well-being, and has increased the need to access user opinions in the redesign of these spaces. During this period, online surveys, interactive digital mapping techniques, and three-dimensional (3D) visualization applications have been the most frequently preferred methods in participation processes. These tools not only visualize different spatial options but also enable users to actively participate in decision-making processes. For example, Fessler et al. (2024) created an accessible and inclusive participation environment by combining 3D visualization, online surveys, and web-based platforms to increase gender awareness in public open spaces. Similarly, Marshall and colleagues (2024) designed an experimental online participation platform for a neighborhood renewal project in London, enabling simultaneous contributions from different demographic groups. In Germany, Drechsel and colleagues (2023) demonstrated that digital tools fostered participation at the neighborhood level by supporting co-production processes. These studies demonstrate the complementary use of 3D modeling and web-based participation methods (Fessler et al., 2024; Marshall et al., 2024; Drechsel et al., 2023).Centering children's participation in the design process, Deon and colleagues (2021) facilitated children's creative contributions in a Pocket Park project in Brazil, utilizing tools such as 3D modeling, laser-cut models, and online focus groups. This directly integrated user experience into the playground design process. Hilmer (2024), in a workshop held in Hamburg, used augmented reality (AR) and virtual reality (VR) technologies to enable participants to experience urban public space design in situ and interactively, thus enabling more concrete discussions of spatial decisions. Smaniotto Costa and his team (2017) analyzed the spatial usage habits and social interaction patterns of park users through the digital platform WAY Cyberparks. The findings were evaluated to align design decisions with user practices. Gamification-based participation approaches are also among the prominent methods in the literature. Ng et al. (2023) developed a 3D gamified platform for public facility planning in high-density public housing areas in Hong Kong, encouraging users to actively participate in spatial decision-making processes. Similarly, Singh and Christmann (2020) demonstrated that digitized and visualized communication tools in Berlin enriched spatial decision-making processes by increasing social interaction. Alvarado Vazquez and colleagues (2023) examined how information processing technologies (ICT) support public participation in the planning, design, and maintenance of public spaces in Latin America, emphasizing that e-participation and web-based platforms are important tools that strengthen participation processes (Ng et al., 2023; Singh & Christmann, 2020; Alvarado Vazquez et al., 2023).Various studies have also been conducted using digital participation tools in social housing projects. For example, Shareef and Ahmed (2024) and Timmerman et al.

(2019) used a combination of 3D modeling, virtual reality (VR), and online surveys to directly incorporate user opinions on semi-public and shared spaces into the design process. Recently, artificial intelligence (AI)-based applications have gained increasing importance. Guridi et al. (2025) demonstrated that AI-generated visuals have the potential to transform user requests into concrete design elements in public park designs. Sou et al. (2021) developed an evaluation model based on human-AI collaboration, enriching participation processes with technology (Guridi et al., 2025; Sou et al., 2021). Furthermore, Quan and Lee (2025) proposed an innovative method for collecting and analyzing user feedback using a ChatGPT-supported planning system. This study attracted attention in the literature because it demonstrated that artificial intelligence-based language models can be used as a supporting tool in participatory planning processes. Overall, these studies reveal that digital tools are not merely technical instruments, but also strategic components that democratize participation in public space design, strengthen social equality, and reinforce social integration. Therefore, the integration of digital technologies into public space design processes is considered a critical application area that supports the fundamental principles of social sustainability, such as inclusivity, equality, transparency, and social belonging.

Literature reviews reveal that studies in this field are largely concentrated in countries such as China, the United States, the United Kingdom, Spain, Italy, and India (Figure 1). In particular, while European-based research emphasizes the integration of digital participation with social sustainability principles, Asian countries have focused on the technological dimensions of participation through smart city and digital governance applications. Furthermore, according to Web of Science data, the majority of publications in this field have been produced under the United Nations' 11th sustainable development goal, “Sustainable Cities and Communities.” This is followed by goals such as “Good Health and Well-Being” (SDG 03), “Industry, Innovation, and Infrastructure” (SDG 09), and “Climate Action” (SDG 13) (Figure 3). This demonstrates that digital participation tools are integrated not only into spatial design but also into sustainability efforts focused on health, the environment, and infrastructure. Thus, the pandemic has not only accelerated the adoption of digital technologies but also highlighted the need to redesign these technologies in alignment with the principles of participation, representation, and accessibility.

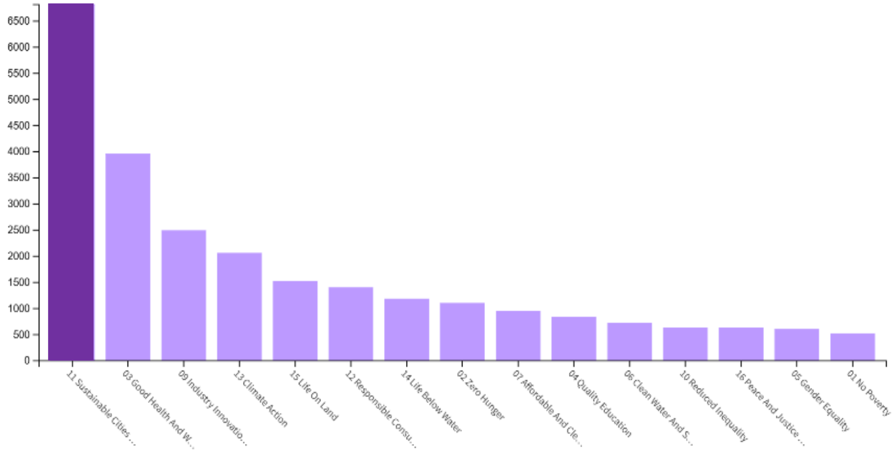

Figure 1. Classification of Studies According to Sustainable Development Goals (Web of Science research analysis report, 2025).

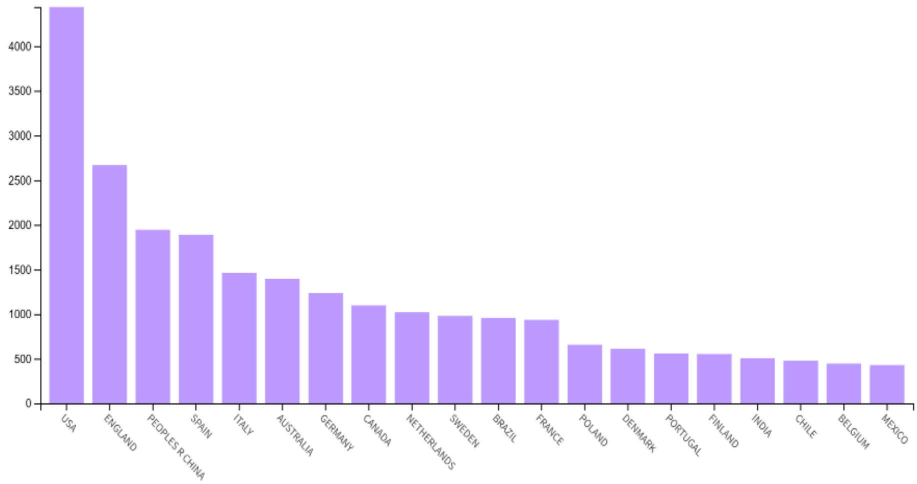

Figure 2. Work scheme on the subject by country (Web of Science research analysis report, 2025).

Although digital tools offer significant advantages in terms of accessibility, inclusivity, speed, and level of interaction in participatory public space design, various limitations and difficulties have been observed in their use. Firstly, differences in digital literacy levels and inequalities in internet access limit the participation of socioeconomically disadvantaged groups, undermining representational justice. Additionally, the fact that online platforms are generally used more intensively by users familiar with technology reduces their capacity to reflect social diversity and may result in certain demographic groups being excluded from the process. Another important issue is the lack of feedback on the extent to which participants' views are reflected in decision-making processes; this can negatively affect users' motivation to participate and their trust in the process. Technical infrastructure deficiencies, data security risks, and the inability of public institutions to sustainably manage digital systems are also among the other important factors limiting the effectiveness of digital participation. All these limitations highlight the need to develop comprehensive strategies not only at the technological level but also at the social, managerial, and ethical levels in order to integrate digital tools into participatory design processes.

4. Conclusion and Suggestions

This study examined the role of digital tools in the participatory design of public spaces in line with social sustainability principles using a literature review method and systematically analyzed national and international publications published between 2015 and 2025. The findings show that digital participation tools are becoming increasingly important in the design of public spaces.

Digital tools (online surveys, PPGIS, VR/AR, AI-supported platforms, etc.) make participatory processes more accessible, inclusive, and interactive, thereby demonstrating their potential to strengthen social sustainability. In the international literature, it has been determined that these tools encourage the participation of different demographic groups in decision-making processes, increase user satisfaction, and contribute to the achievement of spatial justice.

As a result, based on the data obtained, the opportunities offered by digital technologies are seen as an important tool in designing public spaces in a more democratic, inclusive, and sustainable manner. In this regard, participatory strategies to be developed will support not only design quality but also social sustainability goals such as social belonging and spatial justice. It is anticipated that the use of digital technologies will enable both the improvement of design standards and the creation of more equitable and functional public spaces. In this context, it is expected that participatory processes will be strengthened and public spaces will become more responsive to the needs of society in the future, alongside technological developments. Additionally, for countries where digital participation tools are used to a limited extent or where such tools are rarely employed (Figure 1), the following recommendations are provided to contribute to the widespread adoption of digital participation applications:

- The systematic integration of digital participation tools into urban design and planning processes should be encouraged. In this context, local governments and relevant institutions can organize training programs to increase digital literacy.
- In public projects, hybrid participation models (face-to-face + digital) should be developed to enable users to participate in the process through digital tools.
- The effectiveness of digital tools should be continuously evaluated in terms of social representation, data security, and accessibility.
- At the academic level, more quantitative and qualitative research should be encouraged to examine the effects of digital participation tools on different geographical, socioeconomic, and cultural groups.

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All data used in this study were obtained from open access academic databases (Google Scholar, Web of Science, SpringerLink, etc.).

This article has been prepared in accordance with national and international research and publication ethics rules. Since it does not involve an application requiring ethical committee approval, no ethical committee decision has been obtained.

Author Contribution and Conflict of Interest Declaration Information

This study was conducted under the academic supervision of Dr. Hande Akarca as part of a master's thesis process. The literature review, analyses, text writing, and preparation of visual content were carried out by the first author, Elif Kübra Öztürk. The author has no conflict of interest with any person, institution, or organization.

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NDVI Based Change Analysis of Vegetation Cover in Ordu Province

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1. Introduction

Vegetation cover is a biophysical variable that represents the distribution of living biomass on the land surface. It has a direct impact on the energy balance, carbon cycle, and water cycle of Earth's systems (Jones & Vaughan, 2010). Vegetation absorbs carbon from the atmosphere through photosynthesis, contributes to energy conversion processes through evaporation, and helps preserve the physical land structure by limiting soil erosion (Bahre, 1991). Monitoring changes in vegetation provides an analytical basis for assessing environmental processes such as desertification, land degradation, urbanization and land use change (Bai et al., 2008; Yengoh et al., 2015). Performing such assessments requires the integrated use of high-resolution satellite data and numerical approaches that enable the analysis of these data (Verón, Paruelo & Oesterheld, 2006). At this point, Remote Sensing (RS) technologies provide a valuable data source for monitoring environmental changes, while Geographic Information Systems (GIS) offer a strong infrastructure for processing, analyzing and visualizing these data (Jensen, 2009; Goodchild, 1992). The combined use of RS and GIS has become a widely used method, especially in studies aimed at assessing the environmental impacts of urbanization processes and land use changes (Moore & McCutcheon, 2022; Kapluhan, 2014).

In remote sensing-based studies on vegetation, vegetation indices derived from spectral bands produce effective results in terms of spatial and temporal analyses. Among these indices, the Normalized Difference Vegetation Index (NDVI) is preferred especially for monitoring photosynthetic activity and evaluating plant vitality (Ateşoğlu, 2021; Sobrino & Julien, 2011). NDVI is a dimensionless indicator calculated based on reflectance values recorded in the red (RED) and near infrared (NIR) bands and makes it possible to objectively measure vegetation density (Wang et al., 2004).

NDVI data can be applied at many different scales, such as monitoring agricultural areas, monitoring changes in forest cover, and assessing urban green spaces (Ivanova, Kovaley & Soukhovolsky, 2020; Zhu et al., 2021). NDVI series obtained from multispectral satellite images reveal not only plant presence but also important ecological indicators such as vitality level and growth dynamics (Xue, Wang & Hou, 2023).

In this study, it was aimed to evaluate the temporal change in vegetation cover at the spatial level by using NDVI values for the years 2016, 2019, 2022 and 2025 of Ordu province. The study area constitutes a meaningful sample for NDVI-based analyses because it is a region that attracts attention with its topographic diversity and urbanization pressure. Sentinel-2 satellite images were processed in ArcMap 10.5 environment; NDVI rasters were produced, classified and difference analyses were performed. The findings reveal temporal trends in vegetation transformation and provide spatial-thematic indicators that can be used in land use decisions. Such spatial analyses produce functional data at many planning and management levels, from the assessment of environmental impacts of urbanization processes to the protection of natural areas. Quantitative indicators provided by NDVI-based analyses contribute to the formation of a scientific infrastructure for green space management, the development of land use scenarios, and the strengthening of environmental monitoring mechanisms. Such spatial analyses, especially those performed over time series, enable decision makers to interpret spatial change patterns more systematically.

2. Material and Method

2.1.Study Area and Data Sources

Ordu province, where this study was conducted, is a coastal city located on the Black Sea coast in the north of Türkiye and consists of 19 districts in total (Figure 1). The city center is located between the 41° north latitude and the 37°–38° east meridians, in the Eastern Black Sea region. The province is surrounded by Giresun to the east, Samsun to the west, and Tokat and Sivas to the south.

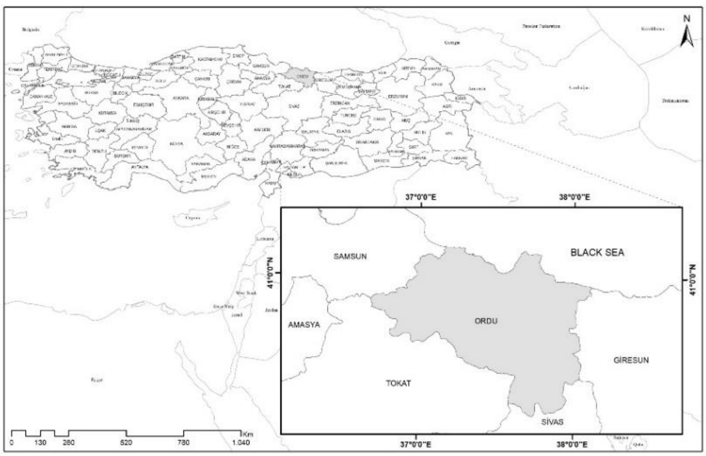

Figure 1. Study Area

The topography of Ordu province is generally rugged and mountainous, with an increasing slope from the coastline towards the inland areas. The humid Black Sea climate prevailing in the province ensures regular rainfall throughout the year and allows the preservation of a high percentage of vegetation. This climatic structure supports various agricultural activities, especially hazelnuts, and shapes the natural landscape character with widespread meadow-pasture areas and wide forest belts. Increasing urbanization and transportation infrastructure, particularly along the coastline, have led to significant changes in land cover in recent years. In this context, Ordu province offers a suitable sampling area for NDVI-based vegetation change analyses. Sentinel-2 10m resolution satellite images provided by the European Space Agency (ESA) were used in the analysis process. Sentinel-2 is a high spatial and temporal resolution satellite system with 13 spectral bands. For NDVI calculations, the red band (Band 4) and near-infrared band (Band 8) were chosen. The images were obtained from the Copernicus Open Access Hub platform.

In order to minimize the effect of seasonal variations and increase interannual comparability in the study, satellite images of July for the years 2016, 2019, 2022 and 2025 with cloud cover below 5% and suitable atmospheric conditions were preferred.

2.2. Image Processing and NDVI Calculation Process

Satellite imagery was processed using ArcMap 10.5 software. Multiple scenes from the same year were combined using raster mosaicing and then clipped based on the administrative boundaries of Ordu province. The Raster Calculator tool was used to generate NDVI rasters, using the following equation:

$$NDVI = (NIR - RED) / (NIR + RED)$$

Based on this formula, NDVI rasters were created for each year, and then normalized to range from -1 to +1. NDVI values were divided into six categories according to the classification system described below. This classification is based on the ranges recommended by Aquino et al. (2018) (Table 1).

Table 1. NDVI Value Ranges and Vegetation Coverage Ratios (Aquino et al., 2018)

NDVI Value Range	Vegetation Cover Rate
NDVI ≤ 0	Bare soil or water surface
0 < NDVI ≤ 0.2	Very low
0.2 < NDVI ≤ 0.4	Low
0.4 < NDVI ≤ 0.6	Medium-Low
0.6 < NDVI ≤ 0.8	Medium-High
0.8 < NDVI ≤ 1	High

2.3. Temporal Comparative NDVI Analysis

NDVI rasters from four different years (2016, 2019, 2022, and 2025) were analyzed to statistically compare temporal changes. Each raster dataset was processed in ArcMap 10.5 software, and pixel-based mean, minimum (min), maximum (max), and standard deviation (std. dev) values were calculated. These operations were obtained through the "Raster Properties > Statistics" tab, which is applied directly to raster data, and were also supported by the Zonal Statistics as Table tool when necessary. NDVI rasters for each year were reclassified with the Reclassify tool according to previously determined classification thresholds (Aquino et al., 2018). Classified rasters were then converted to vector data format using the Raster to Polygon tool and the area amount of each class was calculated in hectares (ha) with the "Calculate Geometry" tool.

As a result of this analysis process, area sizes corresponding to six NDVI classes (bare soil/water, very low, low, medium-low, medium-high, high) were obtained for each year, and thus it was determined how the vegetation cover changed spatially and quantitatively over the four-year period.

2.4. Temporal Comparative NDVI Analysis

To more clearly observe temporal changes in the spatial domain, change detection was applied to NDVI rasters. Using 2016 as a reference, the Raster Calculator tool was used to generate pixel-based difference rasters for 2019, 2022, and 2025, respectively. The formula used is as follows:

$$\text{NDVI Difference} = \text{NDVIyear} - \text{NDVI2016}$$

This process created three different difference rasters:

NDVI_2019 – NDVI_2016

NDVI_2022 – NDVI_2016

NDVI_2025 – NDVI_2016

The generated difference rasters were visualized based on the distribution of positive and negative values, and areas of increase and decrease were clearly mapped using a color scale. For numerical interpretation, statistical summary values were extracted from these rasters, and the mean difference, variance, and distribution density were calculated. In addition, the difference rasters were reclassified with the Reclassify tool, and areas of increase (positive difference), unchanged (neutral difference) and decrease (negative difference) were determined; the number of pixels and area amounts falling into each category were calculated and comparative analysis tables were created.

2.5. Statistical Analysis

Analysis of variance (ANOVA) was first applied to determine significant differences between years in NDVI averages. However, due to the assumption of normality not being met, the Kruskal-Wallis test, a nonparametric method, was preferred. This analysis statistically assessed the differences in distribution between NDVI values across four different years. Statistical analyses were performed using the Jamovi 2.3.28 program.

3. Findings and Discussion

In this study, spatial and temporal changes in NDVI values for Ordu province were analyzed for different years. NDVI values for the study area for the years 2016, 2019, 2022, and 2025 were examined and their distributions were compared. The minimum, maximum, mean, and standard deviation values of NDVI values for the years are presented in Table 2. The 2016 average NDVI was 0.571, the highest compared to other years. In contrast, the average NDVI values in 2019 and 2025 were found to be 0.485 and 0.490, respectively, and the lowest average NDVI value was measured at 0.389 in 2022. Standard deviation values were within a similar range for all years, indicating that the changes were relatively homogeneous.

Table 2. Basic Statistics of NDVI Values by Year

Year	Min.	Max.	Average	Standard Deviation
2016	-1	0.823	0.571	0.117
2019	-1	1.000	0.485	0.116
2022	-1	1.000	0.389	0.102
2025	-0.339	0.769	0.490	0.110

The Kruskal-Wallis test ($\chi^2 = 0.179$, $p = 0.981$) revealed no statistically significant difference between the NDVI averages of different years. However, the boxplot shown in Figure 2 shows that there are variations in the NDVI distribution across years, with values being more concentrated in certain ranges, particularly in 2019 and 2022.

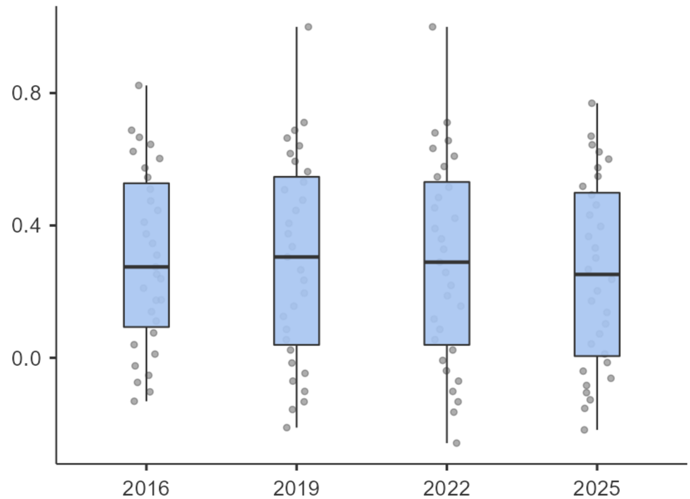

Figure 2. Boxplot Chart of NDVI Values by Year

To assess these general distribution trends in more detail, surface areas related to land cover changes across years, based on NDVI classes, were calculated and presented comparatively. The distribution of NDVI classes in the study area in hectares (ha) by year is presented in Table 3. These data provide the opportunity to quantitatively assess temporal changes in vegetation density. While the lowest NDVI class, NDVI ≤ 0, covered a very limited area in all years, NDVI values in the range of 0.4–0.6 stood out as the most dominant class in 2019 and 2025. It is particularly noteworthy that the class in the range of 0.2–0.4 experienced a significant increase in surface area in 2022. While the dense vegetation area with an NDVI range of 0.6–0.8 was measured at approximately 336,441.53 ha in 2016, this value decreased dramatically to 8,224.97 ha in 2022, and a partial recovery reached 67,236.05 ha in 2025. The highest class, the 0.8–

1 range, remained negligible in all years, and no surface area belonging to this class was detected in 2025.

Table 3. Area Distribution According to NDVI Classification (ha)

NDVI Class	2016	2019	2022	2025
NDVI ≤ 0	1,563.51	1,513.67	953.68	1,544.63
0 < NDVI ≤ 0.2	9,395.25	19,585.05	29,409.06	13,028.05
0.2 < NDVI ≤ 0.4	42,577.88	87,864.86	282,076.16	81,055.44
0.4 < NDVI ≤ 0.6	202,946.29	426,321.45	272,260.56	430,060.30
0.6 < NDVI ≤ 0.8	336,441.53	57,639.20	8,224.97	67,236.05
0.8 < NDVI ≤ 1	0.01	0.24	0.04	—

In line with these quantitative findings, maps visualizing the distribution of NDVI classes in the spatial plane are presented in Figure 3 and the temporal change patterns are detailed.

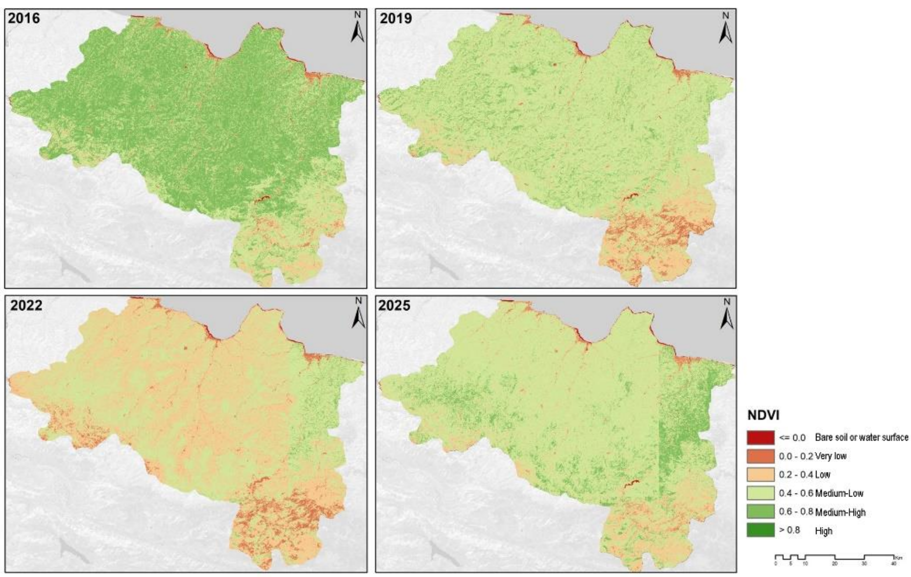

Figure 3. Time Series-Based NDVI Distribution Maps (2016–2025)

Following the general distribution trends of NDVI values over the years, in order to reveal this change more clearly and comparatively, difference analyses were conducted with NDVI data from 2019, 2022, and 2025, using the 2016 NDVI raster data as a reference. The difference maps obtained as a result of the raster calculations visualize in detail the reflection of increases or decreases in vegetative cover on the spatial plane (Figure 4).

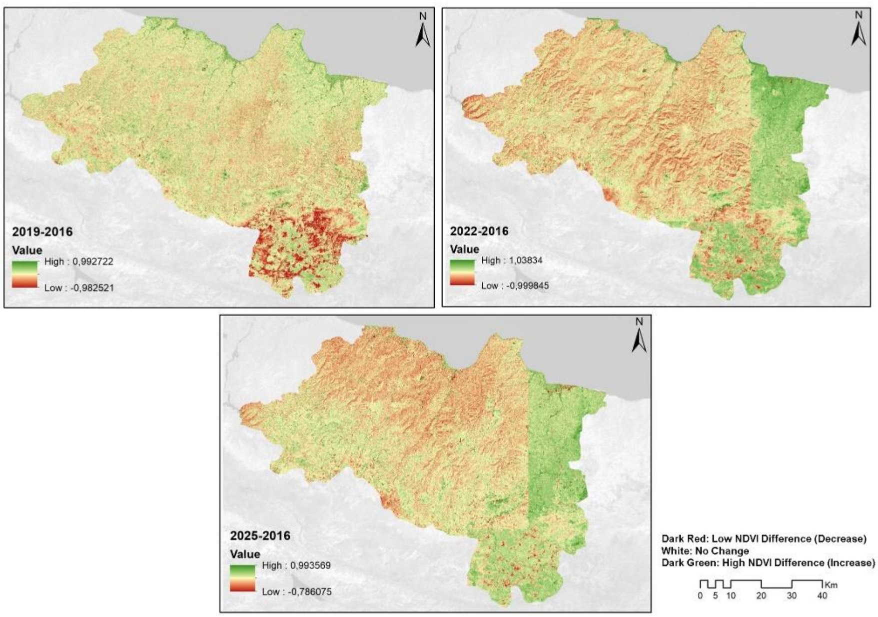

Figure 4. NDVI Difference Rasters (2019–2016, 2022–2016, 2025–2016)
According to these difference maps:

• The 2019–2016 difference ranges between +0.992722 and –0.982521, indicating an increase in vegetation density in some regions during this period, while significant decreases are noted in others.

• The 2022–2016 difference has the widest positive range (+1.03834) and also includes the most negative extreme (–0.999845). This indicates that the study area experienced extensive vegetation loss in 2022.

• The 2025–2016 difference ranges between +0.993569 and –0.786075, indicating a partial improvement compared to 2022, but not fully reaching 2016 levels.

These spatial difference analyses show that the changes in the NDVI time series are not only significant at the quantitative level but also in terms of regional intensity, and provide the basis for relating these changes to precipitation amount or agricultural processes.

Generally speaking, it can be seen that surface areas belonging to NDVI classes have shown significant changes over the years, with notable increases particularly in low and medium density vegetation classes in 2022. NDVI difference rasters clearly reveal the spatial distribution of these changes, clearly visualizing the increases and decreases in vegetative cover in the study area.

4. Conclusion and Suggestions

The study was conducted using NDVI (Normalized Difference Vegetation Index) data for Ordu province for the years 2016, 2019, 2022, and 2025, and interannual vegetation changes were analyzed spatially and quantitatively. NDVI analyses, supported by raster-based difference maps and statistical summary values, enabled a holistic presentation of temporal trends.

In 2016, the beginning year of the study, the period of densest vegetation was observed with an average NDVI value of 0.571; the prevalence of NDVI classes of $0.6 < NDVI \leq 0.8$ and $0.8 < NDVI \leq 1$ (medium-high and high) was particularly notable in the southern parts. In 2019, an increase in NDVI classes in the range of 0.2 < NDVI ≤ 0.4 (low) was recorded in coastal and southern regions, and this increase was thought to be related to increased precipitation and land use changes. The 2022 data showed that the average NDVI decreased to the lowest level at 0.389, and NDVI classes of 0.2 < NDVI ≤ 0.4 (low) became dominant in terms of area. This decrease can be explained by environmental factors such as drought, decrease in agricultural activities, and loss of forested areas. In 2025, the average NDVI value increased to 0.490, and while green area gains were detected in the northeastern parts, the decline continued in the southern regions.

Spatial comparisons revealed a general trend of vegetation increase, with a positive difference of 72% during the 2016–2025 period. The proportion of the NDVI class (0.6 < NDVI ≤ 0.8 (Medium-High) in the area was 336,441.53 in 2016, decreasing to 8,224.97 in 2022 and showing signs of recovery, increasing to 67,236.05 in 2025. One of the main reasons for this fluctuation is the changes in precipitation regime and land use classification, which vary from year to year.

The decline, particularly in 2022, coincides with the drought conditions recorded regionally and is associated with low humidity levels, which negatively impact vegetation health. Furthermore, the transformation of land use classes also supports this trend. The increase in non-agricultural lands after 2016 led to the fragmentation of vegetation areas; by 2025, green areas were apparently restored to a certain extent through interventions such as reforestation, landscaping, and green infrastructure planning.

These findings are consistent with the literature. In their study conducted in the Demre-Akçay basin of Turkey, Benliay and colleagues (2020) demonstrated the significant effects of environmental parameters on regional ecosystem health by correlating NDVI changes with climate comfort factors. Fluctuating NDVI values in Ordu can be interpreted as a result of similar environmental interactions. Furthermore, Lu et al. (2004) demonstrated that NDVI is a highly effective tool for change detection in remote sensing; our study, with up-to-date data and raster analysis, reinforces the validity of this method.

In a study conducted by Yasin et al. (2022), land use changes were analyzed using NDVI and NDBI data, and the transformations in vegetation were detailed. There appears to be a similarity between NDVI declines and the vegetative change trends highlighted in Yasin et al.'s study.

The findings of the study show that NDVI-based analyses are effective in revealing the impact of land use changes and environmental stress factors on vegetation health. The literature also supports the fact that NDVI is a reliable tool for monitoring ecosystem health and providing scientific data for sustainable planning processes (Xue & Su, 2017; Lu et al., 2004). Therefore, the spatial and temporal results obtained are guiding in shaping regional environmental policies and green space management.

Based on the findings, developing sustainable strategies for protecting and expanding green spaces in urban development and planning processes is crucial. Restoration programs aimed at restoring vegetation are necessary, particularly in areas experiencing declines in NDVI values. Integrating additional environmental parameters such as climate variables, soil properties, and land use types, along with longer time-series NDVI data, will enable a more holistic assessment of vegetation dynamics in similar future studies. Local governments and relevant environmental agencies should regularly incorporate remote sensing-based indicators such as NDVI into their monitoring systems, playing a crucial role in the timely detection of environmental changes and the development of science-based response plans. Furthermore, raising public awareness about protecting vegetation health, adopting participatory approaches to green space management, and engaging the public in decision-making processes will foster sustainable ecosystem management.

Acknowledgements and Information Note

The article complies with national and international research and publication ethics.

Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

1st Author % 40, 2nd Author %.30, 3rd Author %30 contributed. There is no conflict of interest.

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The Contribution of Public Transportation and Land Use Planning Integration to Sustainable Urban Development: The Case of Samsun Rail Transit Line

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1. Introduction

Today, cities, where many activities are concentrated, are at the center of the concept of sustainability, and the transportation systems connecting the activities within these cities serve as one of the most crucial driving forces for achieving sustainable urban development. However, demand-responsive approaches based on consumption-oriented habits in transportation represent one of the most significant problems in our cities. Key areas of sustainable transportation aimed at providing permanent solutions to sustainable urban development include reducing automobile usage and promoting walking, cycling, and public transportation.

In contemporary urbanism, the planning of urban transportation systems and the integration of transportation and land use plans play an important role in achieving sustainable urban development. In rapidly growing cities with increasing populations, effective planning and implementation of public transportation systems enable both the rational use of land and increased efficiency in public transit operations. Among public transportation systems, tramways hold great importance due to their high passenger capacity, at-grade operation, and lower implementation costs compared to other urban rail systems. Additionally, tramway systems contribute to sustainable urban development by reducing automobile use. Selecting station locations in harmony with land use during tramway route planning is crucial for ensuring sustainability and accessibility.

In this context, the present study aims to examine the tramway route providing access to Samsun City Hospital, together with the land use plan, and to reveal its impacts on sustainable urban development. While assessing the effects of the tramway line on urban transportation, the study evaluates the integration of the tramway line with land use in social, spatial, and economic dimensions, and aims to develop recommendations for achieving sustainable urban development.

1.1. The Impact of Integrating Urban Transportation Planning and Land Use on Sustainable Urban Development

With the increasing population and the expanding boundaries of our cities today, the integration of transportation planning and land use plays a significant role in addressing accessibility problems. Particularly in contemporary metropolitan cities, the excessive time spent in traffic, which could otherwise be used productively, constitutes a fundamental issue in transportation. Therefore, alongside structural and functional changes in urban spaces, long-term public transportation planning within the city becomes crucial. (Babalık-Sutcliffe , 2012). The integration of urban transportation planning and land use appears to be a continuous process, such as in zoning plans. In the urban transportation planning process, it is necessary to conduct accurate analyses and feasibility studies to identify existing problems and potentials, as well as to ensure integration with land use. (Hamamcıoğlu, 2012).

Another important aspect of urban transportation planning is that, since investments guide urban development, large-scale investments made in the long term must be planned in a way that integrates with urban land use. Therefore, in order to reduce traffic congestion, environmental pollution, traffic accidents, and wasted time experienced in our cities, it is essential to adopt sustainable transportation planning policies and ensure the integration of transportation plans with land use decisions. (Banister, 2005). The integration of land use and transportation plans also makes significant contributions to environmental sustainability by reducing the carbon footprint. (Newman & Kentworthy, 1999).

Banister (2008) argues that the alignment of transportation and land use plans is indispensable for urban sustainability, and that failure to achieve this alignment may lead to negative outcomes such as urban sprawl. (Banister, 2008).

Therefore, since land use determines transportation needs and transportation shapes land use, transportation plans and land use decisions must be in continuous interaction with each other. (Ewing & Cervero, 2010). Since every land use decision generates transportation demand, it is necessary to ensure integration between land use decisions and transportation planning decisions in urban planning. (Aysan, 1996; Joseph, 2000).

The way urban land is utilized generates trips, and the need to make these trips creates transportation demands, leading to the expansion of transportation facilities. In this way, accessibility is provided, and land use is influenced by the resulting increase in land values. (Figure 1).

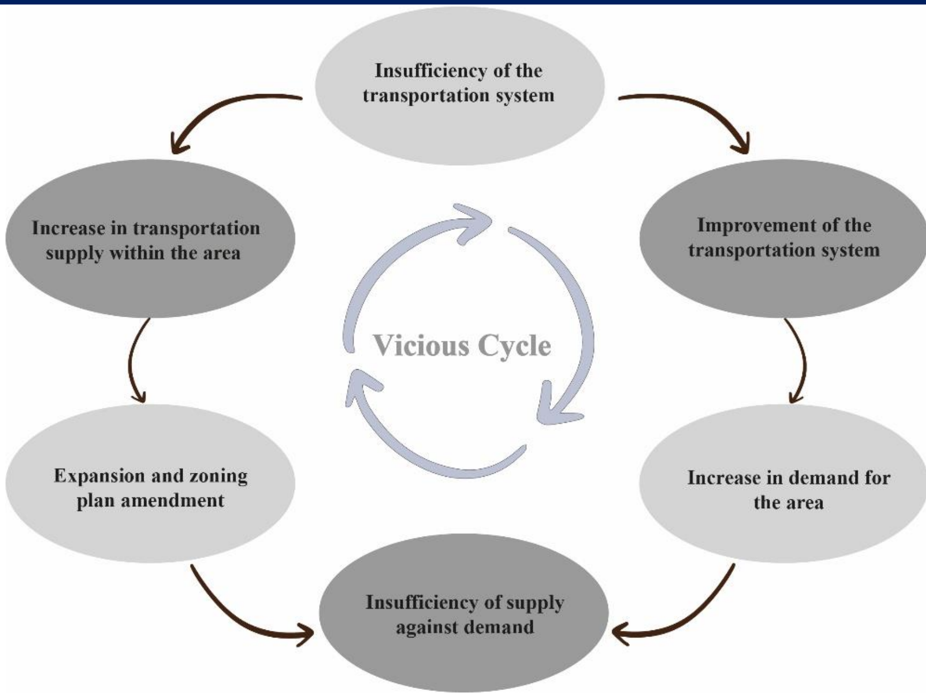

Figure 1. Land Use-Transportation Interaction (Original, 2025).

The concept of sustainability was first introduced to the international public agenda in 1987 by the World Commission on Environment and Development through the report titled *Our Common Future* (Brundtland Report). In this report, sustainable development was defined as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (Black, 2003).

In the United Nations report on *"Planning and Design for Sustainable Urban Mobility,"* it is stated that *"fossil fuel-based fuels, primarily petroleum, are mainly used in transportation, that social data show many low-income individuals in various countries lack access to quality, safe, and healthy urban transportation opportunities, and that economic data indicate traffic problems in urban areas particularly increase fuel* *consumption and time losses in active urban life. "(UN&Habitat, 2013 akt.* (Ayataç, 2013). Therefore, in order to reduce fossil fuel consumption, promote social cohesion, and achieve sustainable urban development in our cities, the effective and efficient use of public transportation systems must be improved. To this end, the integration of transportation planning and land use is essential. (Ewing & Cervero, 2010).

This approach proposes considering the principles of ecological balance, social equity, and economic continuity together in development processes. Over time, the concept of sustainability has also been addressed at the urban scale, leading to the emergence of the sustainable urban development paradigm. This paradigm emphasizes the harmonious development of cities' physical, social, economic, and environmental dimensions; the efficient use of natural resources; accessibility to public spaces; social inclusiveness; and quality of life.

The Agenda 21 document, published at the 1992 Rio Summit, strengthened the feasibility of implementing sustainable development at the local level. Within this framework, the adoption of approaches that prioritize environmental sensitivity, economic balance, and social justice in urban planning and management processes has been encouraged. (OECD, 1996).

The concept of sustainable transportation refers to a transportation approach that is environmentally sensitive, socially accessible, economically efficient, and balanced in resource use. The OECD Vancouver Conference outlined the framework of this concept, emphasizing the importance of renewable energy, clean technologies, public transportation solutions, and multimodal transportation systems.

(OECD, 1996). Similarly, the Sustainable Transportation Center defines transportation as a system that meets basic needs while safeguarding the ecosystem and human health, offering diverse transportation options, supporting social equity, and sustaining economic vitality. (World, 1996). All these approaches demonstrate that transportation is not merely a technical infrastructure service but a strategic tool that guides urban development, shapes social structures, and reduces environmental impacts. Therefore, the integration between transportation planning and land use plays a critical role in achieving sustainable urban development.

1.2. General Characteristics of Tramway Systems

With the Industrial Revolution, intense migration from rural to urban areas led to the rapid growth of our cities. As the urban population increased rapidly, demand for transportation also rose. The adoption of traditional transportation planning approaches, along with an emphasis on investments in private motorized transportation, such as cars, to meet this growing demand, revealed problems in transportation planning. Today, issues related to private vehicle dependence, including inefficient use of urban land, increased waiting times in traffic, higher rates of traffic accidents, and failure to achieve sustainable urban development, have highlighted the necessity to develop public transportation systems in transportation planning.

The development of public transportation in our cities contributes to the efficient use of resources, sustainable urban development, and the rational use of urban land. Public transportation can carry significantly more people compared to private vehicles, which helps reduce urban traffic problems and accidents, shortens travel times, and contributes to the efficient use of urban areas by decreasing the need for investments in transportation infrastructure.

Since completely eliminating traffic congestion worldwide is not possible, the primary goal of transportation planning should be to develop safe transportation systems that save people's time. This can only be achieved through the development of rail-based public transportation systems. Rail transit systems have a significant advantage among public transportation modes because they transport more passengers with fewer vehicles to desired destinations, are fast, comfortable, and economical, enhance land use efficiency, and do not contribute to environmental pollution. (Çubuk vd. 2002, Gündüz vd. 2011, Gökdağ 1999, Keskin 2013, & Salicru vd. 2010).

Among public transportation systems, tramway systems play a significant role as a foundation of sustainable transportation due to their high passenger capacity and at-grade operation, which results in lower implementation costs compared to other urban rail systems. However, increasing the efficiency of tramway systems and meeting user demand requires a well-designed and carefully planned process. To ensure the rentable use of tramway systems, numerous factors such as route selection, environmental compatibility, and accessibility must be taken into consideration.

Although route planning, station location selection, and operational characteristics in tramway systems are distinct elements, these factors must be addressed in an integrated manner to ensure system efficiency. The planning of tramway routes, the determination of station locations, and system design are complementary processes that form parts of a whole.

Each stage of this process should consider user demand, environmental factors, economic conditions, and social needs. In route planning, factors such as traffic density, land use, and environmental interactions should be considered to determine the most appropriate lines. In selecting station locations, considerations should include passenger accessibility, pedestrian mobility, and integration with other public transportation systems.

1.3. Criteria to Be Considered in Optimal Tramway Route Planning

The criteria that must be considered in tramway route planning include land ownership, transportation demand, natural thresholds, proximity to watershed protection zones, geological and slope conditions, population density and traffic congestion, intermodal transportation integration (such as road, maritime, and rail transport), and land use decisions (including industrial zones, university campuses, mass housing areas, hospitals, and city hospitals). The criteria to be taken into account in tramway route planning, along with the key factors related to each, are presented in Figure 2.

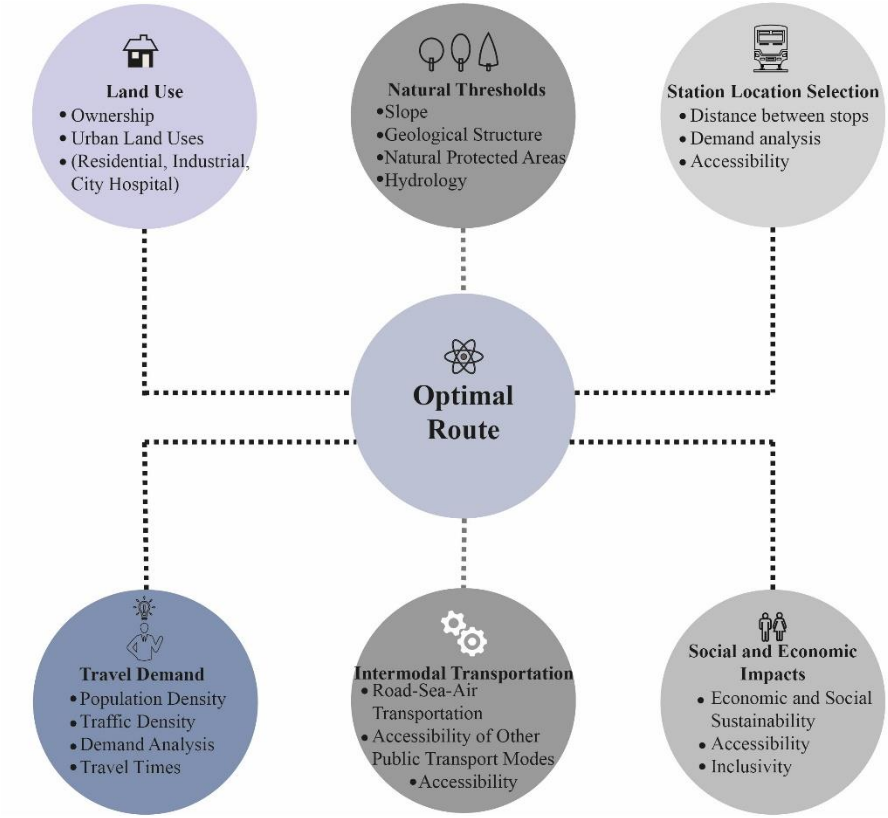

Figure 2. Optimal Route Selection in Tramway Systems (Original, 2025).

- **Land Use**

Studies conducted within the framework of the land use–use-transportation interaction aim to explain the factors that influence the spatial distribution of activities and to identify the interdependence and co-evolution of two key factors: land and transportation. Since transportation involves the movement of individuals and the goods they require, the factors that influence the location choices of individuals and activities are of great importance for transportation studies. (Baycan, 1993).

Since planning is broadly defined as the ability to make projections for the future, it must also be able to explain past and present conditions. Therefore, integration between land use and transportation planning is essential, enabling accurate forecasting and informed decision-making for future development.

While tramway systems guide urban development, they also play a significant role in meeting existing transportation demand. Therefore, considering that tramway systems are irreversible investments, and that rational use of urban land and efficient operation of these systems are essential, it is critically important to plan tramway routes in an integrated manner with land use decisions. Such integration is vital for achieving sustainable urban transportation and enhancing the quality of life within cities (Newman & Kentworthy, 1999).

- **Natural Thresholds**

In determining optimal tramway routes, not only data such as transportation demand and population density, but also environmental factors like natural thresholds play a significant role. In particular, slope characteristics along the route can directly affect the efficiency and energy consumption of tramway systems. In areas with steep gradients, tramway vehicles may require more energy to ascend, which becomes a significant factor that increases operational costs. (Erkut & Pala, 2016)**.** Moreover, in areas with significant slopes, road construction costs may also increase, making it essential to consider such natural obstacles in route design. Developing appropriate infrastructure and engineering solutions in sloped areas contributes not only to the feasibility of implementing the tramway system but also to its efficient operation. (Simon & Fernandez, 2014).

- **Travel Demand**

Transportation planning fundamentally addresses the factors that generate travel demand, including urban planning and land use, the spatial distribution of residents, and the resulting trip length, duration, and cost. It also considers the supply side of the transportation system and the operational interface where supply meets demand.

The primary goal of transportation planning is to create a supply that meets demand. However, establishing a balance between supply and demand requires consideration of principles such as rational land use, sustainable development, improved urban quality of life, social benefit, economic growth, and public interest.

Since high-cost investments like tram systems are sensitive to accurate ridership forecasting, failure to predict passenger demand correctly may jeopardize the economic viability of the system. Therefore, managing project costs and conducting realistic feasibility studies are crucial for tramway route planning, especially given that such projects represent long-term public investments. (Flyvbjerg, 2007).

- **Station Location Selection**

A successful tramway route and its planning are significantly influenced by the choice of station locations. Placing stations near areas with high transportation demand, such as public spaces, densely populated neighborhoods, business districts, workplaces, educational and healthcare institutions, and commercial areas, contributes to meeting passenger needs and improving the efficiency of tram operations. (Cervero & Kockelman, 1997). Selecting tramway station locations within walking distance (500 meters) of the specified areas helps reduce social exclusion among tram users and enables equal access rights for all city residents (Çakır, 2016). Additionally, locating tramway stations within walkable distances encourages a shift in travel habits towards public transportation and reduces private car usage. Therefore, the proper siting of tramway stations contributes to increasing environmental, social, and economic sustainability, thereby supporting sustainable urban development. (Calthorpe, 1993).

- **Intermodal Integration**

The development of public transportation systems and the reduction of automobile dependency in transportation have led to the emergence of the concept of integrated planning, aimed at preventing competition among different modes of transport. Due to their characteristics, tramway systems operate on fixed rails and generally have lower accessibility compared to other rubber-tired transport modes. Therefore, to ensure sustainable urban development and to enhance the efficiency of tramway systems, accessibility should be increased by considering integration with other transportation modes in the planning of tramway systems.

Developing an efficient transfer system between rail systems, which generally have lower accessibility, and other public transportation services encourages the preference of public transport modes over private vehicles (cars) in journeys, thereby supporting sustainable urban development. (Vuchic, 2007).

- **Social Impacts**

Public transportation systems, including tramways, contribute significantly to social inclusion by providing affordable and equitable access to mobility for all urban residents. By improving connectivity to employment, education, healthcare, and recreational areas, these systems help reduce social exclusion and promote equal opportunities. Furthermore, well-integrated tramway systems can foster community cohesion by encouraging social interactions and enhancing the livability of urban spaces. (Çolak & Ercan, 2019). Transportation is a fundamental human right granted to all individuals within society. Therefore, in the planning of tramway route alignments, principles of social inclusivity must be considered to ensure that the transportation services provided enable every individual to reliably access one point from another. (Litman, 2003).

2. Material and Method

The primary aim of this study is to examine the planned tramway route and station locations in our cities in conjunction with urban land use plans, in order to reveal their impacts on sustainable urban development. Within this context, the study seeks to analyze in detail the relationship between transportation investment and urban development, considering the high-cost infrastructure projects in the city. Specifically, by addressing the socio-economic, social, and spatial dimensions of the tramway route and station locations, the study aims to highlight both the positive and negative effects of the planned line on urban development, transportation accessibility, and social structures.

In this study, the sample area selected is the "New Tramway Line to the City Hospital" in Samsun, planned in 2024 but not yet under construction. Within the scope of the study, the planned transportation infrastructure aimed at improving accessibility to major urban functions, such as the Samsun City Hospital, has been analyzed in terms of the advantages and disadvantages it may bring to the city, considering the criteria that should be taken into account in tramway route planning.

The methodology of the study is based on a mixed-methods approach, combining both qualitative and quantitative research techniques to reveal the contributions of the planned tramway line's integration with land use decisions to sustainable urban development.

Within the scope of the study, field research was conducted considering factors such as the integration of tramway station locations with the existing transportation network, their compatibility with the urban fabric, accessibility of the stations, and similar elements.

Additionally, spatial analyses for the case study area were conducted using Geographic Information Systems (GIS) to examine spatial data such as land use around the planned tramway stations, population density, and proximity to social services. During the geographic analyses, various spatial data along the route were collected and processed using software tools including ArcGIS (ESRI) and Google Earth. The obtained spatial data enabled the analysis of accessibility and reachability levels in specific areas through visual maps. For data visualization within the scope of the study, software such as Adobe Illustrator and NetCAD were utilized.

3. Findings and Discussion

Located on the coast of the Black Sea, Samsun is a strategically important city serving as a regional center with concentrated transportation and healthcare services (Figure 3). In this context, the Samsun City Hospital, constructed within the boundaries of the Canik district, stands out as a critical investment both in terms of spatial development and healthcare infrastructure, due to its capacity to serve not only the city but also the surrounding provinces. Situated along the city's eastern corridor, the hospital plays a decisive role in shaping new urban functions and transportation infrastructure in this developing area. The planned 9-stop tram line, designed primarily to facilitate access to the hospital, represents not only an urban transportation project but also a developmental initiative supporting spatial growth along Samsun's eastern axis. In this context, the Samsun City Hospital serves as a significant example by enhancing access to healthcare services while also contributing to urban social cohesion and sustainable transportation objectives.

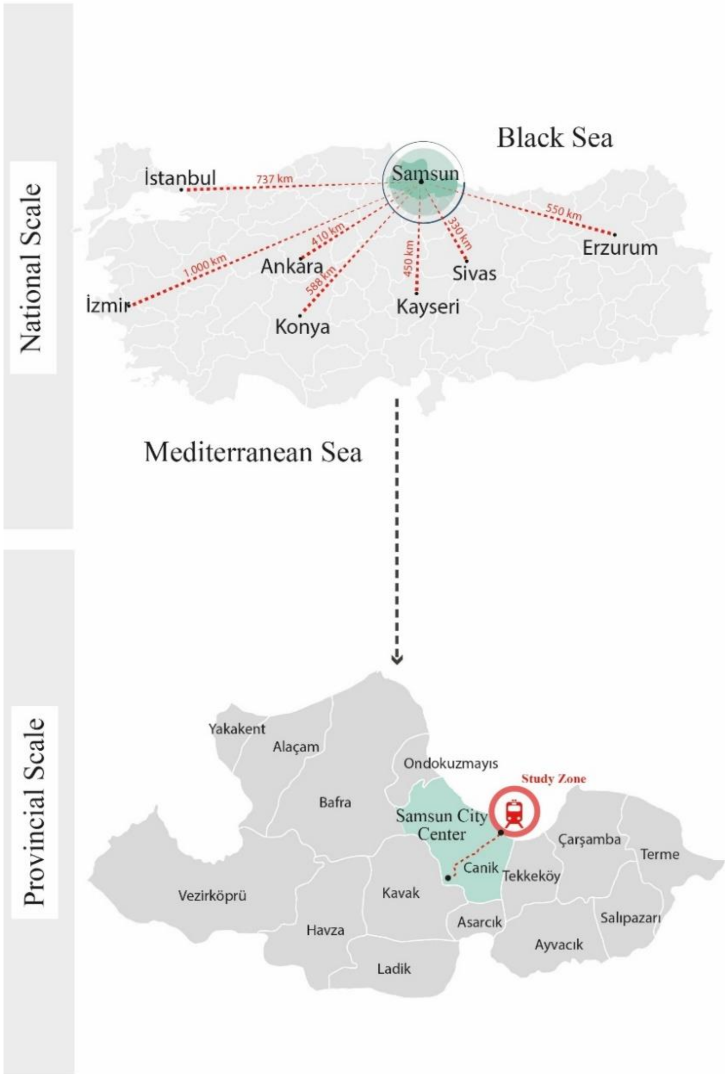

Figure 3. Location of Samsun

Figure 4 illustrates the detailed land use decisions within the study area located in the Canik district of Samsun province. Along the tramway route, commercial zones, industrial zones, publicly accessible green spaces (such as Doğu Public Park, Kefeli Public Park, and National Garden), Canik

Municipality service buildings, and developing residential areas highlight the urban functions that the line will serve. These components demonstrate that the tramway is connected not only to healthcare services but also forms an extensive interaction network encompassing social life, employment, and housing development.

The planning of the tramway line along the eastern corridor, where new residential development areas are located, is directly linked to the goals of sustainable urban growth and balanced land use. Moreover, public spaces and recreational facilities along the route contribute to enhanced social integration and improved pedestrian accessibility.

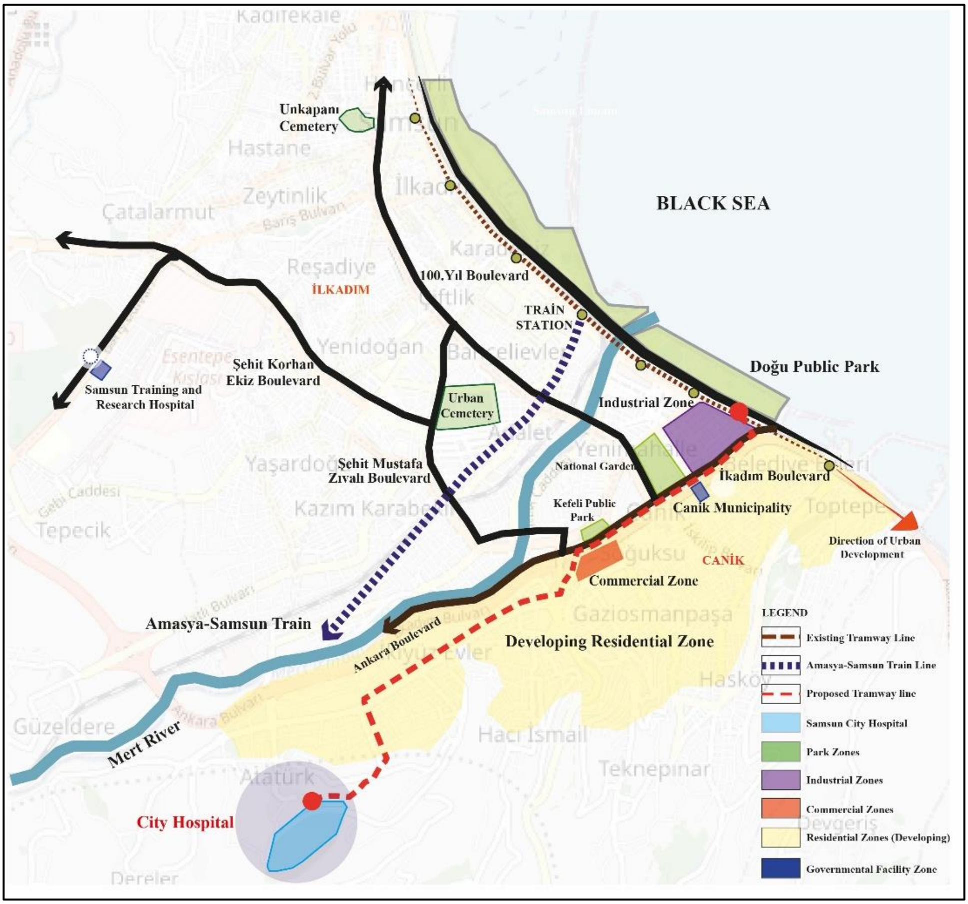

Figure 4. Study Area and Environmental Context (Original, 2025).

3.1. Spatial Analysis

Within the scope of the study, the first spatial analysis conducted involved public transportation demand analysis and traffic volume assessment of the region. The research and examinations carried out in this context provide critical data for understanding the current transportation infrastructure and capacity, as well as projecting future demand.

As presented in Figure 5, the Samsun Transportation Master Report was reviewed, revealing that the İlkadım and Ankara Boulevard sections along the planned tramway route experience high traffic volumes, ranging between 4,500 and 6,000 vehicles per hour. Considering the existing traffic density on this 50-meter-wide main urban corridor, alongside the demand for both public transit and private vehicles, the selection of the tramway alignment along this route is justified and supports the correctness of the route choice.

Figure 5. Public Transport Demand and Traffic Volume Analysis in Samsun Province (Samsun Metropolitan Municipality, 2020). (Original, 2025).

The planned City Hospital tram line consists of a total of 9 stops and has an approximate length of 4,350 meters (4.35 km). The line starts from Canik East Park, with its final stop at the City Hospital. In the 1/1000 scale Canik Implementation Zoning Plan, the area where the 2nd stop is located is designated as a park area. However, it currently functions as an industrial zone. Additionally, there are residential and developing residential areas, mixed commercial-residential zones, commercial areas, mass housing zones, public spaces, official institutions (municipality), and park areas along the route. The mixed-use land pattern is an important factor affecting travel demand. While the industrial area generates worker population mobility, residential areas have a fixed population, and public and commercial areas accommodate a more dynamic population.

Figure 6 shows the integrated zoning decisions and the tram line route. The first 500 meters of the line pass through a mixed-use area. It is located along a 50-meter-wide boulevard where pedestrian and vehicle traffic, as well as population density, are quite high. After the boulevard, the route connects to secondary inner-city collector roads where the settled population is denser but traffic volume decreases; from there, the line continues via the local road network to reach the City Hospital.

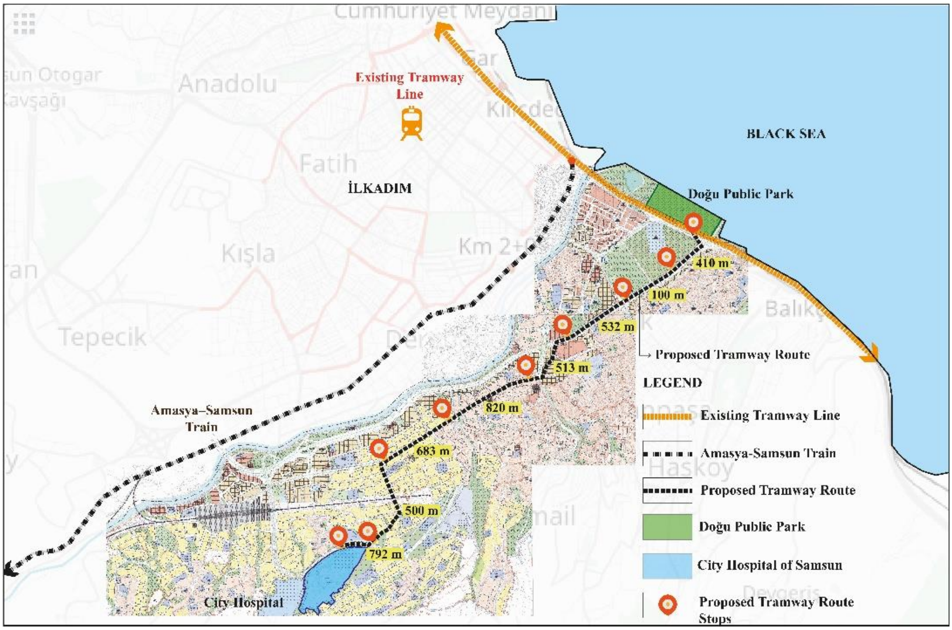

Figure 6. Canik District of Samsun Province 1/1000 Scale Zoning Plan and City Hospital Tramway Line (Original, 2025).

A comparative analysis of travel times to the city hospital by walking, private vehicle, and tramway was conducted within the scope of this study. The effectiveness of transportation systems is measured by comparing the travel times of different modes and evaluating their suitability to users' needs. Accordingly, a significant difference in travel times among walking, private vehicle, and tramway modes has been observed. Travel time is one of the most influential factors affecting demand for transportation modes. While a 1-hour and 45-minute walk may be accessible and sustainable, it is not time-efficient (Figure 7).

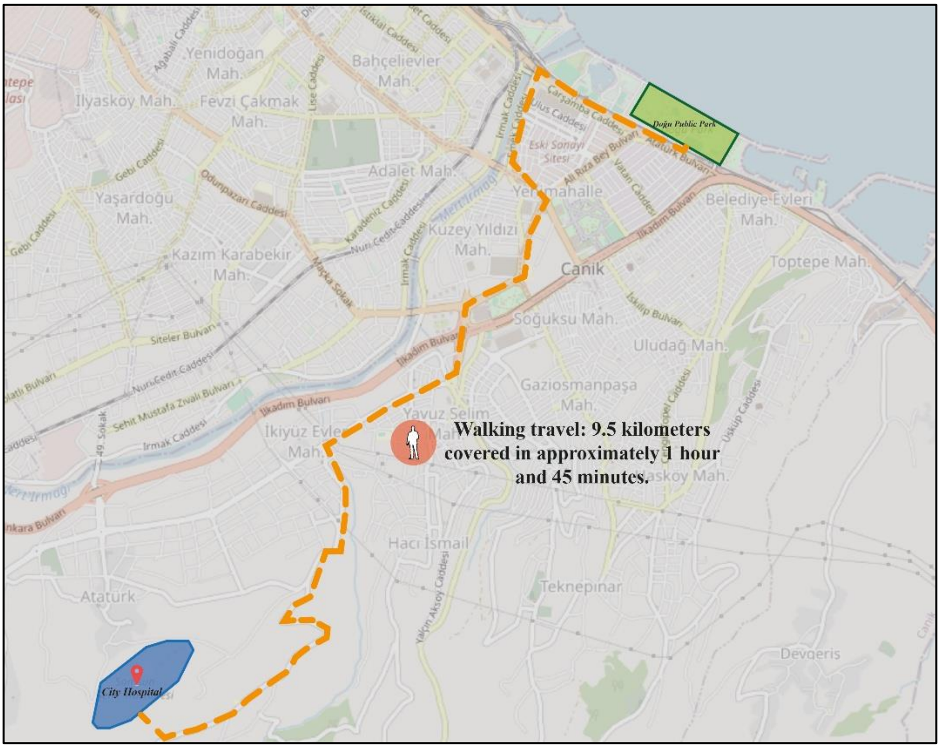

Figure 7. Walking Distance between Doğu Park and City Hospital (Original, 2025).

The 17-minute travel time by private vehicle offers a highly attractive transportation option for passengers in terms of speed and comfort. The flexibility provided by personal cars, direct access to destinations, and the absence of waiting times create significant advantages for users. However, alongside these benefits, private vehicle use presents serious disadvantages in terms of sustainability. Firstly, the operating and maintenance costs of private vehicles are significantly higher compared to public transportation, imposing an additional economic burden on individuals and society. Moreover, heavy private vehicle use causes traffic congestion, increasing travel times and reducing urban transportation efficiency. Additionally, carbon emissions from private vehicles contribute to air pollution and climate change, conflicting with environmental sustainability goals (Figure 8).

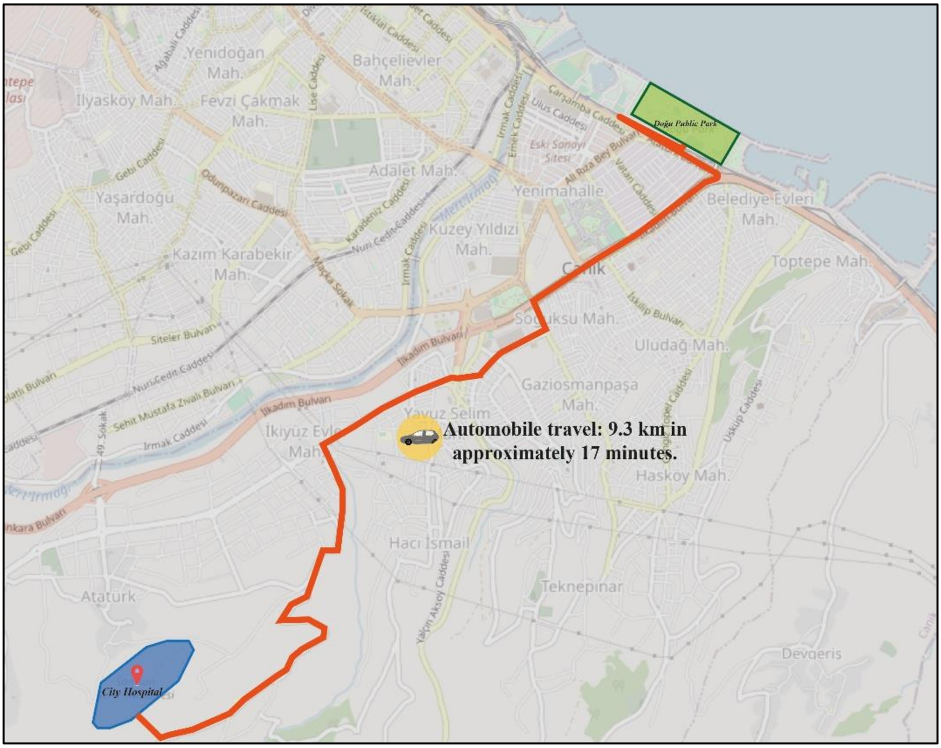

Figure 8. Private Vehicle Distance between Doğu Park and City Hospital (Original, 2025).

As shown in Figure 9, the 33-minute travel time, considered as an option between walking and private car use, demonstrates that the tram is an important alternative among transportation modes. The fixed-route advantage of rail systems plays a critical role in public transportation planning by providing more predictable and consistent travel times. Additionally, the tram offers an environmentally and socially sustainable transportation solution with its low carbon emissions and wide accessibility features. Consequently, the differences in travel times between walking, private car, and tram modes highlight the need for expanding public transportation systems and strengthening infrastructure.

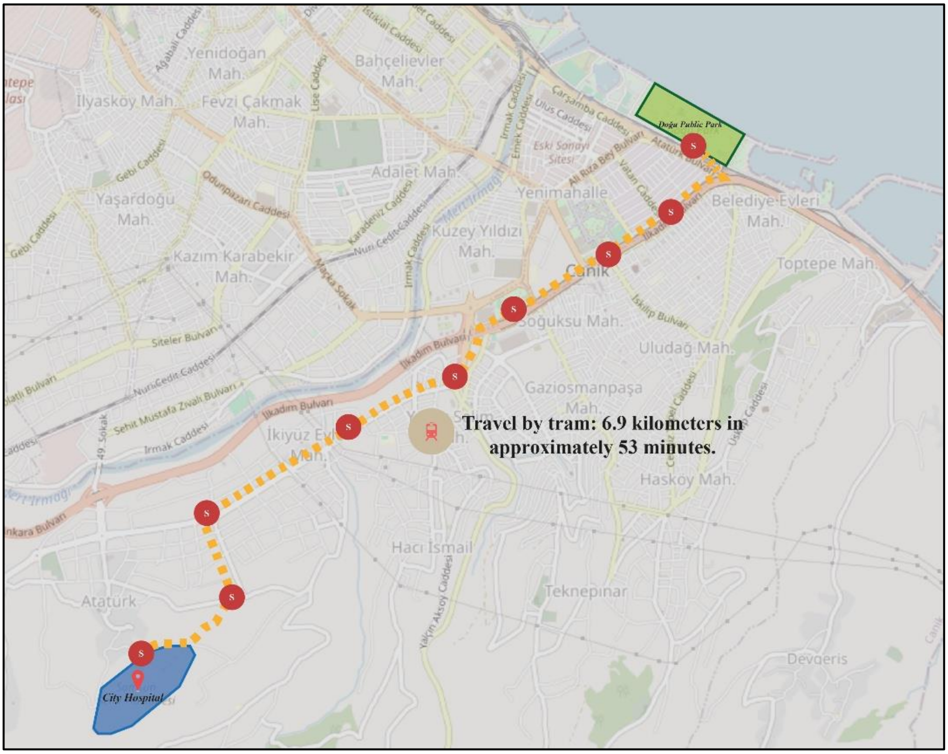

Figure 9. Distance of the Tramway Line between Doğu Park and City Hospital (Original, 2025).

The tram presents itself as an optimal solution in terms of time efficiency, accessibility, and social inclusivity. However, beyond being selected as the most optimal mode of transport, the integration of the tram route with land use planning, as well as the criteria for station location selection and their contribution to sustainable urbanization, come to the forefront. Therefore, the tram route must be designed and interpreted in harmony with physical, environmental, and social contexts. Particularly when considering land use decisions, density analyses, and user needs together, it becomes crucial not only for the tram to be an optimal choice but also to be integrated with land use and for station locations to be carefully selected.

Within the scope of this study, station location selections were analyzed in an integrated manner with land use. This approach ensures that the tram system is incorporated into the urban fabric holistically, addressing not only the physical layout but also the social, economic, and environmental impacts comprehensively.

The suitability of the proposed tram line within the scope of the Samsun City Hospital tramway project was analyzed based on criteria established in the literature. As shown in Figure 10, the initial stop of the line, which connects from Doğu Park, is located on Atatürk Boulevard. The second stop is situated 410 meters further along the route. Although this area is designated as a park in the zoning plan, its current use is industrial. The third stop, located 100 meters beyond, is positioned opposite the Samsun Chamber of Commerce and Industry.

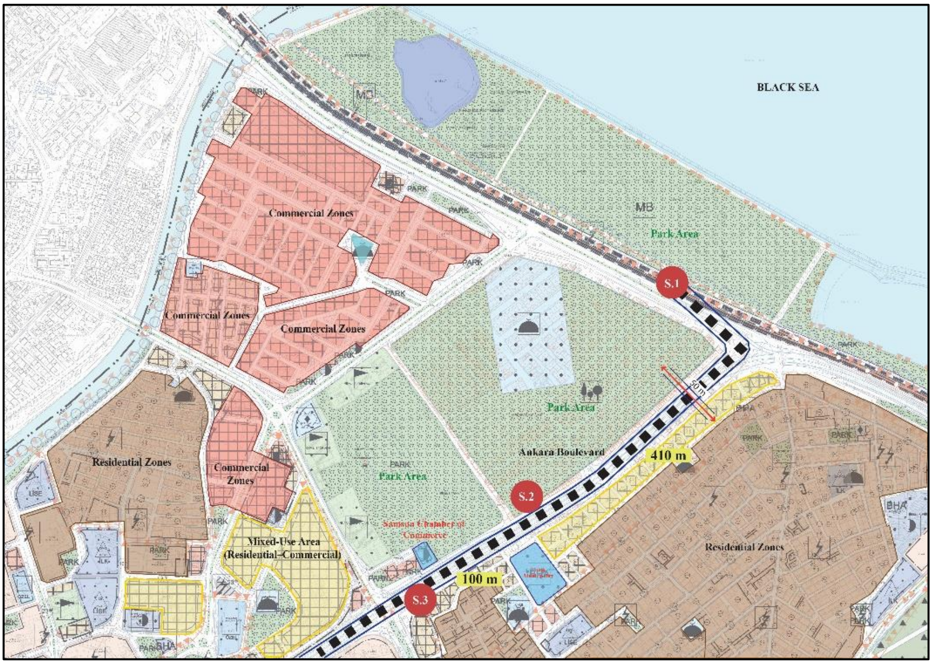

Figure 10. Tramway Line Stop Distances – (Stops 1, 2, and 3) (Original, 2025).

An examination of land use, density, and distances between stops reveals that the area between the three stops stands out as one of the locations within the Canik district with the highest volume of vehicular traffic, pedestrian flow, and both static and dynamic population. On average, the ideal walking distance to a tram station is considered to be between 300 and 500 meters. While the access distance between the first and second stops meets standards, the 100-meter gap between the second and third stops necessitates frequent tram stops. This situation extends the total travel time and reduces time efficiency for users. Such effects are particularly notable in fixed-route systems like rail transit.

Moreover, the land use decisions in the area, traffic and population density, presence of mixed-use zones, and high urban mobility collectively make this one of the areas with the most intense demand for public transportation.

The fourth stop of the tram line on the 50-meter-wide Ankara Boulevard is located at Kefeli Park. The distance between the third and fourth stops is 532 meters. As seen in Figure 11, the land use in this area includes commercial zones, parks, mixed commercial-residential areas, and residential zones. The distance between these stops falls within the ideal walking distance. The tram line continues from the first main distributor road, which is 50 meters wide, via a local road connection and proceeds along a 35-meter-wide urban collector road.

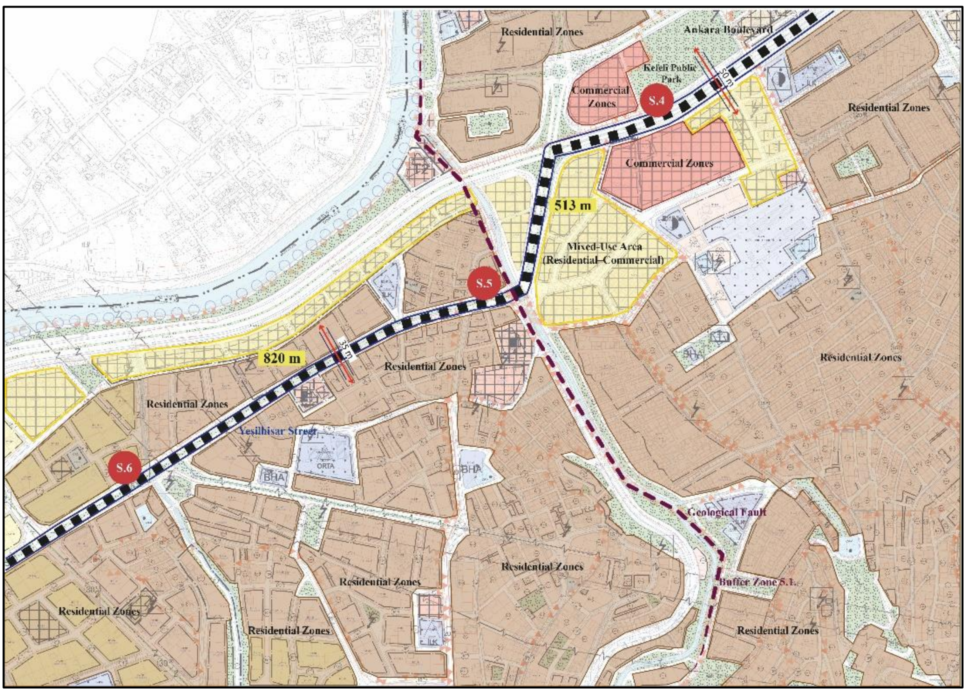

Figure 11. Tramway Line Stop Distances – (Stops 4, 5, and 6) (Original, 2025).

After the fifth stop, there is a transition from highly dense central areas to moderately dense residential sub-regions. The distance between the fifth and sixth stops is measured at 820 meters, which is the longest gap between any two stops on the line. Longer distances between stops increase the walking distance for users to reach the tram stations. When walking distances exceed 500 meters, the interest of individuals in using public transportation tends to decrease. Additionally, this reduction in the number of stops leads to more passengers boarding at each stop, potentially causing overcrowding during peak hours and congestion.

Furthermore, the absence of an alternative public transportation option along this route compels users to rely solely on this tram line. This dependency indicates the need to plan the system not only to serve those accessing the city hospital but also to accommodate the wider urban population, thereby ensuring a more efficient and sustainable transit system.

The seventh stop, located on the 35-meter-wide Yeşilhisar urban collector road, is 683 meters away from the sixth stop. As shown in Figure 12, residential sub-areas are clustered around the station. Population and traffic density in this area range from medium to low. The route proceeding southward intersects with the TCDD. (Turkish State Railways) railway line at this point. The distances between stops have been determined based on urban land use and density, with longer intervals between stations in low mixed-use and low density areas.

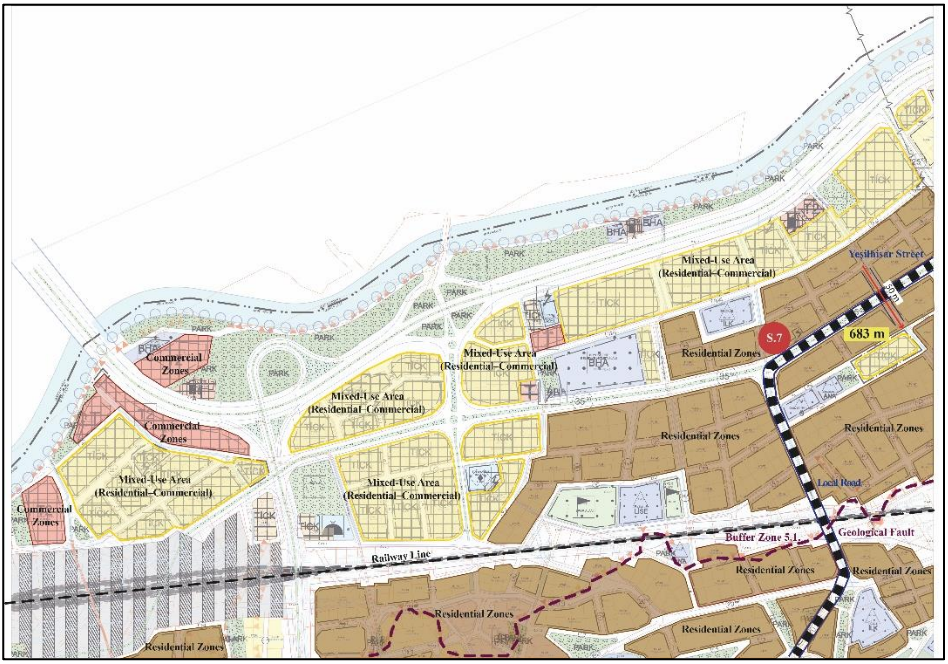

Figure 12. Tramway Line Stop Distances – (Stop 7) (Original, 2025).

This approach has both positive and negative aspects. The positive aspect is that by avoiding unnecessary frequent stops in low-density areas, travel time is reduced and the operational efficiency of the system is improved, which provides faster transportation for passengers and reduces operating costs.

On the other hand, the negative aspect is that increased distances between stops can make station access difficult for some users. This is especially critical in areas with limited pedestrian accessibility, where it may reduce the attractiveness of the public transportation system and lead to a decline in ridership.

The tram route continuing southward reaches the eighth stop after a distance of 500 meters. Following this, the final destination of the system, the City Hospital, is reached after an additional 792 meters. According to the land use decisions presented in Figure 13, this segment of the line passes through an area characterized by low urban population density and low traffic volume. The sloped topography of the area further limits accessibility.

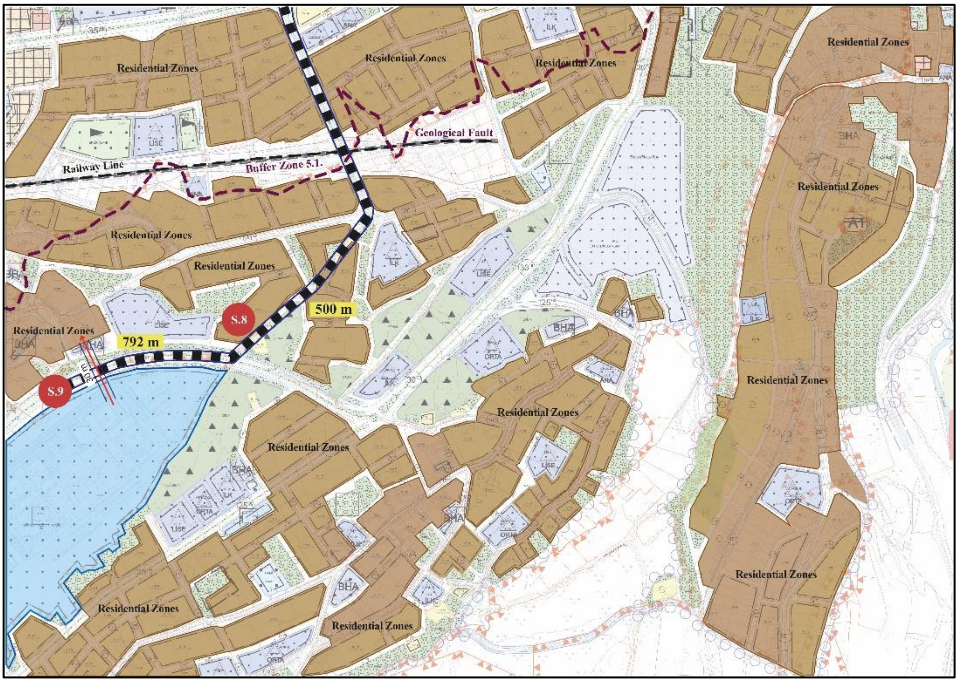

Figure 3.11. Tramway Line Stop Distances – (Stops 8–9) (Original, 2025).

This part of the line has the lowest levels of accessibility, population density, and mixed land use. However, the presence of a major facility such as the City Hospital is expected to generate a significant demand for public transportation in this area.

Spatial analyses aside, one of the key factors influencing the alignment and station selection of the entire tram line is natural constraints. Among the identified natural thresholds, slope and geology analyses were evaluated within the scope of this study. The geological structure of the land through which the tram line passes corresponds to Precautionary Area 5.1. According to the geological report, this area consists of Neogene and alluvial ground. It indicates that the area can be made suitable for development with the necessary engineering precautions. No geological disaster risk has been identified in the region.

Slope analysis plays a significant role in the planning of rail system alignments. Considering slope values during the planning phase is of critical importance for the technical feasibility of the system, as well as for construction, operation, and maintenance costs. Slope directly affects the tram's maneuverability, passenger comfort, and operational safety. In general, the recommended maximum slope for rail systems ranges between 6% and 8%. In order to assess how well the route conforms to the topography, a slope analysis was carried out using geographic information systems software. The results showed that the majority of the line lies within a slope range of 5 % to 10 %

Following the eighth stop, approximately 1, 292 meters of the route fall within a slope range of 36 % to 45 %. According to Figures 14 and 15, these sections represent high-gradient areas. In such areas, the tram's energy consumption increases significantly. This not only raises operating costs but may also negatively impact environmental sustainability goals.

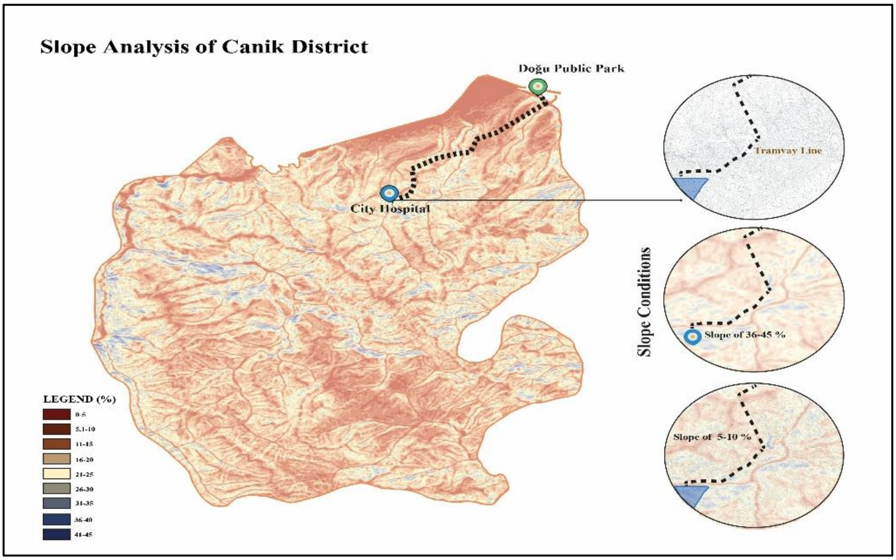

Figure 14. Slope Analysis of Canik District and Tramway Route Gradient Condition (Original, 2025).

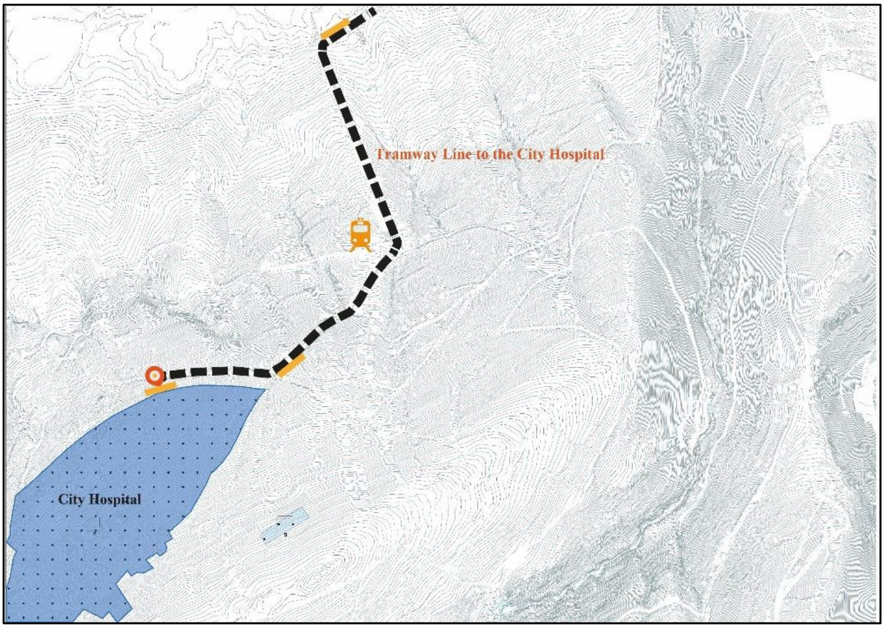

Figure 15. Tramway Line Slope Condition (Original, 2025).

4. Conclusion and Suggestions

This study aims to evaluate the planning process of the Samsun City Hospital tram line project by integrating various analyses conducted throughout the process. The primary objective of the research is to address transportation systems not only from a technical standpoint but also within a holistic sustainability framework that encompasses social, economic, and environmental dimensions. Within this context, the findings reveal the practical applicability of sustainable transportation policies based on empirical data, while simultaneously highlighting the critical interrelationship between urban development and transportation planning. One of the most significant findings of the study is that the integration of the tram line route with urban land use planning substantially enhances the efficiency and sustainability of the public transportation system. The route's passage through areas associated with diverse urban functions, such as residential, commercial, educational, and healthcare not only improves accessibility but also ensures spatial coherence among these functions. This demonstrates the successful application of the land use and transportation integration principle in the case of Samsun. In particular, the inclusion of commercial and healthcare zones as primary focal points along the line emerges as a key factor in supporting public transport demand. In this regard, the study highlights the critical role of public transportation systems in the spatial organization of sustainable urban development.

The route planning based on land use analyses and settlement densities has contributed to the promotion of social equity. Ensuring that public transportation is accessible to different social groups within the city represents a significant advancement in terms of the right to mobility. This highlights that sustainable transportation serves not only environmental objectives but also the dimension of social sustainability.

Slope, as a critical parameter in rail system projects, has been analyzed in detail with respect to the Samsun tram line. Measurements conducted through Geographic Information Systems (GIS) indicate that the majority of the line has slope values ranging between 5% and 10%, while in some sections, this ratio increases up to 36% to 45%. High slope values directly affect energy efficiency and operating costs and are also closely related to environmental sustainability goals. Therefore, evaluating alternative routes with lower gradients and developing engineering solutions during the tram line planning process is essential.

In the scope of travel demand analysis, it has been determined that routing the line through areas with high concentrations of industry, commerce, and public services is a well-founded choice to meet high passenger demand. Additionally, the spacing between stops is a crucial variable for the efficiency and user comfort of the public transportation system. Frequent stop placement prolongs travel time, whereas sparse stop spacing can lead to accessibility issues. Therefore, in the case of Samsun, stops were selected based on population density and social attraction centers, adopting a planning approach consistent with the principle of walkability. However, the imbalance between crowding and comfort at certain stop intervals necessitates dynamic stop optimizations in the future to enhance the operational effectiveness of the public transportation system.

The integration of the tram line with existing transportation systems in Samsun is limited. The complex structure of bus routes and the prevalence of paratransit modes such as shared taxis complicate the development of a multimodal transportation network. However, the integrated planning of different modes, including tram, bus, bicycle, and pedestrian pathways, is a fundamental principle of sustainable transportation. Enhancing integration will reduce passenger transfer times, balance traffic loads, and contribute to the reduction of the carbon footprint.

The tram line's planning has considered access to transportation services for disadvantaged groups. Specifically, the placement of stops near residential areas of the elderly, people with disabilities, and low-income groups supports social equity and inclusivity. This approach enhances equal opportunities within the city and reduces the risk of social exclusion. By connecting disadvantaged neighborhoods with the city's central business districts, the line facilitates the access of economic opportunities to diverse social segments. Thus, the tram line functions not only as a transportation infrastructure but also as an urban development tool that promotes social integration.

Thanks to the low carbon emissions characteristic of rail systems, the Samsun tram line can be regarded as a model contributing to environmental sustainability goals. The energy efficiency of the tram, its role in reducing carbon emissions, and its positive effects on air quality position this system within a transportation policy that prioritizes ecological balance.

In line with these evaluations, the Samsun City Hospital Tram Line Project presents an urban development model integrated with sustainable transportation principles. The project addresses multidimensional objectives such as transportation and land use integration, social equity, environmental sensitivity, and economic efficiency, thereby standing out as a concrete implementation of sustainable urban development.

This study demonstrates the critical importance of an integrated transportation approach in planning the Samsun City Hospital tram line. The combined evaluation of parameters such as land use, stop location, slope analysis, and the integration of transportation modes optimizes the sustainability and social impacts of transportation systems. The findings indicate that the tram line should be viewed not only as a transportation tool but also as a social transformation project aimed at enhancing urban quality of life.

Tram lines not only provide a transportation solution but also support objectives such as social equity, economic accessibility, and environmental sustainability. The Samsun case demonstrates that focusing on combating social exclusion in transportation planning significantly enhances urban quality of life. In such projects, multidisciplinary approaches should be adopted, and urban transportation systems must be designed with consideration of social contexts.

This study conducted various analyses on the planning process of the Samsun City Hospital tram line, and the findings provided significant data for the efficient design of the line. The results of the research can be summarized as follows, considering transportation efficiency, environmental impacts, social inclusivity, and urban integration of the tram line:

Land Use: Based on the evaluation of the conducted analyses, it has been determined that the tram route is planned in harmony with urban land use decisions. The presence of dense commercial and residential areas along the route increases public transportation demand while facilitating the integration of the rail system into the urban fabric. The integration of land use and transportation systems is considered a key factor in promoting public transit usage.

Natural Thresholds: The slope analysis along the route revealed that the majority of the line complies with slope limits between 6% and 8%. However, certain sections exhibit high slope values (approximately 36% to 45%), which increase energy consumption and operational costs of the tram system. This factor is evaluated as a potential constraint affecting the technical feasibility of the route.

Travel Demand and Trip Durations: The tram line offers shorter travel times compared to alternative modes, especially for accessing the city hospital. In areas with long walking distances, the tram system emerges as a time-efficient and environmentally sustainable option. With a travel time of 33 minutes, the tram produces lower carbon emissions compared to private vehicles, aligning with sustainable transportation goals.

Station Location and Accessibility: The evaluation of station location analyses indicates that pedestrian access, as well as integration with private vehicles and other transportation modes, has been ensured. The distance between stops has been maintained within an ideal walking range; however, longer distances between certain stops may negatively affect user comfort and demand for the tram.

Intermodal Transportation and Accessibility: The successful operation and efficiency of the tram line depend on its integration with other transportation modes. It has been identified that the Samsun City Hospital tram line lacks sufficient integration with existing public transport systems, and enhancing this integration is necessary for efficient operation. The complex structure of bus routes and the widespread use of paratransit modes such as shared taxis limit the tram line's potential effectiveness. Moreover, establishing transfer stations with other transportation modes at key stops will facilitate passenger access to public transit.

Social Impacts: From the perspective of social inclusivity, station location planning has taken into account the needs of people with disabilities, the elderly, and low-income groups, thereby supporting social equity. Such planning efforts reduce the adverse effects of transportation systems on social exclusion.

In this context, the tram line is evaluated based on the analysis findings, with the overall assessment presented in Table 1. According to the conclusions drawn from the table, the stations are classified into six categories ranging from very low to very high service quality (Figure 16). The station with very high service quality is identified between the initial stop and the first stop, while the station with very low service quality is found between the seventh stop and the city hospital.

Table 1. Evaluation of Samsun City Hospital Tram Line and Stations

Station Name	Distance Between Stations	Natural Constraints (Slope, Geology)	Land Use	Density	Demand and Need	Land Ownership	Social and Economic Impacts	Evaluation
Doğu Park –Station 1	410 m	There is a slope between 0% and 5% and no geological problems have been identified.	The surrounding area includes residential, mixed-use residential and commercial, developing residential, commercial, industrial, and public land uses.	Traffic and population density are high.	There is a high demand for private vehicle use, while public transportation routes are insufficient.	All properties are parcels subject to zoning regulations, and the tramway route is effectively used as a 50-meter main distributor road.	Local residents have easy access, significant worker mobility, convenient transfers to the existing tram line, mixed-use development, and high pedestrian circulation.	The stop distance is walkable, so the need for public transportation may be minimal.

Station 1-Station 2	100 m	The slope ranges between 0% and 5%, and no geological issues have been detected.	The surrounding area includes residential, mixed-use residential and commercial, developing residential, multi-family housing, commercial, and public land uses.	Traffic and population density are high.	There is a high demand for private vehicle use, while public transportation routes are insufficient.	All properties are parcels subjected to zoning regulations, and the tramway route is effectively used as a 50-meter main distributor road.	There is a high presence of commercial and public land uses, significant economic impact, and heavy pedestrian circulation.	The stop distance is very short, which may cause congestion, and the need for public transportation may be minimal.
Station 2-Station 3	532 m	The slope ranges between 0% and 5%, and the area falls within the precautionary zone 5.1 in terms of geological conditions.	The surrounding area includes commercial-residential, developing residential, multi-family housing, commercial, public land uses, and official institutions such as Canik Municipality.	Traffic and population density are high, with heavy pedestrian circulation.	There is a high demand for private vehicle use, while public transportation routes are insufficient.	All properties are parcels subject to zoning regulations, and the tramway route is effectively used as a 50-meter main distributor road.	There is significant public space activity, indicating a demand for public transportation in the area.	The station distance is walkable, and there is a demand for public transportation.
Station 3-Station 4	513 m	The slope ranges between 0-5%, and geologically it corresponds to precautionary zone 5.1.	The area surrounding the region includes land uses such as commercial-residential, developing residential, mass housing, commercial zones, public spaces, and official institutions.	Traffic and population density are moderate.	There is a high demand for private vehicles, and public transportation routes are insufficient.	All properties are parcels that have undergone zoning implementation, and the tramway path is effectively used as an urban local road. The road width is narrow.	Mixed-use is high, and the service area primarily consists of urban residents.	The station distance is walkable, and there is a demand for public transportation.
Station 4-Station 5	820 m	The slope ranges between 0-5% and corresponds to geological precaution area 5.1.	The area around includes mixed-use residential and commercial zones, as well as developing and established residential areas..	Traffic and population density are moderate.	Demand for private vehicles is high, and public transportation routes are insufficient.	All properties have undergone zoning regulations, and the tramway route is effectively used as a 35-meter collector road.	Residential area usage is high, with a balanced day and night population, primarily serving residents in the area.	The distance between stops is beyond walking distance, indicating a demand for public transportation. This is the stop with the longest distance between stations.
Station 5-Station 6	683 m	The slope ranges between 0.5% and 5-10%, and geologically, it falls within the precautionary zone 5.1.	The area is characterized by mixed-use functions, including commercial-residential, developing residential, and established residential zones.	Traffic and population density are low to moderate.	Demand for private vehicles is normal, while public transportation routes are insufficient.	All properties are parcels subject to zoning implementation, and the tramway route is effectively used as a 35-meter	Residential land use is predominant, with a balanced day and night population, primarily serving the residents of the area.	The station distance is walkable, and there is a demand for public transportation.

						collector road.		
Station 6-Station 7	500 m	The slope ranges between 10% and 20%, and it falls within the geologically protected area 5.1.	The area surrounding the station includes mixed-use functions such as commercial-residential, developing residential, and established residential zones. It also intersects with the TCDD railway line.	Traffic and population density are low.	Demand for private vehicles is normal, but public transportation routes are lacking.	All properties are parcels that have undergone zoning implementation, and the tramway route is effectively used as a 35-meter collector road..	Residential land use is predominant, with a balanced day-night population, primarily serving residents staying in the area.	The station distance is walkable, and there is a demand for public transportation.
Station 7-City Hospital	792 m	The slope ranges between 36% and 45%, and the area falls within the geologically protected zone 5.1.	The area is surrounded by developing and residential housing land uses.	Traffic and population density are low.	The demand for private vehicles is within normal levels, while there is a deficiency in public transportation routes.	Most of the properties are parcels that have not undergone land-use (zoning) implementation, and there is no existing access road in practice. Expropriation costs may be added to the overall construction cost.	Pedestrian circulation is currently minimal; however, the presence of the city hospital indicates potential for increased social and economic activity.	The bus stop is located beyond a walkable distance; the terrain slope is steep, resulting in high expropriation and construction costs. The need for public transportation is high, yet access remains limited and constrained.

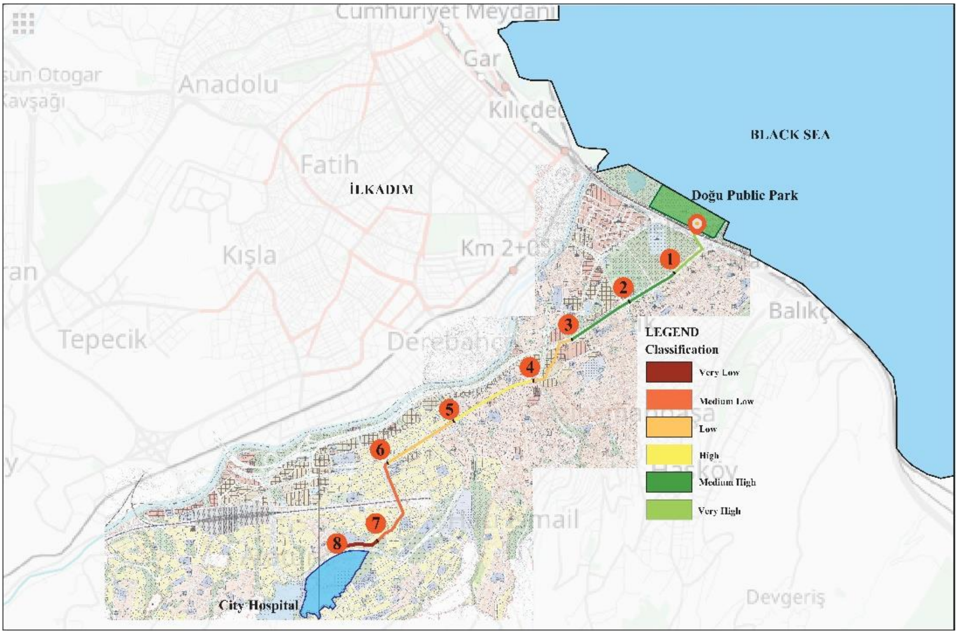

Figure 16. Station Ratings (Original, 2025).

In conclusion, this research demonstrates that the spatial, technical, and socio-economic analyses conducted in planning the Samsun City Hospital tram line can be utilized to enhance the efficiency of the transportation system both technically and socially. This multidimensional planning process, covering route selection, station placement, slope analysis, and passenger demand assessments, largely aligns with the fundamental principles of sustainable transportation.

Such an integrated approach not only enhances the efficiency of the transportation system but also strengthens urban spatial organization by harmonizing land use and transportation. Increasing access to public transit while simultaneously addressing social inclusivity, reducing environmental impacts, and improving economic efficiency offers significant benefits for sustainable urban development.

Therefore, the Samsun case presents a successful model that enhances the feasibility of sustainable transportation policies and integrates these policies with urban planning. This model can serve as an example for improving urban quality of life and preserving long-term environmental, economic, and social balances.

Acknowledgements and Information Note

Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article. There is no conflict of interest.

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Designing with the Senses: Cultural and Therapeutic Dimensions of Medicinal Plants in Sensory Gardens

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1. Introduction

In a world characterized by fast-paced urban life and a screen-dominated environment, people are increasingly disconnected from direct, meaningful interactions with nature. Sensory gardens have emerged as an inclusive and restorative design approach that encourages individuals to interact with the environment through the basic senses of sight, hearing, touch, smell and taste, using landscape elements such as carefully selected plants, materials and spatial arrangements (Hussein, 2012). These gardens not only provide esthetic experiences but also have a direct impact on mental and emotional health by activating the neurosensory systems (He et al., 2022a; Tutova et al., 2025). They are therapeutic environments designed to promote cognitive, emotional and physiological well-being. The main objectives of sensory gardens include fostering therapeutic experiences such as stress reduction and emotional regulation and providing educational opportunities, especially for children and people with sensory integration problems. These spaces are particularly beneficial for people with disabilities, the elderly, children, and neurodiverse individuals, as they provide accessible, stimulating and meaningful contact with nature.

Sensory gardens serve as environments that offer natural aesthetics while functioning as intricate systems that promote cognitive, emotional, and social well-being. In this context, this study examines the contribution of medicinal plants to sensory landscapes, aiming to inform sustainable and inclusive garden design.

2. Approach to Sensory Gardens from the Perspective of Medicinal Plants

Sensory gardens were first used in rehabilitation centers to contribute to the healing process of individuals with mental and physical disabilities. Over time, they have become prevalent in public spaces, schools, hospital campuses and even university campuses (Souter-Brown, 2020; Stepansky et al., 2022). The individual effects of sensory gardens include reduced stress, stabilization of mood and increased attention capacity (Ferrentino et al., 2024; Lu et al., 2025).

For children, it has the function of supporting the development of motor skills and environmental skills, while for the elderly, it stimulates memory and social interaction (Dudkiewicz et al., 2020; Yusop et al., 2020). Neuroscientific studies also show that sensory stimuli interact with the brain at the neurasthenic level and have effects on memory and mood in the limbic system (Biondi, 2025; Denno et al., 2025). It is of great importance to plan these gardens on the level of accessibility for people with disabilities. Ramp systems, Braille labelling, tactile orientation aids and raised beds can ensure that sensory experiences can be experienced equally by all (Souter-Brown, 2014). The notable examples in Turkey 'Accessible (Barrier-Free) Garden' in Bursa Botanical Park as well as international examples The Alnarp Rehabilitation Garden in Sweden, the sensory garden of the Royal National Institute of Blind People in the UK and the Healing Garden at the Singapore Botanical Gardens will be detailed in section 7. All these examples show that sensory gardens are not only spaces that provide natural aesthetics, but also complex systems that support cognitive, emotional and social health.

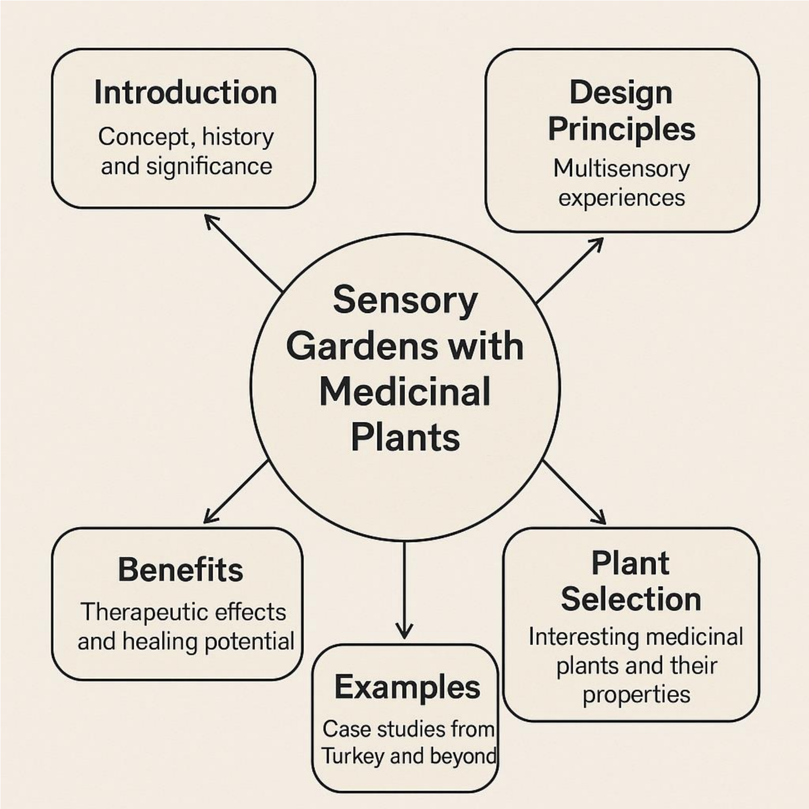

Figure 1. Topic flowchart (Created by the author)

Figure 1 shows the topic flowchart of the research used in this study. The aim of this study is to contribute to sustainable and inclusive garden design models by examining the effects of medicinal plants on sensory landscapes, both theoretically and practically. This research uses a literature-based approach, where previous research is critically analyzed to inform the design of inclusive and therapeutic sensory landscapes. The next section explains the definition, historical use, classification and cultural context of medicinal plants and why these plants should be prioritized in sensory gardens. The relationship between aromatic plants and individual olfactory memory is important for creating a healing atmosphere in sensory gardens (Krzeptowska-Moszkowicz et al., 2022).

3. Definition, Classification and Cultural Context of Medicinal Plants

Medicinal plants play a unique and versatile role in landscape design. They offer aesthetic appeal, sensory stimulation and therapeutic potential. Unlike ornamental plants, which are chosen primarily for their visual impact, these plants appeal to multiple senses simultaneously through colorful flowers, fragrant essential oils, tactile foliage, edible components and even sounds including the gentle movement of leaves in the breeze and the presence of sound-producing pollinators. These sensory properties make them particularly suitable for use in sensory gardens, where interaction with nature is intentionally designed to promote human well-being. Medicinal plants are natural resources that are used to protect, improve or support human health. Thanks to their active chemical constituents, these plants have had an important place in both traditional and modern medicine throughout history (Souter-Brown, 2014). Phytotherapy, or herbal treatment, draws attention not only because of its pharmacological efficacy, but also because of its place in cultural memory. Today, the growing interest in medicinal plants is supported by both ecological sustainability and a low side effect profile (Iommelli et al., 2025; Locqueville et al., 2025; Mykhailenko et al., 2025).

The classification of medicinal plants is usually based on their functional effects, pharmaceutical ingredients or aromatic properties. For example, species containing essential oils, such as lavender and lemon balm, are generally known for their sedative and anxiolytic effects, while species such as rosemary and mint exhibit cognitive stimulant and memory supportive effects (Krzeptowska-Moszkowicz & Moszkowicz, 2025a). Some classifications categorize these plants according to their effects on the digestive, respiratory, nervous or immune systems (He et al., 2022a). From a cultural perspective, Anatolian lands are rich in both endemic diversity and historical use. For example, plants such as *Origanum vulgare* (oregano), *Salvia officinalis* (sage) and *Althaea officinalis* (marshmallow flower) have been used for centuries not only in culinary culture but also in folk medicine. This traditional knowledge gives cultural depth and identity to today's sensory landscapes. The use of medicinal plants in sensory gardens not only enhances biodiversity, but is also valuable for re-establishing cultural ties, supporting learning processes and making natural heritage visible. These plants enhance the sensory experience on both a mental and emotional level through their visuality, texture, scent and historical context (Xu et al., 2025). In this context, the selection of medicinal plants should be considered not only as an aesthetic but also as a meaningful and functional design decision. The use of these plants, especially in sensory gardens designed for children, the elderly and various disability groups, produces both pedagogical and therapeutic benefits. Examples such as the anxiety-reducing effect of lavender scent, the mental alertness of mint leaves and the support of cognitive processes by sage allow sensory stimuli to be directly linked to health (Hao et al., 2025). Therefore, the deliberate use of medicinal plants in sensory landscape designs in accordance with the local context is of high value both for the user profile and for environmental sustainability. In this context, the next section will focus on the most used medicinal plant species in sensory gardens and their physiological, psychological and social effects (Wang et al., 2025).

4. Main Medicinal Plants Used in Sensory Gardens

At the heart of a successful sensory garden is a carefully considered selection of plants that stimulate one or more senses. The selected species not only appeal to the five senses but also offer scientifically proven health benefits thanks to their bioactive compounds. Furthermore, the medicinal plants used in the sensory gardens are selected both for their aesthetic qualities and for their therapeutic effects, sensory stimulation and cultural context. These plants activate the senses while appealing to the individual's mental and emotional world (Kim & Park, 2025; Xie et al., 2025). In other words, the rich sensory and therapeutic profile of medicinal plants makes them ideal for creating emotionally engaging and health-promoting gardens. When selecting plants, it is helpful to ask how each plant interacts with the senses, which sensory effects align with which user needs and which scientific principles support these interactions. Some examples of medicinal plants the most used in sensory gardens, their scientific names, sensory effects and reasons for use are presented in Table 1.

Table 1. Examples of medicinal plants commonly used in sensory gardens (Created by the author)

Scientific Name	Sensory Impact	Reason for Use
Lavandula angustifolia L.	Smell, Sight, Hearing	respiratory tract disorders such as bronchitis (Kayiran et al., 2025), ease strees and anxiety (Karoń et al., 2024)
Melissa officinalis L.	Smell	antidepressant, stress reliever (Priya et al., 2025), supports mood and nerve system (Kera et al., 2024)
Calendula officinalis L.	Sight	promotes skin healing (Deka et al., 2021), antibacterial and anti-inflammatory (Davoudabadi et al., 2023), immune stimulating (Ashwlayan at al., 2018)

Rosmarinus officinalis L.	Smell, Taste, Touch	mental stimulation (Hussain et al., 2022), memory support (Priya et al., 2025; Zhang & Lu, 2025), anti-inflammatory (Benincá et al., 2011), antinociceptive (González-Trujano et al.,2007)), neuroprotective (Rahbardar & Hosseinzadeh, 2020)
Rosa spp. L.	Smell, Sight	Anti-tumor activities, atherosclerosis prevention (Pan et al., 2025), symbolic and aesthetic value colorful fragrant flowers (Takahashi et al., 2024)
Aloe vera L.	Touch	soothes burns, skin irritations and heals wounds (Massoud et al., 2023), gastro-protective, antifungal, and anti-inflammatory (Asif et al., 2023), cool, gel-filled leaves
Origanum vulgare L.	Smell, Taste	antioxidant and immune boosting properties (Azimzadeh et al., 2024), anti-inflammatory and prevents cardiovascular diseases (Mojahed & Ghomi, 2024)
Salvia officinalis L.	Smell, Touch	anti-bacterial, cognitive stimulant (Renugaadevi, 2025), digestive support and textured aromatic leaves (Garg & Kumar, 2024), treat pharyngitis (Vaja et al., 2024)
Althaea officinalis L.	Sight, Touch	treats dermatological, respiratory and gastrointestinal disorders (Bahari et al., 2025), throat soothing (Vaja et al., 2024), aesthetic structure (Mahboubi, 2020),
Pelargonium graveolens L.	Smell, Taste, Sight	anxiety reliever, aesthetic colors (Wendin et al., 2023), Uplifting rose-like scent; velvety leaves for tactile engagement (Krzeptowska-Moszkowicz et al., 2025b)
Matricaria chamomilla L.	Smell, Sight	facilitating transition to sleep (Araújo et al., 2025), calming scented flowers for stress relief; visual charm from flowers (Akram et al., 2024)
Foeniculum vulgare Mill.	Taste, Smell	carminative, relaxing for children (Paşayeva, 2022), Stimulates appetite with aroma; fine foliage adds visual delicacy, aromatic smell, feathery foliage, seeds (Zeeshan et al., 2023)
Thymus vulgaris L.	Smell, Taste	anti-septic, immune system support (Shahrajabian & Sun, 2025), cognitive stimulation through aroma and texture with edible aromatic leaves (Silva et al., 2021)
Ocimum basilicum L.	Smell, Taste	attention enhancer, relaxing (Rajput et al., 2025), scented edible leaves, stimulates appetite and clarity; culinary use (Krzeptowska-Moszkowicz et al., 2025b)
Urtica dioica L.	Touch	strengthens the central nervous system and has a detox effect (Chahardehi et al., 2012), stinging hairs on leaves, high nutritional value (Szabo et al., 2023; He et al., 2022b)

Mentha spicata L.	Smell, Taste, Touch	relaxing digestion (Fakhri & Farzaei, 2023), energizing (Singh & Kaushik, 2024), coarse leaves create refreshing smell when rubbed (Naureen et al., 2022)
Mentha suaveolens Ehrh.	Taste, Smell	nausea, bronchitis, flatulence, anorexia, ulcerative colitis, and liver disease (Magdy et al., 2025), invigorating scent and culinary potential; soft to the touch (Aldogman et al., 2022)
Lonicera caprifolium L.	Sight, Smell	treats bacterial and viral infections and inflammation (Gavit et al., 2024), Strong floral fragrance attracts pollinators (Cristina et al., 2024)
Dianthus superbus L.	Smell	anti-viral and anti-cancer effect (Kim et al., 2019), ornate petals and pleasant smell (Zhou et al., 2022)
Tilia tomentosa Moench.	Smell, Hearing	anti-inflammatory, analgesic, anti-cancer, anti-anxiety properties (Zhou et al., 2025), rustling leaves, calming aromatic scent and relaxing sound from leaves (Öner & Pouya, 2024)
Laurus nobilis L.	Smell	antioxidant, anti-diabetic, and anti-cholinergic properties (Altın et al., 2025), Aromatic leathery leaves have culinary value (Paparella et al., 2022)
Syringa vulgaris L.	Smell, Sight	anti-inflammatory and antioxidant properties (Filipek et al., 2025), Iconic scent for relaxation; seasonal beauty with white or purple flower clusters (Mehdi et al., 2022)
Acacia farnesiana L.	Smell	Yellow fluffy fragrant flowers, used in pharmaceuticals anti-diabetic, anti-ulcer, anti-spasmodic, anti-diarrheal, anti-rheumatic and anti-malarial (Chekchaki et al., 2025)
Pinus sylvestris L.	*Taste,* Smell	stomach pain, mouth ulcers, and stomach ulcers (Kılıç et al., 2025), Forest-like scent for invigoration and rustling needles adds depth (Kutvonen, 2024)
Paulownia tomentosa Steud.	Smell, Sight, Hearing	coughing, asthma and phlegm, conjunctivitis, dysentery, enteritis, erysipelas, gonorrhea, hemorrhoids, mumps, traumatic hemorrhage, tonsillitis, and lower blood pressure (Nasraoui et al., 2025), large fragrant violet flowers and broad leaves create soothing sounds (Sakr et al., 2022)
Hypericum calycinum L.	Sight	treatment of mild to moderate depression (Szegedi et al., 2005), bright yellow flowers (He et al., 2022)
Pistacia palaestina Boiss.	Smell	treat injuries, tumors, asthma, skin inflammations, stress, and gastrointestinal disorders (Jamhour et al., 2025), fragrant leaves and bark (Pouya et al., 2024)
Prunus avium L.	Taste, Sight	antioxidant and anti-Inflammatory properties (Frusciante et al., 2025), blossoms and edible red fruits (Ak & Güneş, 2023)

Acer palmatum Thumb.	Sight	anti-hyperglycemic and antioxidant properties (Zhang et al., 2016), seasonal color variation of leaves and textural contrast (Wang et al., 2022)
Phyllostachys nigra Lodd. ex Lindl.	Hearing, Sight	anti-oxidation, antidiabetic, cardiovascular, anti-inflammatory, antihypertensive (Santosh et al.,2021) produces calming and rhythmic sounds, associated with tranquility and resilience in some cultures (Nnedinma et al., 2025)
Cortaderia selloana Schult.	Hearing, Sight, Touch	creates soothing natural sounds (Pla, 2020), soft and fluffy plumes with fountain-like form add vertical structure and visual movement (Leão, 2008)
Stachys byzantina K. Koch.	Touch	silky and fuzzy leaves, calming and tactile comfort (Kim & Park, 2025), anti-inflammatory, antibacterial (Lima et al., 2024)
Helianthus annuus L.	Taste, Sight, Hearing, Touch	Attractive large bright color flowers, fuzzy stems and rough leaves give unique texture (Awuchi & Morya, 2023), attract birds, nutritious seeds (Kajal et al., 2025)
Allium cepa L.	Hearing, Taste	(Kianian et al., 2021) seeds heads create clicking tones, attract pollinators (Saleh et al., 2021)

The plants listed above are widely preferred in sensory gardens, not only because of their physiological effects, but also because they stimulate sensory memory and deepen individual experiences. In addition to creating visual contrast, these plants support emotional balance through aromatic interactions. Improved attention in children, memory stimulation in the elderly, and relaxation in anxiety patients are examples where the therapeutic effects of such plants have been observed in practice (Krzeptowska-Moszkowicz et al., 2022).

Designing sensory gardens with medicinal plants requires careful consideration of how each plant engages the five human senses to create a cohesive, inclusive, and therapeutic landscape experience. The visual sense is stimulated by color contrasts, the structure of the foliage and flowering patterns bold pigments such as chlorophyll, carotenoids and anthocyanins add to the appeal of species such as *Calendula officinalis* (pot marigold) and *Lavandula angustifolia* (lavender), which range from calming pastel shades to bright, attention-grabbing hues. The sense of smell taps into emotional memory through essential oils in plants such as *Lavandula angustifolia* (lavender), *Mentha spicata* (mint) and *Rosmarinus officinalis* (rosemary), whose compounds are linalool, cineole have both medicinal and mood-enhancing properties. The sense of touch is about interacting with surface textures — the soft leaves of *Stachys byzantina* (lamb's ear) are pleasing to the user, while the rough stems of *Lavandula angustifolia* (lavender) and *Salvia officinalis* (sage) provide a contrast that requires careful selection, especially in inclusive gardens. Through the sense of taste, edible medicinal plants such a*s Ocimum basilicum (basil), Thymus vulgaris (thyme) and Mentha suaveolens* (apple mint/ woolly mint) offer flavor and digestive properties that accentuate both taste and well-being. Finally, the sense of hearing is awakened by the rustling of *Mischanthus sinensis* (eulalia grass) or *Phylllostachys nigra* (black bamboo) and the presence of wildlife such as birds and bees, which are encouraged by plants such as *Pennisetum alopecuroides* (fountain grass), *Cortaderia selloana* (pampas grass) or *Helianthus annuus* (sunflowers). Successful sensory gardens rely on thoughtful plant selection that considers multi-sensory value, safety, seasonal rhythm and accessibility to create a space that is as inclusive as it is stimulating.

5. Design Principles of Sensory Gardens

The design principles of sensory gardens provide a crucial framework that connects the theoretical classification of plants with their practical application in built projects. To plan sensory gardens effectively, a multidimensional design approach is required that is both appropriate to the user profile and takes environmental factors into account. The main purpose of such gardens is to promote the individual's multi-sensory interaction with nature and to provide psychological, cognitive and social benefits.

The selection of plants determines the sensory palette of a garden during the design process. The sensory qualities are effectively translated into experiences for users through accessibility, spatial organization, circulation and supporting design elements. The design principles serve as a bridge between botanical diversity and spatial practice, ensuring that the projects showcase not only the diversity of plant species, but also the ways in which these species are staged in accessible, therapeutic, and meaningful environments.

There are several basic principles that need to be considered in the design process. First, the concept of 'accessibility' should not only include physical access, but also sensory access. Elements such as ramps for wheelchair users, Braille labelling and audio guidance systems increase the inclusiveness of the design (Souter-Brown, 2014). It is also important that the height of the plant beds is suitable for the different age groups, that the plant arrangement provides visual contrast and that the landscape lines allow for easy orientation (He et al., 2022). Plants should be arranged in such a way that they stimulate the senses simultaneously or sequentially. For example, visually striking flowers can be followed by aromatic plants to stimulate the sense of smell. These transitions in the plant arrangement integrate the therapeutic experience (Krzeptowska-Moszkowicz & Moszkowicz, 2025). Seasonality is a crucial parameter for sensory richness. Plants that can remain active during seasonal transitions and offer a variety of colors and aromas should be preferred. This ensures not only aesthetic but also sensory continuity (Wilson, 2006). Maintenance sustainability should also be considered. Irrigation systems, simple pruning and the use of native plants support both an environmentally friendly and economical approach. These criteria ensure long-term efficiency, especially in urban applications. Another function of sensory gardens is to promote social interaction. Therefore, sub-modules such as relaxation corners, individual therapy areas, learning pods for children's groups should be planned. In this way, sensory gardens can become active environments not only for the individual but also for social health and learning (Delbert et al., 2025). In conclusion, the success of sensory gardens depends not only on plant diversity, but also on an accessible, functional and sustainable design approach that is sensitive to user needs. In the next section, the physiological and psychological effects of these applications on individuals will be examined.

6. Psychological and Physiological Effects of Medicinal Plants

Medicinal plants have a direct effect on human physiology through their bioactive components such as essential oils, flavonoids and alkaloids. The presence of these plants in sensory gardens activates both psychological and physiological processes, especially through olfactory, tactile and visual stimuli. This effect manifests itself in many areas, from individuals' stress levels to attention capacity, sleep patterns and immune response (Krzeptowska-Moszkowicz & Moszkowicz, 2025). The psychological effects focus on anxiety, depression, attention deficits and mood disorders. Studies have shown that the volatile compounds emitted by plants such as lavender, lemon balm and chamomile stimulate the limbic system in the brain and regulate serotonin and dopamine levels (Caballero-Gallardo et al., 2025). This ensures mental relaxation and emotional balance in individuals. On the other hand, physiological effects are observed at various levels. While herbs such as *Mentha spicata* (mint), *Rosmarinus officinalis (*rosemary) and *Salvia officinalis* (sage) increase mental alertness, herbs such as *Thymus vulgaris* (thyme) and *Pelargonium sidoides* (geranium) stand out with their ability to open the respiratory tract (Gulla et al., 2023; Kwasniewska et al., 2025) and support immunity (He et al., 2022). In addition, it is known that some plants (e.g. *Foeniculum vulgare* (fennel), *Althaea officinalis* (marshmallow flower) are preferred especially for elderly individuals and children due to their digestive system regulating effects. The use of sensory stimuli in a holistic system can improve not only individual health but also social well-being. For example, many experimental studies have shown that even short periods of time spent in gardens with fragrant plants have positive effects on blood pressure, cortisol levels and respiratory rate (Souter-Brown, 2020). These effects of medicinal plants should not only be considered from a pharmacological point of view, but also within the context of the integrity of the spatial and environmental experience as part of the sensory landscape. Thus, sensory gardens offer their users not only a short-term relaxation environment, but also a health-promoting environment. The next section will focus on how sensory gardens are designed and used in different contexts by examining national and international examples that embody these effects.

7. Application Examples: Sensory Garden Projects from Turkey and the World

One of the notable examples in Turkey in this context is the 'Accessible (Barrier-Free) Garden' in Bursa Botanical Park. It aims to stimulate different senses simultaneously using lavender, thyme and various tactile surfaces. In the Botanical Garden of Ege University, an interactive and educational environment for students and visitors has been created with beds of medicinal plants.

International examples show how broad and functional this practice can be. The Alnarp Rehabilitation Garden in Sweden is a strong example of therapeutic landscape planning, especially for psychological support processes. In the sensory garden of the Royal National Institute of Blind People in the UK, design elements for the visually impaired are striking. The Healing Garden at the Singapore Botanical Gardens provides an exemplary structure by combining a multisensory experience with Southeast Asian medicinal plants (Souter-Brown, 2014; Ferrentino et al., 2024).

The functionality of sensory gardens depends not only on their design principles, but also on how they are realized in the real context. For this reason, it is worth examining selected examples from Turkey and around the world in terms of both landscape architecture and therapeutic effects. The following projects are discussed in detail regarding the phytochemical components of the medicinal plants used, their sensory effects and the targeted user groups. The first example is the Alnarp Rehabilitation Garden in Sweden. With the aim of healing psychiatric patients through nature, this space has an arrangement focused on olfactory therapy. Plants such as *Lavandula angustifolia* (lavender), *Salvia officinalis* (sage) and *Thymus vulgaris* (thyme) are used here. Lavender has a sedative effect thanks to its linalool compound, while the thujone compound in sage works as a cholinesterase inhibitor to support cognitive functions. The thymol in thyme is known for its antiseptic properties. The regular placement and intense olfactory experience of these plants offers an effective therapeutic environment, especially for people struggling with conditions such as anxiety, depression and schizophrenia (Hardman, 2020). Similarly, the Healing Garden at the Singapore Botanical Garden aims to integrate tropical medicinal plants into the public health system. This project uses plants such as *Ocimum sanctum* (holy basil), *Cymbopogon citratus* (lemongrass) and *Zingiber officinale* (ginger) to provide anxiolytic, anti-emetic and stress-reducing effects thanks to active ingredients such as eugenol, citral, and gingerol. This garden has a structure that appeals not only to the sense of smell but also to the sense of taste, and creates an open health area for the public, the elderly and students (He et al., 2022; Lu et al., 2025). One example from Turkey is the Barrier-Free Garden in Bursa Botanical Park. This project aims to facilitate access to sensory stimuli, especially for people with visual, mental and motor disabilities. *Melissa officinalis* (lemon balm), *Mentha spicata* (mint) and *Althaea officinalis* (marshmallow flower) are the prominent species in this garden. *Melissa* provides an anti-anxiety effect with its rosmarinic acid content, while the menthol in mint has a cooling and stimulating effect. The marshmallow flower offers softness to the touch thanks to its mucilaginous structure. The textural and olfactory integrity of the garden creates an accessible and effective experiential space for these groups

(Wildwood, 2011). The RNIB Sensory Garden project developed in the UK was designed specifically for visually impaired people. *Pelargonium graveolens* (nail basil), *Foeniculum vulgare* (fennel) and *Lavandula stoechas* (French lavender) were favoured as plant material. Phytochemicals such as geraniol, anethole and camphor with their olfactory and stimulating properties support these groups in orientation, balance and memory. The scent intensity zones, walkways and guidance systems within the garden provide a holistic support environment for people with neurodiversity (Souter-Brown, 2014). These examples show that sensory gardens gain meaning beyond plant diversity, with the therapeutic power of the active ingredients contained in these plants and the design details suitable for the user profile. The correct selection of plants, knowledge of their phytochemical properties and spatial integration in harmony with the senses are among the most important factors that determine the success of sensory landscapes.

8. *General Evaluation and Conclusion*

This study has shown that sensory gardens are not only aesthetic and spatial, but also holistic structures that are effective on a cognitive, physiological and emotional level. The reason behind the use of medicinal plants in sensory landscapes is the scientifically proven effects of these plants on individual health through the phytochemicals they contain. The functions of compounds such as linalool, thymol, eugenol, citral and rosmarinic acid, such as relaxation, immune system support and mental alertness, transform the design of sensory gardens from a superficial landscape design into a public health strategy. In Chapters 1 and 2, the conceptual background and classification of medicinal plants are presented, followed by a discussion of example plants, design principles and the effects of these systems on individuals. Chapter 6 demonstrates how this theoretical knowledge is translated into practice through national and international applications. Both rehabilitation centers in Sweden and barrier-free gardens in Turkey prove that sensory landscapes can be effectively applied in different cultural and geographical contexts.

In line with these findings, several key recommendations can be offered:

1. The use of medicinal plants in sensory gardens should be guided not only by traditional knowledge but also by scientific data based on phytochemical analysis.

2. Sensory gardens should not only be used in rehabilitation centers but also in school gardens, rehabilitation centers, mental health institutions, elderly care homes and public spaces where immersive natural experiences can benefit all users.

3. The selection of plants that are compatible with the local flora and sustainable maintenance systems will ensure the longevity and effectiveness of these gardens. The deliberate integration of medicinal plants into sensory gardens should support a multi-layered, holistic design approach that bridges aesthetic experience with health-centered landscape design.

4. To design emotionally engaging and health-promoting spaces that can heal, stimulate and inspire, it should be clarified how each plant interacts with the senses, which sensory effects correspond to which user needs.

5. Multidisciplinary approaches (landscape architects, psychologists, botanists, therapists) should be integrated into the design process.

In conclusion, sensory gardens allow individuals to reconnect with nature while providing an environmental experience that supports health by activating medicinal plants through multiple senses. As such, they are both a tool for urban health policy and a practical example of sustainable landscape design.

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All authors contributed equally to the article. There is no conflict of interest.

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Revitalizing Urban Morphology Through Transportation: Sustainable and Resilient Utilization of Ankara's Streams

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1. Introduction

Humanity often exploits the environment to improve its own conditions, leading to the alteration and transformation of natural ecosystems. In recent years, the consequences of this impact have become increasingly destructive. The harmful effects of human actions on nature are referred to as anthropogenic pollution, which typically arises from processes like industrialization and urbanization. This problem reflects an imbalanced and unsustainable approach to the human-nature relationship. Factors such as population growth, increased mechanization, and expanding urban areas contribute to the overuse of natural resources, environmental degradation, water and air pollution, loss of vegetation, and the extinction of various animal species (Sümer et al., 2020). Cities are human-made spaces shaped through the transformation of natural environments into built areas. The creation of urban functions arises from the need to meet human demands. This gives rise to a conceptual paradox: while urban development reflects human progress, it simultaneously relies on the consumption of natural resources, which creates significant challenges. To address this contradiction, solutions should prioritize scenarios that minimize environmental harm (Harris & Ullman, 1945).

The city and its surrounding areas, where people reside, possess a distinct biodiversity structure. Human life unfolds within an ecosystem where biodiversity is both sustained and diminished over time. Within this system—where energy and nutrients cycle—humans alter their surroundings through the use of natural resources. However, these environmental interventions are not always beneficial. Today, one of the pressing issues is habitat destruction, a consequence of harmful human impacts. Urbanization often leads to environmental degradation such as soil, water, and air pollution, deforestation, the urban heat island effect, and the loss of wetlands. Nevertheless, it is recognized that sustainable practices can help mitigate these effects and offer ecological benefits. (Çakmak, 2008). The city emerges through the integration of various spaces shaped by a certain narrative or design. In contemporary times, political shifts and socio-economic dynamics influencing these spaces also transform the urban structure. In this sense, the urban form can be seen as a human habitat that reflects the culture and values of its inhabitants (Özkök & Yenen, 2022). One study highlights the crucial role that urban road networks play in analyzing and interpreting the structure of a given city (Ünlü Yücesoy & Özüduru, 2018).

In urban studies, considerable attention has been given to examining the anthropogenic impacts shaping the urban environment. The concept of the "Urbanocene" has been introduced to describe the contemporary era in which over half of the global population resides in cities. This term underscores humanity's central role in the transformation of rural and agricultural landscapes into urbanized areas. While highlighting the significance of adopting sustainable urbanism practices in managing this transformation, the literature also draws attention to the associated environmental consequences, including the degradation of natural ecosystems (Chatterjee et al., 2022). Anthropogenic impacts have become increasingly evident in the more recent stages of the historical process, with global challenges—such as the climate crisis—occupying a central place in contemporary discourse. In response to these challenges, the preservation of the natural environment and the sustainable transfer of resources to future generations emerge as critical issues requiring resolution. Scholarly perspectives emphasize that planning plays a fundamental role in addressing these concerns. Specifically, nature-based or ecologically informed planning approaches are seen as essential for creating spatial configurations that maintain a sustainable balance between the built and natural environments (Erbaş & Salt, 2020).

The city functions as a complex and dynamic organism, and identifying its evolving needs in the face of contemporary challenges presents a considerable analytical difficulty. Since the 1950s, urban morphology has served as a key framework for interpreting the structure and development of modern cities. As a methodological tool, urban morphology plays a vital role in examining patterns of urban growth and in elucidating the interactions between human activity and the natural environment (Maretto et al., 2023).

According to Konuk et al. (2017), urban morphology examines the evolving form of the city over time, focusing on its transformation, spatial integration, and physical characteristics with particular attention to scale integrity. In a broader sense, urban morphology is also defined as the study of form within the disciplines of planning and urban design, offering insights into how spatial patterns and built environments develop and interact (Giritlioğlu & Gürleyen, 2018).

Urban morphology, which examines the spatial consistency of urban form across multiple scales, is increasingly recognized as a critical field for promoting sustainable urban development (Chen, 2021). It cannot be studied in isolation from environmental factors such as physiography, topography, climate, hydrology, vegetation, and fauna, nor can it be claimed that it does not influence these elements. These natural components collectively shape the spatial form of settlements and contribute significantly to the morphological structure of cities (Giritlioğlu & Gürleyen, 2018).

The formation of a city is fundamentally a synthesis of human cultural outputs within the context of the natural environment. The natural landscape shapes the city's form, density, and appearance through its interaction with the artificial components of the built environment. Through this interplay, distinct morphological textures emerge, and the city is ultimately formed through their integration (Konuk et al., 2017).

Transportation is one of the key elements in the morphological development of cities. The human pursuit of access to opportunities generates a need for mobility, which in turn necessitates the transformation of portions of the natural environment to accommodate transportation infrastructure. With advancements in transportation technologies, the urban footprint has expanded due to increased travel distances within shorter timeframes. This phenomenon is frequently cited as a major driver of urban growth. However, recent research suggests that transportation-related opportunities have become more influential than traditional physical determinants such as topography in shaping urban form (Kam & Ulusay Alpay, 2023).

Historically, transportation and settlement patterns have mutually influenced one another and have played pivotal roles in urban development. Scholarly investigations have increasingly focused on the interrelationship between urban form and transportation, with findings indicating that urban form serves as a mediating factor in sustainability-related outcomes. These include greenhouse gas emissions, species segregation, energy consumption, quality of life, and urban expansion (Zhang et al., 2023). The road network, a fundamental component of the city, emerges as a product of cultural interpretation shaped by the physical environment and serves to organize urban space (Aysan Buldurur, 2022). The intrinsic interconnection between transportation infrastructure and urban form within this spatial organization calls for renewed analytical frameworks grounded in sustainability and urban resilience (Esposito et al., 2023).

Existing research highlights that roads are not merely infrastructural elements within urban morphology but also exert significant economic, social, and environmental impacts on both the natural environment and urban populations. Accordingly, when road network development is carefully regulated and balanced, it can yield substantial benefits. Conversely, unplanned or economically driven unchecked expansion often generates challenges that must be addressed through sustainable and resilient urban planning strategies.

In contemporary discourse, the anthropogenic impact on the environment necessitates solutions framed within the paradigms of sustainability—often referred to as the green agenda—and urban resilience, or the blue agenda. Recent studies emphasize the emergence of a "turquoise agenda," which synthesizes these two approaches, advocating for the elimination of negative effects in new settlement developments through the creation of sustainable and resilient urban spaces (Aydın, 2023).

Modern technological advancements have facilitated the transformation of natural environments into built spaces designed to serve human needs.

This morphological expansion of cities, however, results in the depletion of finite natural resources. Such resource consumption is viewed negatively, posing threats to future sustainability and challenging present-day urban resilience (Akdemir & Duman Yüksel, 2022).

With a significant proportion of the global population now residing in urban areas, issues such as the redevelopment of vacant, underutilized brownfields into new real estate projects, the formation of urban heat islands, air and noise pollution, and flooding have become pressing concerns linked to rapid urbanization (Zhu et al., 2022; Birik & Tezer, 2018). The literature highlights the critical importance of reintroducing green and natural spaces into urban contexts to counteract or mitigate these negative impacts. In this respect, nature-based solutions have gained prominence as effective strategies for enhancing both sustainability and urban resilience.

From the perspective of urban morphology, environmental factors—including geological, physiographic, hydrological, and microclimatic characteristics—play a decisive role in shaping planning and design approaches. These physical qualities of the environment directly influence urban development patterns and guide the direction of spatial growth.

Water is one of the environmental issues that are emphasized sensitively in planning activities. The hydrological cycle refers to the circulation of water on the ground and in the air, emphasizing that water is a great functional wealth for the city, a source of life in terms of sustainability, and an element that integrates and develops the city (Hamamcıoğlu, 2025). Over the years, human activities affect stream flows and the river hierarchy system, which is an important hydrological element, and negatively change the level of benefit obtained from water. Although there are efforts to improve the ecosystem with restoration, rehabilitation and reclamation works according to the need, it is possible to say that water problems continue today due to construction pressure. Interventions such as blocking the roads at the point of construction pressure and covering the streams with roads in order to increase the supply in parallel with the density of construction and travel demand negatively affect the city in social, economic and environmental terms. While the increase in the city's population requires the provision of services, this requirement should not increase environmental destruction.

Environmental pollution in automobile-dependent cities, alongside the loss of natural areas due to expanded parking facilities and the increased impervious surfaces from road network growth, adversely impacts the water cycle. Consequently, the adoption of green transportation systems and sustainable solutions that encourage pedestrian and bicycle use becomes imperative (Aysan Buldurur, 2022).

The rising density of impervious surfaces impedes water infiltration and participation in the hydrological cycle. To address this, the implementation of water management systems designed with geomorphological principles—aligned with natural water flows, vegetated, compatible with existing infrastructure, and responsive to local environmental conditions—is increasingly recognized as essential (Mobaraki & Oktay Vehbi, 2022).

Gehl (1987) articulates a hierarchy in spatial planning consisting of life, space, and structure, implying that urban spaces should prioritize the protection of natural resources and biodiversity, the facilitation of recreational activities, support for economic development, community gathering, and enhancement of public health. A strategic response to construction-related challenges, emphasizing the water element, involves the restoration and daylighting of buried or culverted streams through nature-based solutions.

In the context of sustainability and urban resilience, many countries are now actively reopening streams as part of ecological resilience strategies to mitigate climate crisis impacts associated with excessive urbanization. This approach not only leverages the hydrological potential of urban waterways but also generates new public spaces, fostering a multifaceted relationship between communities and the natural environment. Table 1 provides examples illustrating these notable initiatives.

Table 1. Sample Practices in the Daylighting of Streams

Location	Project Information	Results
Cheonggyecheon Creek, Seoul, South Korea (Global Street Design Guide, 2016).	5.9 km corridor, 50 meters wide, 345.2 million USD cost, project completion time 3 years and 6 months	Pedestrian activity increased by 76%, Urban heat island effect 4.5%, Reduction in air pollution by 10.3%, increase in bus (15.1%) and metro (3.3%) use,
Paso Robles, California, USA (Global Street Design Guide, 2016).	A 24 meter wide corridor the size of 5 building islands, cost of 2.5 million dollars, project completion time 3 years and 11 months	Vehicle speed reduction (30%), Reduction in vehicle traffic (20%), Increase in the amount of planted trees and the amount of filtered water, Reduction in traffic accidents,

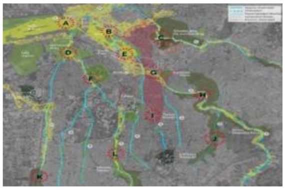
Rio Park, Madrid, Spain (Franchini, 2011; Lopez - de Abajo et al., 2020).	A 10-kilometer section of the M30 highway, at a cost of 4,100 million euros, is under construction between 2003 and 2018,	429 hectares of new green space, 33,623 trees of 47 different species, 470,844 bushes of 38 different species, Potential to remove 35,000 tons of air pollutants,
Utrecht Canal, Utrecht, Netherlands (Dutch,2016; Dutch,2020; Metropolis,2020)	2 kilometers and 30 meters wide corridor, at a cost of 16.6 million euros,	Prevention of traffic congestion, Creating a touristic and recreational area,

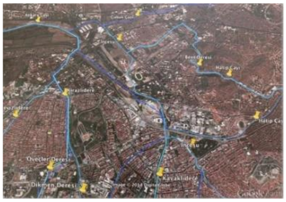
As demonstrated by various case studies, the restoration and daylighting of streams contribute significantly to sustainability and urban resilience across economic, social, and environmental dimensions. The global distribution of these projects highlights the widespread applicability of nature-based approaches at multiple scales, particularly as responses to common challenges faced worldwide. Moreover, the relatively short implementation timelines of these initiatives represent a crucial advantage, enabling timely interventions to address pressing environmental issues.

In the case of Ankara, official reports acknowledge the impacts of global crises and identify the reopening of streams as a viable solution. For example, the Sakarya Basin Flood Management Plan indicates that unplanned urban development—including construction within and closure of stream beds—has increased flood risk and caused damage to surrounding vegetation (Ministry of Agriculture and Forestry General Directorate of Water Management, 2018). Similarly, Ankara's Local Climate Change Plan highlights challenges such as air and noise pollution, urban heat island effects, and inadequately designed stream rehabilitation efforts, emphasizing the need to integrate streams within resilient urban infrastructure strategies (Ankara Metropolitan Municipality, 2019). The Ankara Green City Action Plan further notes a decline in urban biodiversity and advocates for the restoration of underground and natural habitat corridors (Ankara Metropolitan Municipality, 2023).

These official documents reflect Ankara’s alignment with global trends concerning the consequences of climate change and rapid urbanization. Specific assessments related to Ankara’s streams are summarized in Table 2.

Table 2. Evaluations on the Daylighting of Ankara Streams

Name of the Study	Comments and Workspace
Tunçer, M. (2019). Ankara's Vanishing Natural and Cultural Values. Turkish Journal of Landscape Research, 2(2), 108-138.	For 90 years, Ankara has lost its streams and creeks, which have very important landscape value.
(Yılmaz, M., & Ercoşkun, Ö. Y. 2020). Streams under transportation systems in Ankara: bentderesi example. IBAD Journal of Social Sciences, (7), 1-18.	States that damage to infrastructure due to floods is not random. 
(İdali Özden, Ö. 2022). Revealing the Disappearing Ankara Streams as Landscape Infrastructure. Turkey Urban Morphology Network, 1217-1251.	Emphasizes that in the city center, approximately 56 km of water trace has disappeared in an area of 100 square kilometers. 

(Tunçer, M. 2023). Seoul Tore Down a Highway Through the City and the City Can Breathe Again: Cheonggyecheon Restoration Project. Journal of Spatial Planning and Design, 3(1), 89-103.	It is stated that planning activities should be carried out at the basin scale.	

2. Material and Method

This research aims to evaluate the potential of streams as nature-based solutions to address urban challenges in Ankara, following practices observed in other countries. Specifically, the study focuses on the approach of daylighting—or unearthing—underground streams. Within the context of Ankara, one existing underground stream has been identified, and a hypothetical scenario is developed to assess the feasibility and impacts of exposing this stream and removing a road currently situated above it.

To achieve this, the study analyzes clusters of underground streams alongside the spatial characteristics of their surrounding settlements, drawing on frameworks from urban morphology and landscape ecology. Additionally, the morphological features of the road network in relation to the stream corridors are examined. The scope of the analysis includes ten underground streams, which are subdivided into 35 segments to facilitate a detailed evaluation (Figure 1).

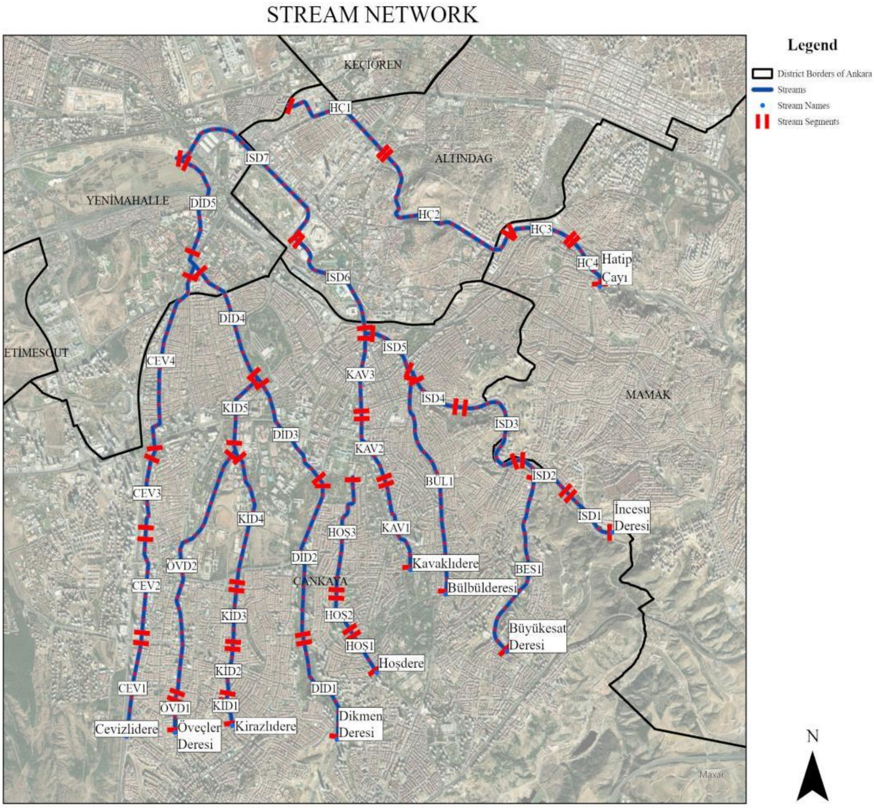


Figure 1. Ankara Streams (İdali Özden, 2015)

The assessments made in the area covered by the stream network are as follows (Table 3).

Table 3. Analytical Approaches for Evaluation

Settlement Geography (A)	Landscape Ecology (B)	Road Network Morphology (C)
Stream Hierarchy, Convexity, Negative - Positive Clearance, Valley Depth, Valley Structure and Flats, Longitudinal Slope, Cross Section Curvature, Plan Curvature, Profile	Forest Index, OSAVI, SAVI, Vegetated Area, Herbaceous Surfaces, Water Surfaces, Built-up Area Weighted Average Values.	Angular Connectivity, Connectivity, Choice, Depth, Integration, Number of Nodes

Curvature, Land Surface Moisture - Hardness, Land Appearance Factor, Sky Appearance Factor, Wind Speed, Wind Shelterability, Wind Exposure, Aspect, Anisotropic Heat, Earth Surface Temperature, Photovoltaics, Wind Power, Tree Dense	

The analytical framework of this study is organized into three primary categories: A, B, and C. Each category is further subdivided into specific sub-analyses. Upon completion of the individual analyses, a comprehensive synthesis is developed by integrating the findings from clusters A, B, and C, thereby forming a holistic assessment for the stream proposed to be daylighted.

Presented below are exemplar analyses and syntheses derived from the settlement geography, landscape ecology, and road network morphology pertaining to the streams examined within Ankara’s urban morphology. The accompanying map illustrates the synthesis of the settlement geography cluster (A). When evaluated according to the criteria established within the sub-analyses of this cluster, the results indicate that daylighting streams within the designated blue zone is appropriate from the perspective of settlement geography components (Figure 2).

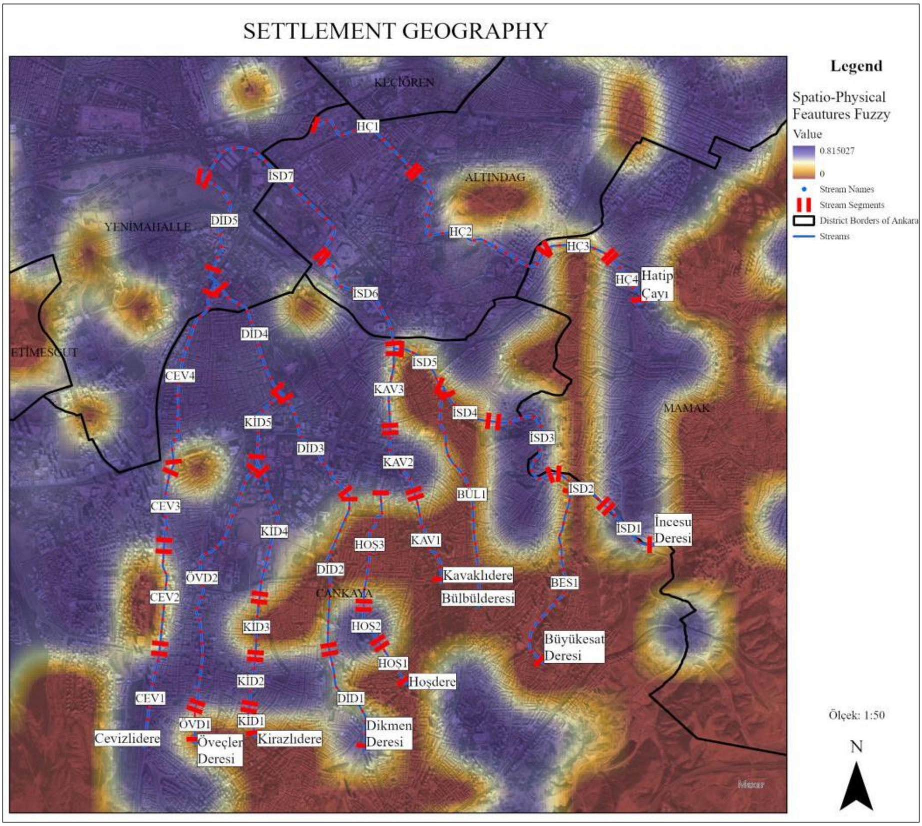


Figure 2. Underground Streams and Settlement Geography Synthesis

Within the landscape ecology cluster (B), individual components were systematically assessed, and an example evaluation of one such element is presented here. Following the methodology of Cengiz and Oğuz (2018) in their study on the transition of urban landscape patterns in Ankara, analytical software tools capable of processing remote sensing data and conducting landscape ecological analyses were employed. Specifically, the Widest Patch Index (WPI) was calculated using satellite imagery spanning from 2000 to 2024 to assess vegetated surface coverage. The analysis reveals a notable decrease in vegetated patches along the stream corridors over time, indicating a reduction in natural vegetation within these areas (Figure 3).

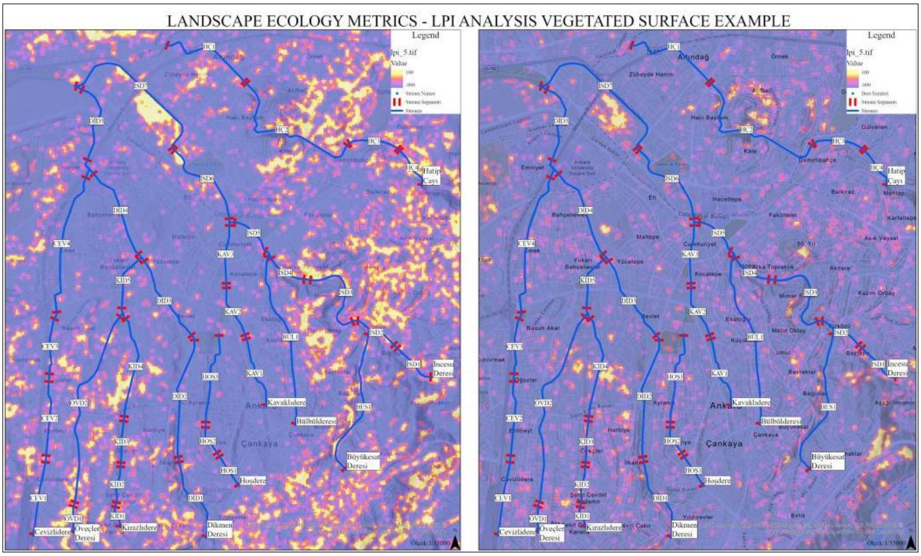


Figure 3. Underground Streams and Landscape Ecology (LPI Analysis - Vegetated Surface Example)

Within the scope of road network morphology (C), individual elements within the cluster were evaluated systematically, and an illustrative example is provided below. Morphological network analyses were conducted on the road network surrounding the streams. Among these analyses, integration analysis was employed to assess the relative accessibility of different road segments within the transportation system. In this context, lighter-colored areas on the resulting maps represent zones of higher accessibility (van Nes & Yamu, 2021). Integration analysis was performed using varying distance thresholds tailored to each mapped area, with particular attention paid to intersections occurring in proximity to underground streams (Figure 4).

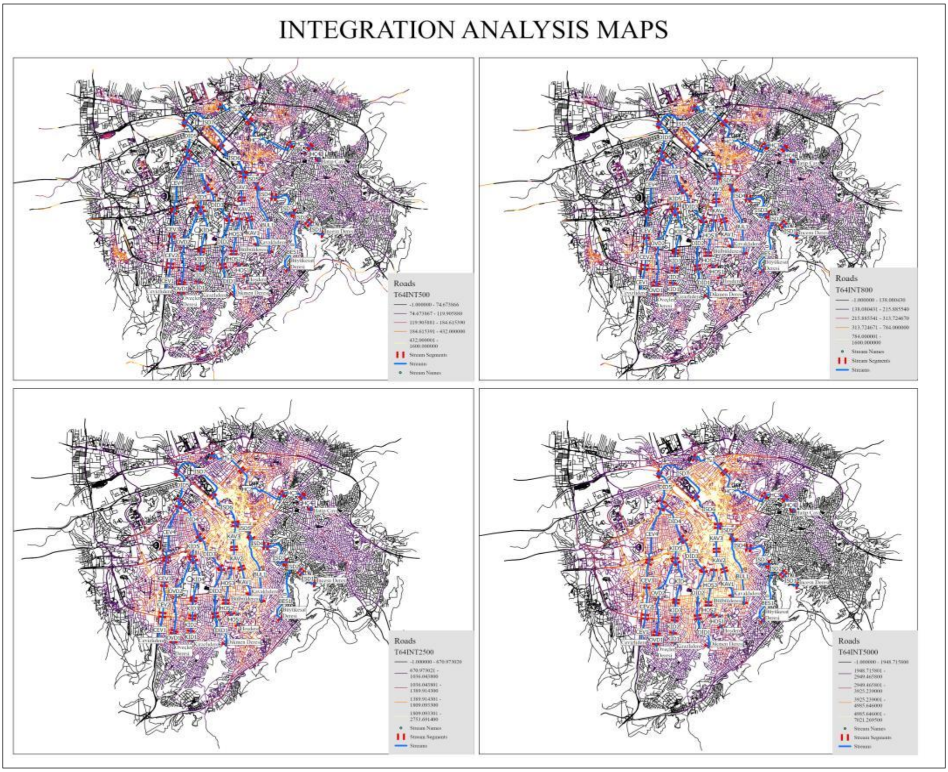


Figure 4. Underground Streams and Road Network Morphology (Example of Integration Analysis)

Within the scope of the study, an analytical assessment of the underground streams was conducted based on the components listed in Table 3. Each criterion was examined individually to assess whether it was met, and the tests that yielded positive results were marked in green. The stream deemed most suitable for daylighting was evaluated in terms of its overall suitability, as illustrated in Figure 5. In the figure, blue colored areas correspond to regions with higher stream daylighting potential.

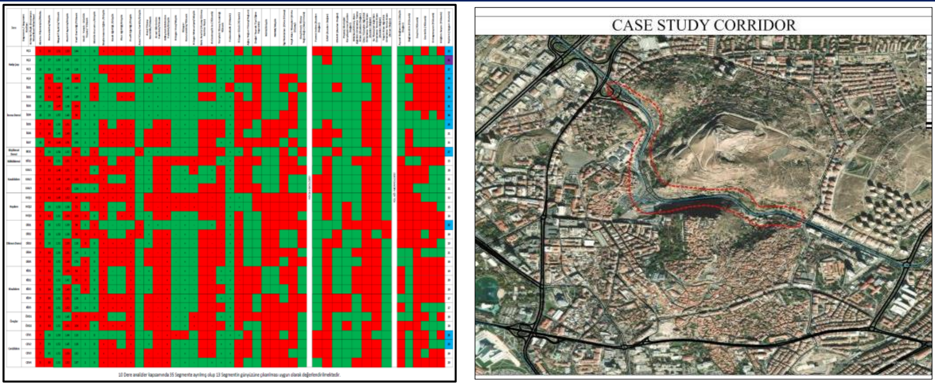


Figure 5. Evaluation of Underground Streams and Determination of the Study Area

In the assessment, the current condition of the stream was evaluated according to each main analytical cluster and its respective sub-components. Conditions deemed suitable were marked in green, while unsuitable conditions were marked in red within a summary table. The stream segment exhibiting the most favorable results across these criteria was identified as the most appropriate candidate for daylighting. In this study, the segment coded "HÇ2," corresponding to the Bentderesi corridor of the Hatip Stream, was determined to be the most suitable for opening to the surface.

3. Findings and Discussion

After identifying the appropriate segment for daylighting, two scenarios were examined: the current situation and a proposed scenario involving the removal of the road above the segment. The impact of this intervention was then evaluated through the lenses of road network morphology and transportation planning.

The morphological assessments, as depicted in the figures, indicate that removing the road and exposing the stream results in notable changes to key elements of the road network within the study area (Figure 6).

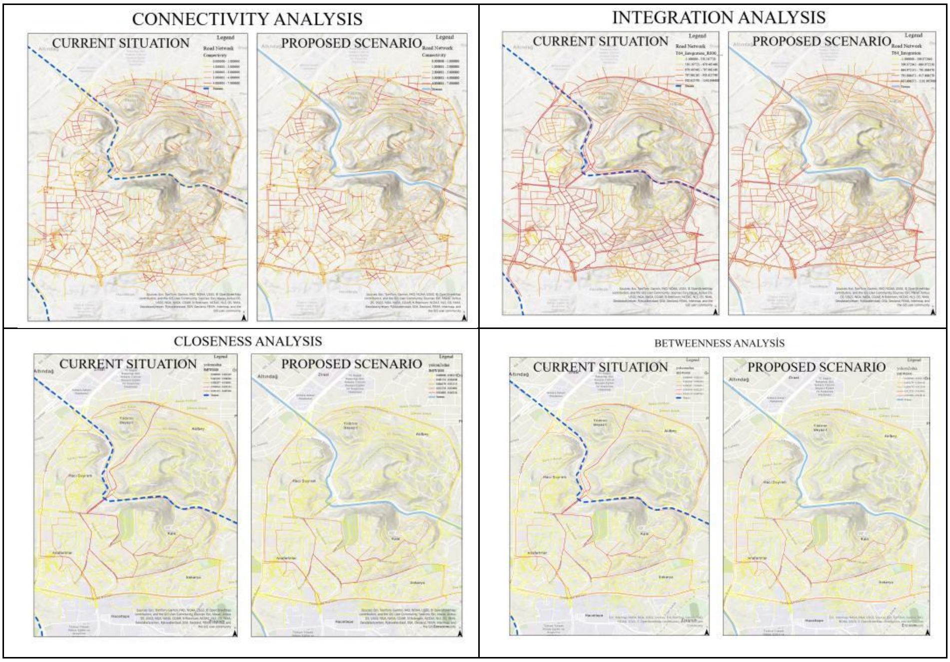


Figure 6. Evaluation of Scenarios in terms of Road Network Morphology

The proposal to remove the road and daylight the creek—while repurposing the corridor exclusively for sustainable mobility modes such as cycling and pedestrian travel—is further examined within the transportation model. According to this assessment, travel demand patterns and environmental impacts shift significantly following the closure of the road to vehicular traffic and its adaptation for sustainable mobility. Representative examples of these changes are illustrated in Figure 7.

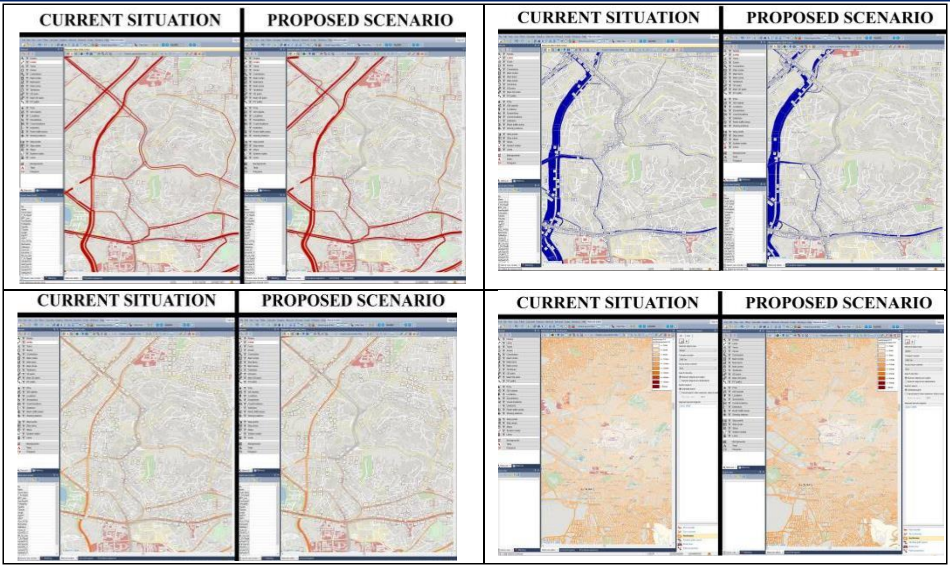
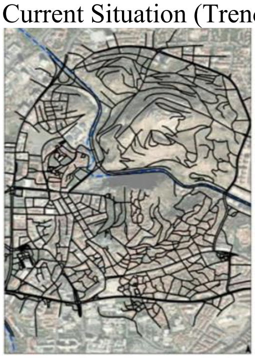
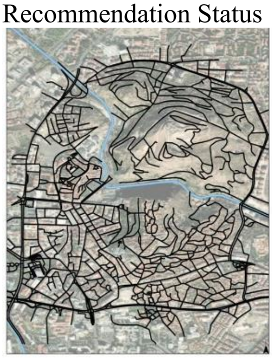


Figure 7. Evaluation of Scenarios in terms of Transportation Planning

The comprehensive assessment comparisons illustrated in the example maps are presented in detail in the following table (Table 4).

Table 4. Scenario Comparasion Table

Morphological Intervention Evaluation Results		
Comparison Criteria	Current Situation (Trend) 	Recommendation Status 
Noise (db)	64	0
NO(X) (g/km)	53	0
SO(2) (g/km)	11	0
CO (kg/km)	0	0

HC (g/km)	22	0
Loaded Traffic Speed (km/h)	47	0
Isochrone Area (ha)	120	100
Shortest Distance	2,12	3,74
Mode Choice	Private Vehicles 29%, Public Transportation 66%, Pedestrian 4%, Bicycle 2%	Pedestrian 67%, Bicycle 33
Integration	Network Max. Value: 1148	Network Max. Value: 1101
Connectivity	Network Max. Value: 333	Network Max. Value: 272
Betweenness	Network Max. Value:0.067	Network Max. Value:0.045
Proximity	Network Max. Value 54	Network Max. Value:45

4. Conclusion and Suggestions

While specialized morphological interventions—commonly referred to as stream restoration—are implemented under diverse conditions worldwide, they share several fundamental characteristics. These include anticipated project benefits, identification of beneficiaries, implementation steps, key stakeholders involved, strategies for stakeholder engagement, project cost estimation, approaches to secure pre-investment financing, identification of potential revenue streams, risk assessment, and evaluation of growth opportunities. Collectively, these components constitute what is known as a business model for nature-based solutions, as defined by authoritative bodies such as the Copenhagen Climate Center (UNEP-CCC, 2024).

The business model proposed by the Copenhagen Climate Center serves as a representative framework for stream daylighting projects. This model defines the core objective as the restoration of continuous urban hydrological elements—such as streams—returning them to their natural hydrological state within the urban fabric. The primary benefits anticipated from such projects include temperature regulation to acceptable levels, enhanced water quality, biodiversity improvement, creation of spaces for leisure and tourism, and increased real estate values. Beneficiaries encompass local residents, business owners, and municipal authorities tasked with enhancing quality of life.

Implementation activities involve assessing the current hydrological and ecological status, pollutant identification, re-establishing natural stream courses, managing channel and landslide risks, channel installation, landscaping, installing monitoring equipment, and maintaining project integrity. The main actors responsible for project execution typically include municipal and district authorities, environmental protection units, and local governments. Essential stakeholders comprise local communities, civil society organizations, associations, and development agencies.

Stakeholder engagement is facilitated through organizational activities, consultancy, and stream-cleaning recreational events. Project inputs consist of technical studies—such as valuation and feasibility analyses—acquisition of construction permits, preparation of green infrastructure plans, and facility construction. Financing sources often originate from local government funds and anticipated increases in property values, supplemented by sponsorships and private investments. Revenue streams are expected to arise from reduced water management costs, ecotourism, recreational opportunities, and benefits associated with improved water and biodiversity conditions.

Although the business model outlines a strategic framework for stream restoration, it also necessitates a thorough identification of risks and growth potential. Risks include adverse effects of extreme weather events, environmental pollution during construction, ongoing maintenance costs, land acquisition challenges—especially where property rights are established—and possible local opposition. Conversely, recreational benefits from blue-green urban design can enhance urban aesthetics and provide economic stimulus at the city scale. Educational institutions engaged in biodiversity research may further expand the project's impact (UNEP-CCC, 2024).

This study examines the impact of a strategic intervention addressing anthropogenic effects within the research area, drawing on analogous projects implemented internationally. The analysis indicates that the proposed intervention has the potential to yield positive outcomes across the evaluated criteria. While the selected stream corridor serves as the focal case study, it is not unique; other stream corridors could similarly be daylighted. However, due to the scope limitations of this research, only one stream was subjected to detailed analytical evaluation. The approach presented here establishes a comprehensive framework for future investigations, enabling researchers and urban authorities to tailor context-specific strategies by adjusting the weighting of evaluation criteria through multi-criteria decision-making methodologies.

This study has also some limitations that should be acknowledged. Firstly, the study relied on available remote sensing data and existing maps, which may not capture fine-scale environmental or infrastructural details due to limitations in resolution and currency. The transportation and morphological models incorporated certain simplifying assumptions that may not fully represent the complex dynamics of urban mobility and infrastructure interactions. Moreover, while the research focused on physical and environmental factors, it did not deeply integrate socioeconomic considerations such as community acceptance, land ownership issues, or economic feasibility. The absence of direct stakeholder engagement further limits insights into potential social impacts and practical implementation challenges. Finally, the analysis was primarily static, relying on cross-sectional data, which restricts the ability to assess temporal changes or future scenarios such as ongoing urban development or climate change effects.

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All authors contributed equally to the article. There is not a conflict of interest.

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The Heart of Green Cities: The Role of Meadow and Pasture Plants in Landscape Areas in Sustainability and the Fight Against the Climate Crisis

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1. Introduction

Increasing urbanisation and the climate crisis have brought new approaches to urban planning. Green infrastructure (GI) and nature-based solutions (NBS) are critical to making cities more liveable and environmentally and socially resilient. The concept of green infrastructure has become increasingly important in today's world, where urbanisation is on the rise, climate change is occurring, and biodiversity is declining, in terms of sustainability, increased ecological resilience, and public health. It is a concept based on the integration of nature-based solutions into urban systems, improving air quality, regulating microclimates and providing various benefits to ecosystems (Parlak & Atik, 2020). According to distinguished research literature, GI applications can simultaneously provide a range of ecosystem services, including flood control, microclimate regulation, air quality improvement, carbon emission reduction, biodiversity support, and social well-being. In a meta-analysis of 850 studies, the most frequently addressed ecosystem services were microclimate regulation (36%) and aesthetic values (23%) and the relationship between urban greenness and human health was revealed (Veerkamp et al. 2021). The use of meadow and pasture plants in urban landscapes brings not only environmental benefits but also social dimensions such as social interaction and cultural belonging (Zhang & Qian, 2024).

2. Material and Method

The present study addresses The Role Of Grass And Pasture Plants In Urban Landscape, The Relationship Between Grassland/Pasture Plants and Green Infrastructure and Applications in Türkiye andCarbon Balance and

Greenhouse Gases as outlined in the following headings. The recommendations are presented in the conclusion section in light of the examples examined.

3. Findings and Discussion

3.1. The Role Of Grass And Pasture Plants In Urban Landscape

3.1.1 Biodiversity And Habitat Isolation

It has been reported that the reduction in maintenance of traditionally maintained lawns increases the number, richness and diversity of plants and arthropods and that these passively created urban grasslands may have a positive effect on biodiversity (Venn and Kotze, 2014; Watson et al., 2020). Lawns have been the dominant form of urban grasslands since the 20th century and have become a social norm associated with ease of installation, maintenance, recreational and aesthetic benefits (Hoyle et al. 2017). As an alternative approach to creating environmentally friendly and urban meadow areas, they have proposed replacing or modifying the large-scale management of short, single-species, homogeneous grass areas with flower meadow areas (Southon et al., 2017; Lane et al., 2019; Norton et al., 2019; Bretzel et al., 2020; Marshall et al., 2023). Grasslands, particularly perennial herbaceous species, serve as habitat and food sources for pollinators and global insect populations. Structural diversity at the cellular level includes the flowers of leguminous forage plants and wild flowering species. This structure plays an important role in the conservation of biodiversity within cities.

3.1.2 Aesthetic And Social Perception

Meadow slopes provide aesthetic richness with their irregular shapes and different flower colours and sizes. These areas are preferred more in ‘campus-like’ neighbourhood landscapes with an emphasis on naturalness. A study found that ‘‘respondents thought meadows provided greater aesthetic, educational and mental wellbeing services than lawns... overwhelmingly in favour of meadow planting in place of lawn’’ (Marshall et al. 2023). Additionally, the preference for meadow areas increases landscape value, social satisfaction, and access to green spaces. This provides city dwellers with a more attractive and natural environment. In various studies, participants in China have reported that meadows are the most attractive option among the choices (Jiang & Yuan, 2017).

3.1.3 Easy Maintenance And Energy Saving

Meadow ecology has been reported to reduce costs and greenhouse gas emissions due to lower mowing, irrigation, and fertilisation requirements compared to traditional lawns, directly affecting energy consumption and carbon footprint (Paudel & States 2023; Trémeau et al. 2024; Anouymous, 2025). Ignatieva et al. 2015 and Allchin (2023) have stated that dense lawns can be a source of greenhouse gases and that the use of mechanical equipment in their maintenance increases carbon emissions.

3.1.4 Resilience For Urban Ecologies

Grasslands used within cities provide a more resilient vegetation cover against drought, temperature changes, and urban stress conditions. A study has shown that grasslands are more drought-resistant (Trémeau et al. 2024).

3.2 The Relationship Between Grassland/Pasture Plants and Green Infrastructure and Applications in Türkiye

3.2.1 Why Are Grassland and Pasture Plants an Element of Green Infrastructure?

As mentioned earlier, green infrastructure produces climatic, environmental, and social benefits by integrating ecological systems into urban life in a planned manner. Here, grassland and pasture plants encompass critical elements such as connectivity, multifunctionality, microclimate improvement, rainwater retention, biodiversity support, and social participation (Demiroğlu et al. 2019; Parlak & Atik, 2020). Grasslands help create blue-green infrastructure integrity by retaining moisture and reducing surface runoff.

3.2.2 Türkiye Examples: Legislation, Practices and Challenges

Analyzes conducted in Türkiye reveal that the biggest obstacle to the full integration of the Green Infrastructure approach into the spatial planning process is legislative inadequacies. A study dated 2019 emphasizes that "the applicability of green infrastructure systems in Türkiye is inadequate both at the legislative and administrative levels" (Demiroğlu et al. 2019). Current regulations are not designed to ensure the continuity of ecological structures. In Turkey, meadow and pasture plants promise potential as a sub-component of green infrastructure. However, this potential can be turned into real gain if it is realized by strengthening the legal framework, integrating scientific methods into local planning processes and increasing the participation of society in the process. In addition, tools based on analysis based on geographic information systems are important for monitoring and evaluating these areas.

3.2.3 Urban Meadows and Pollinator Communities

Meadow and pasture plants, which are densely found in the city, provide important food and hosts for many pollinator species such as bees, butterflies and flies, thanks to the rich resources they provide with their flowers. In their study published in 2025, Ulrich & Sargent reported that urban park restorations created a large diversity of pollinator species in a short time and that species richness remained sustainable in the long term after the regulation. This points to a permanent increase in biodiversity without limits. Different studies have reported that wild flower slopes created within the city contribute to the diversity of pollinator species seen in natural meadows at a very similar level, and even though the number of wild bees and butterflies is lower, the species diversity is at a similar level (Guariento et al. 2023; Heiniger et al. 2023).

3.2.4 Plant Functional Traits and Ecological Selection

Floristic characteristics of plants, such as flower color, size, and UV reflectance, determine their potential to attract pollinators. In a study conducted in dry meadow communities in Berlin, significant relationships were detected between the level of urbanization and the strength of floral UV reflections and flower size diversity. While flower size diversity decreases in the city center, species with strong UV reflection appear in a more differentiated form (Cabon et al. 2022). Plant-microbial symbioses and fluorification may be effective in increasing pollinator attraction. For example, plants supported by bacteria or mycorrhizal fungi can produce more flowers and increase pollinator visitation accordingly. In the example of Utrecht, microbial supported plant plantings on green roofs are recommended to be used for this purpose (Stewart et al. 2024).

3.3 Carbon Balance and Greenhouse Gases

3.3.1 Urban Meadows and Carbon Sequestration

Meadow and pasture plants used in cities contain species that have the potential to store more carbon in the soil compared to ground cover species. When legumes are used in agricultural systems, they are capable of symbiotically binding 100-380 kg of N per hectare per year, which is a more environmentally friendly and sustainable application (Acar et al. 2018). A new term has come to the fore recently; "Carbon farming" projects developed within the scope of sustainable soil management in agricultural and urban areas are called applications to increase carbon storage of pasture/meadow systems. These projects aim to improve soil and long-term carbon sequestration. However, it is emphasized that these projects require comprehensive monitoring and management systems, as well as difficulties such as ensuring their permanence and receiving technical consultancy support (Singh et al.2024).

3.4 Socio-Cultural Dimensions and Social Ties

3.4.1 Aesthetic Perception, Identity and Social Engagement

The visual diversity created by meadow and pasture plants, in a survey study, stated that meadows are more aesthetic, educational and mental health beneficial than grasses, and that biodiversity has a positive contribution to perceived quality and belonging (Southon et al. 2017; Marshall et al. 2022).Urban meadows; They are suitable environments for recreation, nature-based education and social scientific projects. For example, participatory projects of municipalities and non-governmental organizations, such as “bee hotels” or pollinator observations, help increase ownership of the local environment while accompanying citizens' interaction with natural cycles. Studies in Turkey on the importance of effective use of open green spaces, especially after the pandemic, show that society has changed its perspective on these areas positively (Anonymous, 2021;Türker & Gül, 2022).

The global climate crisis, biodiversity loss and urbanization pressure make it important to redefine the relationship between nature and humans. Some studies show that grassland and pasture plants have the potential for multifunctional use in green infrastructure.

3. Conclusion and Suggestions

The global climate crisis, loss of biological diversity and urbanisation pressure make it important to redefine the relationship between nature and humans. Some studies show that grassland and pasture plants have the potential for multifunctional use within green infrastructure. Grassland/pasture species incorporated into urban landscapes contribute to various areas, including the strengthening of green infrastructure networks, supporting pollinator populations, reducing carbon emissions, ensuring the continuity of ecosystem services, and enhancing social well-being. In Turkey, while the integration of meadow and pasture areas into landscape projects has not yet reached the desired level, these areas are considered a potential nature-based solution. Grassland areas based on natural species composition offer lower maintenance costs, higher levels of biological diversity and greater contributions to soil-water balance compared to lawn areas. Additionally, studies have shown that meadow areas provide habitats for pollinators such as bees and butterflies, thereby supporting agricultural production and ecological networks in cities. From a socio-cultural perspective, green spaces enhance individuals' psychological well-being, social bonds and environmental awareness levels. The inclusion of meadow and pasture plants in these systems increases urban dwellers' contact with nature and strengthens cultural landscape identity. The effective and conscious use of meadow and pasture plants in urban landscape planning will provide multi-dimensional contributions to both environmental sustainability and human well-being. Therefore, local governments and landscape planners in Turkey must consider these plant that ecological, economic, and socio-cultural aesthetic.

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The article complies with national and international research and publication ethics.

Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

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Resilient Modular Housing Systems for Earthquake-Prone Regions in California

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1. Introduction

This article seeks to critically interrogate the potential of resilient modular housing systems as adaptive architectural responses within earthquake-prone territories of California, foregrounding dimensions of seismic resistance, environmental sustainability, and socio-economic viability. Methodologically, the study proceeds through a systematic appraisal of the existing scholarly corpus, a comparative examination of pertinent housing typologies, and the incorporation of emblematic case studies that illuminate both structural and socio-cultural determinants of resilience. The exposition is organized into a series of interrelated sections: an initial conceptual delineation of resilient modular housing; a contextualized analysis of the Californian seismic condition; a thematically clustered discussion encompassing technological innovation, regulatory frameworks, and participatory modes of community engagement; and a final synthesis of insights that consolidates the theoretical and empirical strands of the investigation. By pursuing this trajectory, the article endeavors to extend prevailing discourses on architectural resilience, simultaneously contributing to the refinement of policy, professional practice, and the epistemological foundations of housing studies in disaster-prone geographies.

Table 1. Comparative Table: Housing Types in California by Key Criteria

Criteria	Traditional Housing	Modular Housing	Container-Modular Housing
Construction Time (days)	180	60	45
Seismic Resilience Index (%)	50	85	90
Carbon Footprint (kg CO_2/m^2)	100	65	55

Criteria	Traditional Housing	Modular Housing	Container-Modular Housing
Cost per Square Meter (USD/m²)	2200	1600	1400

Construction Duration (Modular: 60 days, Traditional: 180 days, Container: 45 days): (Navaratnam et al, 2019).
Earthquake Resistance (Modular: 85–90%, Traditional: around 50%): (Greene, 2020), (Haque, 2021)
Carbon Footprint (Modular: 65 kg CO_2/m^2, Traditional: 100+ kg CO_2/m^2): (Jaillon and Poon, 2008). (Vithanage et al, 2021).

2. Material and Method

The study employs a qualitative research design structured around three complementary methodological components. First, a systematic review was undertaken to identify prevailing discourses on resilient modular housing, with particular emphasis on seismic resilience, sustainability, and socio-economic feasibility. Academic databases, peer-reviewed journals, and institutional reports were surveyed to establish a comprehensive theoretical framework.

Second, a comparative typological analysis was conducted, drawing upon selected architectural precedents of modular housing systems both within and beyond seismic zones. This stage involved the evaluation of design strategies, construction techniques, and regulatory conditions in order to discern convergences and divergences relevant to the Californian context.

Third, a series of emblematic case studies were incorporated to anchor the investigation in real-world practice. These cases were chosen according to their representativeness in terms of technological innovation, environmental performance, and community-oriented adaptability. Each case study was examined through document analysis, architectural drawings, and secondary data sources, thereby allowing for a triangulated understanding of resilience across structural and social dimensions.

Through the integration of these methods, the research establishes a multi-layered analytical lens that enables the critical assessment of modular housing as an adaptive strategy for earthquake-prone territories.

3. Resilient Modular Housing Systems

Resilient modular housing systems have gained considerable attention as effective solutions for addressing the challenges posed by climate change and increasing urbanization. The overarching theme in the recent studies emphasizes the urgent need for housing that can withstand environmental stresses alongside the necessity for sustainable practices in construction and design.

One of the critical aspects of resilient modular housing is its inherent ability to adapt to climate challenges. Modular housing systems, particularly those that integrate sustainable architectural practices, can provide significant advantages in flood-prone areas. The Amphibious House in the UK exemplifies innovative design strategies that ensure resilience through its adaptation to changing water levels, further supported by the notion that multi-faceted strategies involving both design and institutional measures are essential for effective flood resilience (Naseri, 2024). Climate-resilient housing frameworks across various regions underline similar principles, advocating an inclusive approach that incorporates sustainability in the physical and operational design of housing (Zahra et al., 2025; Mansoor et al., 2023).

Moreover, the modular construction process itself presents advantages that are pivotal in emergency and post-disaster reconstruction scenarios. The prefabrication of modular components allows for rapid assembly on-site, which is crucial for providing timely housing solutions to displaced populations. Research indicates that the time-efficient nature of modular construction not only facilitates quicker recovery but also enhances the overall structural resilience of buildings against natural disasters (Ghannad et al., 2020; Shahzad et al., 2022; Gunawardena et al., 2014). This approach is increasingly recognized as vital globally, where displacement due to climate-related events is anticipated to rise (Jayakody et al., 2022). Furthermore, contemporary studies recognizes the integration of green building principles within modular housing designs as a robust strategy for a sustainable future. Modular buildings designed with environmental considerations can significantly contribute to the green economy while addressing housing shortages and improving community resilience. The adoption of modular systems in environmentally sustainable practices fulfills immediate housing needs while promoting long-term ecological benefits and community development goals (Kusbiantoro et al., 2024; Khan et al., 2022).

The adaptability of modular systems sets them apart as a preferred solution in rapidly urbanizing settings. The intersection of modular construction with concepts such as the circular economy and affordable housing reflects a growing recognition of the need for innovative construction practices that support social inclusion and economic sustainability (Parisi & Donyavi, 2024; Khan et al., 2022). Furthermore, modular housing offers flexibility, making it easier to repurpose for different uses over time, which is vital for ever-changing urban landscapes (Ginigaddara et al., 2023; Chen et al., 2021).

In conclusion, resilient modular housing systems embody the convergence of rapid construction technology, sustainability, and climate resilience. While providing immediate solutions to pressing housing crises, these systems also pave the way for more adaptive urban environments. The growing body of features surrounding this topic emphasizes not only the necessity of such systems in disaster-prone areas but also their broader implications for sustainable urban development. Highlighted themes on this topic are systematically presented and grouped in the following table (Table 2).

Table 2. Comparative Table: Themes and studies.

Thematic Area	Key Features	Benefits	Representative Studies
Climate Adaptation	- Amphibious design- Flexible structural systems	- Resistance to flooding- Adaptive to water level changes	Naseri (2024), Zahra et al. (2025), Mansoor et al. (2023)
Emergency & Post-Disaster Housing	- Prefabricated modular components- Rapid on-site assembly	- Quicker response in crisis- Improved structural resilience	Ghannad et al. (2020), Shahzad et al. (2022), Gunawardena et al. (2014)
Sustainability Integration	- Use of green building principles- Environmental material selection	- Reduced ecological footprint- Contribution to the green economy and long-term ecological goals	Kusbiantoro et al. (2024), Khan et al. (2022)
Urbanization & Flexibility	- Modular units with repurposing potential- Affordable construction methods	- Social inclusion- Suitability for changing urban needs and circular economy	Parisi & Donyavi (2024), Ginigaddara et al. (2023), Chen et al. (2021)
Holistic Resilience Frameworks	- Integration of institutional and design strategies	- Comprehensive flood resilience- Inclusive planning	Naseri (2024), Zahra et al. (2025)

4. Earthquake-Prone Regions in California

California is one of the most seismically active regions in the United States, necessitating robust approaches to earthquake preparedness and building resilience in structures. Among these approaches, integrating advanced building techniques and materials into modular housing systems shows promise for increasing the seismic resilience of residential structures in earthquake-prone areas. Recent studies indicate the effectiveness of modular construction in speeding the building process while enhancing the seismic robustness of new housing developments.

California's ongoing seismic activity requires continuous evaluation of building codes and construction practices to ensure safety. Research suggests that increased earthquake frequencies call for strengthened building codes, particularly near fault lines to ensure that structures are designed to withstand major seismic activity (Debnath et al., 2024). This regulatory framework has prompted the exploration of modular systems, which can be constructed to meet stringent seismic norms while addressing community housing needs. For example, modular designs can incorporate flexible materials that dissipate seismic energy more effectively during an earthquake, helping to minimize damage (Kaven, 2020).

Methodologies applied in the modular housing sector should also leverage technological innovations. The Southern California Seismic Network (SCSN) provides extensive data on seismic activity, which can inform the design of modular housing systems that are both cost-effective and resilient (Hauksson et al., 2020). Additionally, continuous research on seismicity patterns and predictive modeling can guide modular construction practices, ensuring they are prepared for potential seismic threats (Guo, 2025). This is critical as urban development often occurs in high-risk areas, reinforcing the need for advanced systems capable of withstanding natural disasters (Debnath et al., 2024).

Research has shown that modular housing can mitigate the adverse effects of severe seismic events by utilizing innovative reinforcement techniques. Trends in seismic data reveal that certain regions experience seismic bursts and swarms, necessitating the adaptive capabilities of modular homes to accommodate these environmental stressors. Studies utilizing machine learning approaches to analyze seismic patterns suggest that developers can design homes that dynamically respond to increasing levels of tectonic stress (Rundle & Donnellan, 2020). This includes features such as adjustable foundations or specialized bracing systems that enhance structural integrity during seismic events.

Collaboration with local authorities and communities is vital for the successful integration of modular housing systems. Educational initiatives on earthquake preparedness and construction safety can foster a culture of resilience, enhancing community ownership over housing projects (Dobrovolsky et al., 2013). Building on collective knowledge about seismic risks can guide the selection of materials and practices that are environmentally friendly and cost-effective (McClellan, 2015).

Importantly, insurance coverage poses a significant challenge for homeowners in California, with many residents opting not to secure earthquake insurance despite the high risk (Pothon et al., 2019). This disparity emphasizes the need for public outreach and education initiatives to shift perceptions of risk versus the financial realities of earthquake preparedness. Modular homes could potentially lower owner costs through faster construction times and reduced material waste, thereby encouraging more residents to invest in earthquake insurance due to the assured safety and longevity of their homes.

Finally, implementing the MyShake platform, a smartphone-based earthquake early warning system, can enhance public safety and preparedness in modular housing environments (Allen et al., 2019). Such technologies, integrated with modular construction practices, provide an added layer of resilience, not only ensuring the structures are seismically safe but also keeping occupants informed about impending threats.

In conclusion, as California grapples with the challenges posed by its disaster-prone geography, the development of resilient modular housing systems presents a multifaceted solution that addresses immediate housing needs while improving long-term safety. Through collaboration across research, technology, regulatory frameworks, and community engagement, California can lead in creating housing that withstands seismic hazards. The table below outlines and categorizes the prominent themes concerning this issue (Table 3).

Table 3. Comparative Table: Themes and studies.

Thematic Area	Key Features	Benefits	Representative Studies
Seismic-Resilient Construction	- Flexible materials- Reinforced modular frames- Adjustable foundations	- Enhanced resistance to seismic energy- Minimized structural damage	Debnath et al. (2024), Kaven (2020), Rundle & Donnellan (2020)
Regulatory & Safety Standards	- Seismic-specific building codes- Location-based design criteria	- Compliance with safety norms- Protection in high-risk fault-line areas	Debnath et al. (2024), Guo (2025)
Technological Integration	- Seismic sensors- Early warning	- Improved disaster response- Data-	Hauksson et al. (2020), Allen et al.

Thematic Area	Key Features	Benefits	Representative Studies
	systems (e.g., MyShake)- AI modeling	informed modular designs	(2019), Rundle & Donnellan (2020)
Community Engagement & Education	- Public awareness programs- Construction safety workshops	- Greater resilience culture- Informed material choices and safety practices	Dobrovolsky et al. (2013), McClellan (2015)
Affordability & Insurance Impact	- Reduced construction costs- Efficient material use- Safety assurance	- Increased willingness to invest in earthquake insurance- Financially viable housing for vulnerable populations	Pothon et al. (2019), McClellan (2015)

5. Resilient Modular Housing Systems for Earthquake-Prone Regions in California

In the context of earthquake-prone regions like California, resilient modular housing systems present a viable approach to addressing both immediate housing needs and long-term safety concerns. The advent of modular construction can be traced back to various historical events that necessitated quick housing solutions, such as the California Gold Rush and the aftermath of significant wars. Modern modular construction has evolved through advances in technology and design practices aimed at countering the disruptions caused by natural disasters, including earthquakes (Ginigaddara et al., 2023). This contemporary strategy encompasses the use of prefabricated materials and methods that not only hasten the construction process but enhance the resilience of buildings against seismic activities (Navaratnam et al., 2019).

The significance of implementing modular housing systems, particularly in earthquake-prone areas, can be attributed to their intrinsic characteristics of adaptability, affordability, and sustainability. A systematic review by Vithanage et al. provides insight into the safety risks associated with off-site manufacturing, critical for understanding the broader implications of modular housing (Vithanage et al., 2021). Lean construction techniques, which advocate for waste reduction and efficiency, can be integrated into modular housing practices, thereby improving safety and resilience without sacrificing cost-effectiveness (Ikuma et al., 2011). These methods ensure that modular homes can be constructed rapidly without compromising their structural integrity, making them particularly beneficial in the wake of seismic events.

Resilience in modular housing goes beyond mere physical robustness; it necessitates designing homes that can effectively respond to changing environmental conditions. Achumie et al. emphasize that the integration of operational models leveraging community participation and emergent smart technologies enhances housing project outcomes, aligning with goals of affordability and sustainability (Achumie et al., 2024). Implementing smart technologies in modular designs contributes to energy efficiency and promotes environmental sustainability, increasing the adaptive capacity of these structures against future disasters (Achumie et al., 2024).

Moreover, as highlighted by Haque et al., container-modular housing (CMH) specifically fosters community resilience through its ability to withstand environmental adversities, such as flooding or earthquakes, while promoting sustainable development (Haque et al., 2021). The adaptability of container modular homes makes them particularly suitable for varied geographical contexts, including California's diverse seismic landscape. Their research emphasizes that integrating robust construction materials and methods fosters communities capable of enduring and recovering from natural disasters. Major themes associated with this matter are elaborated and organized into clusters in the subsequent table (Table 4).

Table 4. Categories and insights.

Category	Sub-Components / Focus	Key Insights	Representative References
1. Historical Context	- Post-crisis housing solutions- Evolution of modular systems	Modular housing roots trace back to rapid shelter needs during Gold Rush & wars; now evolved for disaster resilience	Ginigaddara et al. (2023)
2. Construction Innovation	- Prefabrication & Lean practices- Off-site manufacturing- Container Modular Housing (CMH)	Speeds up building while ensuring seismic strength; reduces waste and enhances safety during construction	Navaratnam et al. (2019); Ikuma et al. (2011); Haque et al. (2021)
3. Structural & Operational Resilience	- Seismic adaptability- Smart tech integration- Community-driven design	Homes are not just physically strong but also adaptable, energy-efficient, and responsive to user/community needs	Vithanage et al. (2021); Achumie et al. (2024)
4. Sustainability & Affordability	- Green materials- Cost-effective processes- Modular reuse potential	Promotes long-term environmental and economic resilience, especially in urban earthquake-prone areas	Haque et al. (2021); Achumie et al. (2024)
5. Community Resilience Building	- Social inclusion- Smart governance- Public participation in design & planning	Enhances recovery speed and local ownership of disaster response infrastructure	Achumie et al. (2024); Haque et al. (2021)

6. Findings

Construction practices in seismic zones must address specific challenges, as exemplified in the work of Chrysanidis et al., who delve into the financial implications of constructing buildings in earthquake-prone areas (Chrysanidis et al., 2021). Their research sheds light on the higher costs associated with ensuring seismic compliance in building design. Nevertheless, modular housing systems, which can be produced at lower costs while maintaining compliance with strict seismic regulations, provide a practical alternative that could lower both initial investments and long-term maintenance costs. This dual focus on resilience and affordability is particularly crucial as California grapples with ongoing housing shortages amidst increasing seismic risks.

The hosts of modular housing benefit from not just structural resilience but also enhanced community involvement in the construction process, fostering a greater sense of ownership among residents. A community-driven approach can significantly improve the overall success and sustainability of housing projects in earthquake-prone areas (Haque et al., 2021). By incorporating local knowledge into the design and construction processes, modular housing can adapt to specific needs, ultimately enhancing community resilience.

Research suggests that educating construction workers on resilience skills specific to modular assembly processes can significantly impact safety and efficiency in high-stress environments typical of earthquake-prone regions (Peñaloza et al., 2017). Training programs focused on these skills prepare workers for immediate assembly challenges and unforeseen circumstances that may arise during or after earthquakes. Understanding how to effectively utilize structural reinforcement techniques contributes directly to the resilience of the modular systems.

Furthermore, incorporating elements of ecological sustainability becomes increasingly crucial as the concept of resilience evolves. Design methodologies prioritizing minimal environmental impact while maximizing structural integrity are imperative (Griffen, 2023). This includes adopting passive energy systems, as shown in studies where attention to solar gain and natural ventilation significantly enhances occupants' quality of life while ensuring energy efficiency and resilience against climatic fluctuations (Lee et al., 2020).

Modular housing systems should be designed to mitigate future climate-related risks. The evolving nature of climate change necessitates innovative responses in the housing sector, where modular designs can play a transformative role. Utilizing modular systems to meet housing demands must align with broader environmental objectives, including energy efficiency and reduced carbon emissions (Selikhova, 2022). As California positions itself at the forefront of earthquake preparedness, promoting research-driven modular housing solutions that embrace both safety and sustainability will be vital.

7. Conclusion

The findings of this study underscore that urban transformation, when conceptualized through alternative strategies, must be approached not only as a spatial or aesthetic operation but as a comprehensive socio-technical process. The analysis of clustered themes demonstrates that material performance, construction logistics, and socio-spatial adaptability emerge as equally decisive variables in shaping the viability of transformation practices.

From a material standpoint, the comparative evaluation of reinforced concrete in relation to alternative systems highlights its paradoxical duality: while concrete remains structurally advantageous due to its compressive strength, durability, and wide availability, its environmental footprint and inflexibility in adaptive reuse scenarios significantly constrain its suitability for future-oriented urban models. The production report further reveals that material life cycles and embodied energy calculations must be considered integral parameters in the design phase, rather than post-facto assessments.

In terms of cost and construction logistics, the data indicate that conventional large-scale interventions tend to exacerbate economic and temporal inefficiencies, particularly in contexts with constrained budgets and high labor variability. The alternative pursuit model, therefore, suggests a shift toward modular, prefabricated, and hybrid systems that optimize both material efficiency and on-site assembly processes. These approaches not only reduce construction timelines but also allow for phased implementation strategies that align more closely with the socio-economic rhythms of local communities.

On the urban scale, the clustering of findings points to the critical role of participatory governance and contextual adaptability. The evidence suggests that top-down, monolithic transformation projects undermine both social cohesion and long-term resilience, while micro-scaled, community-engaged models exhibit greater adaptability to emergent needs. Moreover, the integration of infrastructural flexibility—such as sub-surface vehicular re-routing or incremental structural adjustments—

demonstrates the necessity of treating the city as a dynamic, living system rather than a static end-product.

In light of these conclusions, the study recommends:

- **Prioritizing Life Cycle Assessment (LCA) in Urban Transformation**

Future projects must embed LCA metrics as baseline evaluation criteria, ensuring that material selection, structural systems, and construction processes are aligned with carbon reduction and circular economy goals.

- **Advancing Modular and Prefabricated Construction Systems**

Policy and design frameworks should encourage hybrid systems that combine the structural robustness of concrete with the flexibility of modular or lightweight alternatives, enabling more adaptive and resource-efficient interventions.

- **Embedding Phased and Scalable Implementation Models**

Urban transformation should adopt a temporal dimension, allowing for staged construction processes that can adapt to evolving demographic, economic, and environmental conditions.

- **Institutionalizing Participatory Planning Mechanisms**

Community-driven input must be integrated at early design phases, ensuring that transformation processes address local socio-cultural dynamics and foster ownership among residents.

- **Redefining Transformation as an Ongoing Process Rather than a Finalized Project**

A paradigm shift is required to move beyond static masterplanning toward open-ended strategies that accommodate uncertainty, prioritize resilience, and enable continuous recalibration of urban systems.

The study affirms that the future of urban transformation depends not on replicating conventional practices at a larger scale, but on critically rethinking materials, processes, and governance structures to produce cities that are sustainable, adaptable, and deeply embedded in their social and ecological contexts.

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Nature-Based Water Management Approaches in Arid and Semi-Arid Climates from a Landscape Architecture Perspective

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1. Introduction

Arid and semiarid climates are ecosystems where water resources are limited, evaporation rates are high, and food chains are fragile. In these climate types, water management is not only a technical issue but also a social, cultural, and ecological imperative, touching every aspect of life and influencing design (Abd El Aziz, 2016). Water-Sensitive Urban Design (WSUD), particularly in urban landscapes, is being developed to alleviate water scarcity and strengthen ecosystem services through water recovery, retention, purification, and distribution (Schulze et al., 2024).

The WSUD approach encompasses multilayered strategies such as rainwater harvesting, biological filters, permeable surfaces, and groundwater recharge applications. These strategies aim to restore the natural water cycle and minimize negative hydrological impacts (Climate-Adapt, 2023). For example, a study by ElAziz (2016) in Naser City, Egypt, found that water-saving lands using WSUD techniques reduced water consumption by up to 50% by reducing the use of high-quality water for irrigation. Similarly, unique groundwater modeling in the Cape Flats region of South Africa demonstrated the positive impact of WSUD on groundwater regimes (Gxokwe et al., 2020). These approaches, which should not be limited to engineering-based solutions, offer holistic management in arid climates through nature-based solutions (NbS), ecosystem restoration, water harvesting, land cover modifications such as mulching, and biodiversity-supported design components. Systematic reviews have shown that NBS implementations in arid regions of Africa have achieved significant biophysical and socioeconomic success rates of over 50% (Okello et al., 2024). WSUD is highly important for landscape architecture because it provides a framework for integrating a region's characteristics, such as the water cycle, energy systems, natural ecology, aesthetics, and sustainable use of materials, into the urban fabric to ensure a more livable and healthy environment (Donofrio et al., 2009). Landscapes created in accordance with WSUD principles reduce the urban heat island effect, support ecological diversity, and provide resilience to local communities in accessing water. For example, the Parramatta Road project in Sydney reduced 70% of rainfall by diverting runoff through bioretention pits (a low-impact development technique designed to manage and treat surface runoff), permeable pavements, and rainwater storage systems (UrbanDesignLab, 2024).

This book chapter will examine the theoretical foundations of WSUD and NbS approaches within the context of nature-based water management in arid and semi-arid climates, as well as examples of past (traditional systems) and current applications. The aim is to define the theoretical framework for the contributions of landscape architecture to water management and to demonstrate the potential of this concept. As the chapter progresses, a sustainable and adaptive water management paradigm will be proposed, both from an ecological, social, and technical perspective.

1.1. Theoretical Framework

In arid and semiarid climates, pressure on water resources leads not only to water scarcity but also to soil degradation and a decline in ecosystem services (Okello et al., 2024). In this regard, nature-based solutions (NbS), which offer a complementary and ecological integration with landscape ecology, aim to manage water using ecosystem processes, control erosion, improve soil structure, regulate microclimates, and utilize ecosystem services to retain, purify, and cyclically use water.

Jin et al. (2018) reported that ecological restoration projects significantly improve soil moisture, while natural regeneration and vegetation recovery have the same effect. This resulted in a significant increase in water retention capacity, and the reduction in irrigation requirements significantly contributed to hydrological stability in arid areas.

In their study, He et al. (2022) suggested that developments are not a sustainable way to improve the ecology of arid and semi-arid areas because they put nearly two-thirds (63.2%) of the regions at risk of vegetation degradation. Instead, they suggested that a mixed model would be more effective in improving the ecology of arid and semi-arid areas, where only 15-25% of the land is divided into narrow forest strips and the remaining 75-85% is restored to local natural vegetation.

Nature-based solutions should address not only technical but also social, cultural, and economic dimensions. This multidimensional approach directly contributes to the planning, design, and implementation processes of landscape architecture (Eggermont et al., 2015). Therefore, biophysical indicators, user behavior, and the local ecological context should be considered together when designing NbS systems.

In conclusion, NbS is a powerful tool for improving the sustainability of water management, particularly in arid and semi-arid regions. However, the success of these systems depends on comprehensive monitoring mechanisms, local participation, economic analysis, and institutional support structures.

1.1.2. Water-Sensitive Urban Design (WSUD)

Water-sensitive urban design (WSUD) is a holistic planning approach that aims to mimic the natural water cycle in cities and to manage resources such as rainwater, greywater, and groundwater sustainably (Lloyd et al., 2002). WSUD encompasses both structural solutions (e.g., permeable surfaces, rain gardens, green roofs) and non-structural components such as governance, public awareness, and participation.

The fundamental principles of WSUD are protecting water resources, reducing flood risks, retaining and purifying rainwater, integrating water into urban landscapes, and encouraging community participation (Wong, 2006). Systems implemented in line with these principles include biofiltration systems (bio-retention), wetlands, water collection tanks, and permeable soil systems.

WSUD systems improve rainwater quality while also reducing flood risks (Fletcher et al., 2015). Lloyd et al. (2002) also provided mechanical treatment by retaining up to 60% of the solid waste load in rainwater runoff.

WSUD, which helps balance the hydrological regime of cities, controls surface runoff through bioretention systems and permeable surfaces while also supporting groundwater recharge (Fletcher et al., 2013). According to Payne et al. (2015), these systems ensure the retention of pollutants such as nitrogen and phosphorus in water to a large extent, while Water-Sensitive Urban Design not only provides environmental benefits (better water quality, increased green areas, improved microclimate, etc.) but is also a highly profitable investment financially. In addition, WSUD applications increase urban biodiversity, have high potential for creating green roofs, wetlands, and microhabitats for living things, and public spaces intertwined with nature also contribute positively to human health. The success of WSUD depends on the effectiveness of social processes as well as technical solutions. Community participation in the process ensures the development of solutions supported by local knowledge (Brown et al., 2009). Therefore, in terms of governance, collaboration between local and regional institutions, as well as strategic and legal planning, are essential for WSUD to be sustainable (Furlong et al., 2016). Although WSUD offers many benefits, implementation faces several obstacles. Chief among these are high investment costs, a lack of institutional coordination, insufficient public awareness, and maintenance issues. Furthermore, Vasconcelos et al. (2022) identified the main obstacles in their study as a lack of design and maintenance standards, a lack of long-term planning, a lack of dissemination and information, a lack of incentives, and a reluctance to change.

In summary, WSUD is a holistic approach that addresses not only water management but also healthy urbanization processes, social equity, and ecosystem protection. In arid and semiarid regions, WSUD systems ensure both water conservation and the habitability of urban areas.

1.1.3. WSUD and NbS Interaction

Water-Sensitive Urban Design (WSUD) and Nature-Based Solutions (NbS) are two increasingly intertwined conceptual and practical approaches in contemporary urban water management. WSUD integrates urban stormwater management with aesthetic, functional, and environmental objectives, while NbS enables the design of these systems through nature-inspired processes.

Both approaches are closely related to international systems such as low-impact development (LID) and sustainable urban drainage systems (SUDS) (Fletcher et al., 2015). The difference between the two is that WSUD focuses more on design and urban planning, while NbS is a broader concept focused on producing ecosystem services and increasing climate resilience.

The components of WSUD, such as biofiltration systems, permeable soils, and wetlands, also fall under the NbS classification. The two approaches are largely incompatible in practice. For example, a rain garden serves both rainfall management functions within the WSUD framework and facilitates water-ecosystem interaction within the NbS framework.

Brown et al. (2013) argue that the integration of WSUD and NbS enhances social benefits, participation, and aesthetic quality, particularly in urban transformation projects. This combined approach increases infrastructure resilience and makes cities more resilient to climate-related risks.

Shuster et al. (2021) argue that hybrid projects increase biophysical efficiency, raise public awareness, and facilitate ownership by local governments, while emphasizing the success of community-supported rainwater management systems, particularly in local-scale implementations.

NbS tends to align with customary law and traditional/local knowledge, which may be traditionally important. Many projects also incorporate traditional rainwater collection systems to provide freshwater. A UN report emphasizes that WSUD/NbS systems provide higher social and environmental returns at lower costs than traditional “grey infrastructure” models, but that sustainability requires concurrent planning of monitoring, maintenance, and governance systems (WWAP, 2018).

Consequently, the complementary nature of WSUD and NbS allows cities to consider water not only as a technical resource but also as an ecological asset and social value. Landscape architecture, as one of the disciplines that combines these two approaches, has the potential to realize the spatial configuration of systems and the multi-layered benefit generation at the design level.

1.1.4. Landscape Ecology and Design Perspective

Landscape ecology stands out as the discipline that examines how spatial arrangements in water management can be made functional and ecologically meaningful (Forman, 1995). In this respect, landscape design not only creates visual aesthetics but also provides an environmental design that integrates hydraulic behavior, ecosystem processes, and habitat continuity. For example, supporting water-carrying corridors with natural vegetation can both control water flow and support biodiversity. With this approach, which considers interactions at different levels from the field scale to the regional basin, designers can develop multi-layered water management strategies, from wetlands to irrigation systems such as microstrip systems, and from rooftop landscapes to river corridors.

Landscape design aims to plan both the production and distribution of ecosystem services (Qiu et al., 2025); thus, services such as water regulation, carbon storage, soil conservation, biodiversity, and recreation are systematically designed. Particularly in arid/semiarid climates, landscape ecology provides spatial, ecological, social, and adaptive frameworks for water-centric designs, enabling the effective use of NbS and WSUD in practice, as every design element, from plant species selection to wetland microhabitats, influences water and ecosystem responses. Designers can create sustainable cities through landscape designs that consciously plan for ecosystem services, maintain spatial continuity, and offer solutions that adapt to climate risk and change.

2. Material and Method

This study is a compilation based on a literature review. The study material consists of open-access articles, theses, reports, and books published on water management, climate change, rainwater harvesting, and sustainable landscape practices. Literature selection was made through national and international databases (Google Scholar, DergiPark, ResearchGate, ScienceDirect), with particular emphasis on publications from the post-2000 era.

As part of the method, the obtained resources were classified under thematic headings and a comparative analysis approach was employed. The reviewed studies were interpreted within the framework of water management strategies, rainwater management practices, nature-based solutions, and a landscape architecture perspective. This method synthesized existing knowledge and revealed similarities and differences between different approaches.

No experimental measurements or field applications were conducted in the study; all findings were obtained from data in the literature. Thus, the study aims to provide a theoretical framework and guiding basis for future applied research.

3. Findings and Discussion

3.1. Arid and Semi-Arid Landscape Typologies

Arid and semiarid areas, defined as areas where evaporation exceeds precipitation, cover more than one-third of the Earth's surface, approximately 41% (Gaur & Squires, 2017). According to the Koppen–Geiger classification, arid and semiarid areas are designated by the codes "BWh," "BWk," "BSh," and "BSk" (Table 1) (Kottek et al., 2006), while the "aridity index" is also widely used in the literature (Arora, 2002). This indicator defines the amount of precipitation corresponding to plant water needs.

Table 1. Koppen-Geiger Climate Classification (Kottek et al., 2006).

Type	Description	Criterion
A	**Equatorial climates**	$T_{min} \geq +18$ °C
Af	Equatorial rainforest, fully humid	$P_{min} \geq 60$ mm
Am	Equatorial monsoon	$P_{ann} \geq 25\,(100 - P_{min})$
As	Equatorial savannah with dry summer	$P_{min} < 60$ mm in summer
Aw	Equatorial savannah with dry winter	$P_{min} < 60$ mm in winter
B	**Arid climates**	$P_{ann} < 10\, P_{th}$
BS	Steppe climate	$P_{ann} > 5\, P_{th}$
BW	Desert climate	$P_{ann} \leq 5\, P_{th}$
C	**Warm temperate climates**	-3 °C $< T_{min} < +18$ °C
Cs	Warm temperate climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3\, P_{smin}$ and $P_{smin} < 40$ mm
Cw	Warm temperate climate with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10\, P_{wmin}$

Cf	Warm temperate climate, fully humid	neither Cs nor Cw
D	**Snow climates**	$T_{min} \leq -3$ °C
Ds	Snow climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3$ P_{smin} and $P_{smin} < 40$ mm
Dw	Snow climate with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10$ P_{wmin}
Df	Snow climate, fully humid	neither Ds nor Dw
E	**Polar climates**	$T_{max} < +10$ °C
ET	Tundra climate	0 °C $\leq T_{max} < +10$ °C
EF	Frost climate	$T_{max} < 0$ °C

Typically, areas with annual rainfall below 200 mm are defined as drylands (Figure 1) (Wang et al., 2023). Seasonal irregularities lead to long dry periods. These conditions are not only related to climate but also shaped by hydrological regimes, soil structure, vegetation cycles, and anthropogenic influences, resulting from both natural and cultural processes.

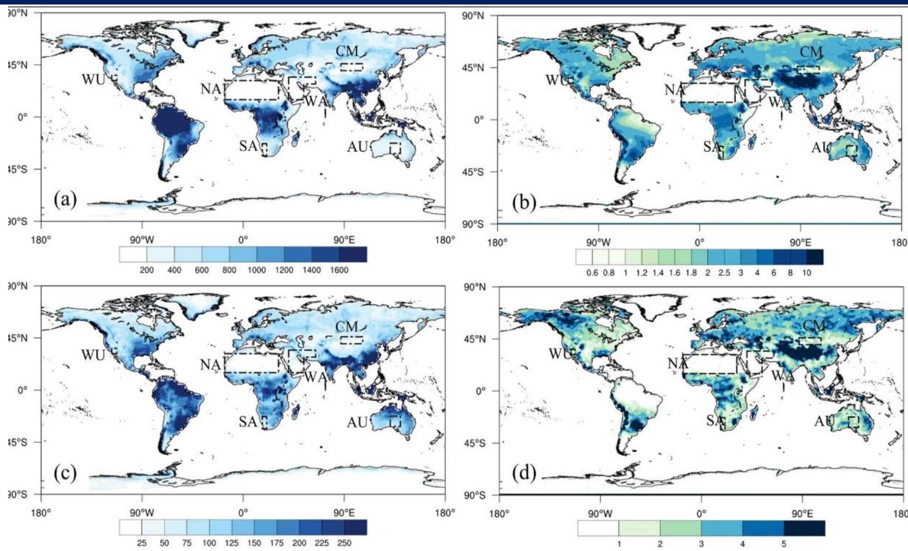

Figure 1. Annual Precipitation Distribution Amount between 1990-2019. a) Annual Precipitation Amount (P, mm), b) Precipitation Recycling Rate (PRR, %), c) Standard Deviation of Precipitation Amount (mm), d) Standard Deviation of Precipitation Recycling Rate (%), Black Line Areas Rule Region Boundaries (Wang et al., 2023).

Landscapes in arid regions generally consist of vast plains, alluvial plains, rugged plateaus, and foothills. This topographic diversity affects the interaction of water with soil and stream dynamics. Üstün (2020) stated that arid and semi-arid regions are classified according to topographic shapes, vegetation, soil types and pedogenesis, drainage characteristics, and climatological data. Sloping areas accelerate surface runoff based on drainage characteristics, while deposits on plains increase water infiltration potential. The micro-regional water cycle can also be enriched through human interventions. For example, while wind erosion dominates plateaus (Çelebi, 2010), water accumulation in valleys (Polat, 2011), resulting in microclimates. This difference guides site selection and NbS strategies in landscape design. Consequently, NbS and WSUD elements can be integrated into topographic micro-units through topography-supported planning.

Shrubs, dwarf trees, grasses, and succulent species dominate the vegetation in arid and semiarid areas (Maestre et al., 2021). Xerophytic plants, which provide soil stabilization with their deep taproots, exhibit the ability to store nearly 50% of precipitation with their large cells and shallow roots (Griffiths & Males, 2017). Therefore, they have natural potential for soil stabilization, water conservation, habitat creation, and pioneer plant use in rehabilitation areas.

3.2. Traditional Knowledge Systems and Nature-Based Approaches

Traditional systems used in water management in arid and semiarid regions (such as qanat, falaj, puquio, and mamanteo) also inspire modern water planning within the context of nature-based solutions. These systems are historical technologies that combine infrastructure strategies and ecosystem services, enabling both efficient and sustainable use in agriculture and daily use (Esenarro et al., 2023). In this regard, it is worth briefly mentioning these prominent systems.

Originating from Anatolia and founded by the Urartians, the qanat (kariz/kehriz/falaj) is a tunnel system that transports water underground by gravity (Bildirici, 2009). It has been used in the hydrological management of arid regions for hundreds of thousands of years. This system, with its low operating costs, constant water flow, and pump-free use, has contributed to sustainability. Furthermore, community-based management and maintenance processes are organized by governments or communities and are based on public water sharing principles. They still exist today in some parts of Iran and Turkey.

Puquios used in the Andes are similar in technology to qanat and have brought reliable groundwater to settlements such as Nazca (Schreiber & Rojas, 1995). These systems have supported local people's access to water in terms of cultural heritage, in line with the NbS approach.

Used in the high Andes of Peru, mamanteo (amuna) systems are a pre-Columbian irrigation technology (probably around 700 AD) that stored rainwater on mountain slopes and filtered it for delayed use during dry seasons, providing dry runoff. They were restored in the 21st century to serve modern cities (Wikipedia, 2025). Modern restorations have been implemented to improve water security, particularly in desert cities like Lima.

These traditional water systems adapt to local hydrological conditions and offer low-energy, sustainable water management. However, in modern times, due to loss of knowledge, urban expansion, and water pollution, some traditional systems are declining in use or collapsing completely due to neglect. Restoration and reuse efforts offer benefits in terms of both ecological and cultural heritage, as well as sustainability, while also providing material for nature-based solutions and water-sensitive urban design.

3.3. Current Landscape Design Approaches

3.3.1. Rain Gardens/Bioretention Cells

Rain gardens are temporary water retention systems designed to reduce surface runoff, prolong infiltration, and improve water quality by retaining rainwater in cities. These systems can increase rainwater runoff, improve groundwater levels, mitigate drought effects by reducing heat island effects, increase soil moisture levels, and allow temperatures to decrease due to increased evaporation (Kasprzyk et al., 2022). Jiang et al. (2015) reported that rain gardens effectively reduced 53% of water volume and approximately halved peak runoff. In one study, where 72% of the rain garden water level was diverted without retention, 100% of rainfall of up to 7 mm was diverted to the bioretention system (Burszta-Adamiak et al., 2023). Rain gardens, which contribute to groundwater recharge, a key factor in securing drinking water supplies in many cities, are both an infiltration solution and a waterproof solution that serves as a water retention function (Kasprzyk, et al., 2022). All things considered, these systems not only perform a water management function but also contribute to the filtration of pollutants through plants and microorganisms.

3.3.2. Permeable Pavements

Permeable soils are permeable structural systems that support the infiltration of water from the surface to the subsurface, improving water quality (Moretti et al., 2025). These types of permeable soils can be produced from many different materials, such as concrete, clay, natural stone, and permeable concrete paving (Edem et al., 2024), and can retain up to 90% of solids during filtration (Beecham et al., 2009). Furthermore, water discharged directly into infrastructure systems contributes significantly to groundwater recharge. Thanks to their porosity, permeable soils maintain lower surface temperatures compared to non-porous or less porous soils, positively impacting the urban thermal environment (Asaeda & Ca, 2000).

3.3.3. Green Roofs

Green roofs are a form of water management that both stores rainwater and releases it into the atmosphere through evapotranspiration thanks to the vegetative infrastructure established on the roof surface. Cao et al. (2013) demonstrated that rainwater harvested from a green roof can save over 61% of irrigation water. In addition to water savings, green roofs (or roof gardens) can improve landscapes, provide thermal insulation in buildings, help reduce pollutant gases, reduce the burning effects of sunlight, and reduce noise, thus providing economic, ecological, and aesthetic benefits (Pudjiastuti & Fatmawati, 2022). When used in conjunction with storage systems, these systems have high potential to reduce urban freshwater loads and contribute to a natural water cycle.

3.3.4. Xeriscaping

Xeriscaping is a landscape approach that utilizes native, drought-tolerant vegetation to significantly reduce irrigation needs. The three main objectives in this approach are "reducing the amount of lawns and other irrigated areas," "using cost-effective designs in irrigation systems," and "improving designs by utilizing local and natural landscape elements" (Bourg, 2004).

The need to better understand xeriscaping as a water-saving approach led to several studies in the 1990s, which found water savings ranging from 20% to 53% (Sovocool et al., 2006). Furthermore, according to Schneider (2008), when water-saving principles are successfully implemented in landscaping, water savings of approximately 50% can be achieved. This approach also significantly reduces maintenance burdens and costs.

3.3.5. Biophysical Microclimate Effect (Oasis Effect)

Oasis is a medium- to small-scale landscape type supported by natural or artificial streams in arid climates and deserts, not specific to a specific region or zone. It is characterized by relatively high primary productivity, a dominant mesophyte or xero-mesophyte vegetation, and a cooling effect of the vegetation through evaporation, which is more intense than the surrounding area (Hao et al., 2016). In areas where oasis effects develop wherever vegetation is present, and therefore wherever a moisture source is available, shading also prevents radiation from directly reaching the ground, thereby exacerbating the warming effect (Saaroni et al., 2004).

Anthropogenic land use and land cover changes can influence microclimate by varying the radiation budget and regulating the balance of surface energy. Changes in surface albedo capacity affect radiation absorption, while vegetation density and moisture availability convert incoming energy into latent or sensible heat, favoring its re-emission into the atmosphere. Urbanization, on the other hand, is an extreme manifestation of anthropogenic land use and cover diversity that can control near-surface weather conditions, increasing urban surface temperatures compared to rural areas through the urban heat island phenomenon (Georgescu et al., 2011). Therefore, increasing the albedo (a) of urban surfaces, as an artificial solution in addition to vegetation, is a highly effective way to reduce temperatures and, consequently, to make landscapes livable (Alchapar & Correa, 2016).

Fan et al. (2017) reported that the oasis effect in Phoenix, Arizona, USA, had an impact of -3°C compared to the surrounding area. Hao et al. (2016) reported that summer temperatures can be 2–7°C cooler in desert regions in environments with oasis effects. These oasis effects also have positive effects on nighttime winter temperatures in arid climates (Potchter et al., 2012). Saaroni et al. (2004) reported that studies have shown that oasis effects can reduce temperatures as much as 7°C in environments with temperatures above 45°C.

Oases stand out with their ability to increase human comfort and reduce energy consumption (Potchter et al., 2012). The urban heat island effect can be reduced by the combined use of permeable soils and green infrastructure; thus, living and ecosystem conditions can be improved.

3.4. Sample Projects/Case Studies

3.4.1. Arizona State University (ASU) Tempe Campus-Xeriscaping

Ünal Çilek (2023) reported that xeriscaping applications at the Arizona State University Tempe Campus could reduce water use by 85% by switching from turf to arid climate plantings. Research has shown that even scenarios that replace turf with xeriscaping up to 100% of the turf achieved significant water savings. This study serves as a strong case for green infrastructure transformations at public universities.

3.4.2. Ku-ring-gai Raingarden, NSW, Avustralia

The WSUD project achieved an annual suspended solids retention of 75 kg at the Ku-ring-gai Municipality's raingarden biofilter facility at Kooloona Crescent in New South Wales, Australia (Zaman, 2025). This project demonstrates the significant impact of small-scale landscape elements on water quality and is a vivid example of how WSUD components can also reduce physical pollution.

3.4.3. Lynbrook Estate, Victoria-WSUD Integration

The Lynbrook Estate project, supported by Melbourne Water, effectively managed stormwater runoff with stormwater routes, underground gravel drains and wetland systems (Wong, 2002). The project won awards for achieving below guideline suspended solids levels (Greenway, 2004) and provides a valuable model for WSUD in large-scale communities.

3.4.4. Lakewood, Colorado-Raingarden

Seven years of field observations showed that rain gardens maintained soil moisture 28.3% higher than control sites, 23% higher than control sites (Kauffman & Stropki 2022). In this project, rain gardens supported groundwater recharge by creating moist micro-catchments integrated into the topography on rainy days.

3.4.5. Western Australia- Green Infrastructure Projects

Across the city of Perth and its surrounding areas, bioretention pits, green walls, and wetlands have combined water management, biodiversity, urban heat reduction, and social benefits at sites such as Carina Loop, Swansea Park, and King Square (New Water Ways, 2025). These projects have demonstrated similar ecological and socio-cultural impacts of integrated WSUD/NbS strategies.

4. Discussion

While nature-based solutions (NbS) theoretically offer multiple ecological, social, and economic benefits, in practice they remain fragmented and unsystematic (Fu, 2023). This limits the full integration of NbS strategies into holistic water management practices, particularly in arid and semi-arid regions.

While WSUD applications provide a detailed understanding of the city-scale water cycle, their effectiveness can be diminished when contextual factors (climate, local culture, socio-economic structure) are inadequately considered. For example, in applications in Darmstadt, WSUD models have been reported to be somewhat monotonous and context-specific parameters overlooked (Schulze et al., 2024).

Another challenge faced by traditional NbS/WSUD applications is their focus on existing urban infrastructure and short-term engineering. Adaptation to existing city structures is, in almost all cases, costly and difficult to plan, limiting the widespread adoption of innovative water management tools. The success of NbS implementations in arid and semiarid regions often depends on socio-cultural acceptance and community participation (Cohen Shacham et al., 2016). Local people's knowledge and values increase their participation in restoration and maintenance processes, strengthening both ecological and social sustainability. Furthermore, NbS projects, which theoretically target water security and climate adaptation, need clear and standardized indicators to monitor their performance in practice (Fu, 2023). These indicators should include multidimensional monitoring tools such as water quality, soil moisture, groundwater recharge, and community satisfaction.

In scenario analyses conducted in arid cities like Phoenix, Arizona, NbS planning was supported by GIS-based assessments, but regulatory, financing, and maintenance gaps persist during the implementation phase. These shortcomings hinder the scaling of innovative landscape infrastructures.

In summary, while NbS and WSUD approaches offer technically robust models, they are not yet operating to their full potential due to a lack of context-sensitive planning, community participation, monitoring and maintenance systems, standardized indicators, and institutional support. In this context, future research and practice should develop a holistic water management paradigm by targeting these missing areas.

5. Conclusion and Suggestions

Water management in arid and semiarid climates has become a multifaceted planning challenge where climatic water deficit, high evaporation, land degradation, and accelerating urbanization pressures intersect. Water is not merely a technical infrastructure input; it is a constitutive landscape component that collectively shapes ecological processes, cultural practices, social justice, and spatial design decisions. As explored in the book chapter, Nature-Based Solutions (NbS) offer the potential to leverage ecosystem processes to retain, purify, reuse, and strengthen water services.

The positive effects of long-term vegetation rehabilitation and natural regeneration on soil moisture, water holding capacity, and hydrological stability should form the basis of dryland restoration strategies. Non-biophysical NbS practices alone need to be planned with social acceptance, economic viability, and institutional governance in mind.

Water-Sensitive Urban Design (WSUD) is a comprehensive planning approach that aims to rebalance the water cycle by integrating rainwater, greywater, and groundwater flows into the urban fabric. WSUD components, such as bioretention systems, permeable surfaces, storage tanks, and wetlands, both reduce surface runoff and mitigate flood risk. In arid and semiarid areas, WSUD applications protect receiving water bodies by retaining a significant portion of rainwater-derived solids and nutrient loads. Combinations of permeable surfaces and biofiltration are considered effective methods for balancing urban hydrological regimes and supporting groundwater recharge.

The spatial planning and technical design framework of WSUD, when combined with the ecosystem-based processes of NbS, is highly capable of producing multifunctional, low-carbon, and climate-resilient waterscapes. The literature has demonstrated that hybrid WSUD/NbS practices not only enhance biophysical performance but also enhance public awareness, local government ownership, and user-based maintenance processes. Integrated green-blue infrastructure programs have the potential to deliver higher social-environmental returns at lower lifecycle costs than gray infrastructure.

Landscape ecology, which analyzes spatial pattern-process relationships related to water management, makes visible the effects of design decisions on ecological resilience, habitat continuity and hydraulic behavior, and monitoring water-focused landscape strategies developed at different scales (parcel, neighborhood, basin) through ecosystem service production, carbon storage and recreational values provides data for adaptive management of the design.

Since the relationship between topography, drainage patterns, soil properties and plant function types directly determines water retention and diversion designs in arid landscapes, spatial analysis has become indispensable for landscape architects, which has been influential in the formation of traditional water management systems.

Historical water collection-transmission systems such as qanat, puquios, and mamanteos offer powerful prototypes for contemporary NbS/WSUD applications, with their low energy requirements, gravity-driven transmission, reduced evaporative losses, and community-based maintenance models. Adapting these traditional infrastructures to current conditions has the potential to support both the preservation of cultural landscape heritage and the development of cost-effective water security strategies adapted to climate change.

Considering their various strategies, rain gardens offer scalable water management modules in arid regions by reducing rainfall volume, filtering pollutant loads, and supporting groundwater recharge. Bioretention systems have demonstrated high performance in reducing peak runoff and increasing storage capacity based on monitoring of actual rainfall events. Permeable soils not only allow water infiltration, reducing both flooding and the urban heat island effect, but also can retain a significant portion of suspended matter and pollutants. Green roofs store rainwater, reducing irrigation water demand, improving thermal comfort within the building envelope, and ensuring the sustainability of urban green networks. Xeriscaping is a low-maintenance approach that provides significant water savings through the use of native xeriscaping plants and limited irrigation. In applications using natural and artificial materials, water-focused landscape structures supported by vegetation can create an "oasis effect" in arid climates, reducing environmental temperatures and improving human thermal comfort. Combinations of surface materials, permeable soils, and vegetative shading supported by artificial materials strengthen water-surface-climate interactions in urban cooling strategies.

Scaling up WSUD and NbS implementations requires coordination between local governments, regulatory incentives, standard design-maintenance protocols, and long-term financing tools. Because the functionality of water-sensitive landscape infrastructures can decline over time without community participation and stakeholder-based maintenance programs, coordinating social processes with design is essential.

Future studies should develop standardized indicators to assess the long-term performance of WSUD and NbS combinations in arid climates. Datasets such as water quality, soil moisture, groundwater recharge, and user satisfaction should be monitored together. These datasets can be used to develop typology-based waterscape guidelines tailored to different topographic and socioeconomic contexts, using monitoring-learning-implementation models based on adaptive design cycles.

The results can be summarized as follows: water scarcity and climate pressures have necessitated integrated landscape-based water management. NbS and WSUD, when used together, are high-potential practices that can provide multi-layered ecological and social benefits. In this sense, traditional systems will serve as a model for contemporary design. Performance monitoring is essential; water, soil, climate, and user data must be integrated.

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The article complies with national and international research and publication ethics.

Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article. There is no conflict of interest.

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Assessment of the Integration of Ecological Planning and Design into Smart City Frameworks in the Context of European Cooperation Perspectives

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1. Introduction

In the 21st century, with the rapid increase in urbanisation, the concept of 'smart cities' has come to the fore with the integration of information and communication technologies into all areas of urban life. Initially developed to increase efficiency in infrastructure management, this model has evolved into a multidimensional urban transformation framework that also encompasses social participation, environmental sustainability, and resilience. Today, smart cities are viewed as holistic systems that increase digitalisation in areas such as energy, transportation, and waste management while also promoting social welfare and ecological harmony. The concept of smart cities has evolved over time, not only through technological developments but also through changes in governance structures, service delivery, and approaches to urban life. Sharifi et al. (2021) examined the evolution of smart city literature between 1991 and 2021 through bibliometric analysis, highlighting research clusters that have intensified since 2010, particularly in the areas of IoT, big data, and conceptual structures. Pavlov (2021), on the other hand, focuses on the integration of the concept with administrative structures, emphasising how the digitalisation process has accelerated the transition to integrated intelligence-based structures in public administration. This transformation has led to the positioning of smart cities as a new form of administration built on multi-layered digital systems. This conceptual transformation has brought about a multidimensional change that affects not only administrative but also all components of urban life through technological infrastructures. Singh et al. (2022) and Gracias et al. (2023) systematically evaluate the components and technological architecture of the smart city concept, highlighting the role of sustainability, public participation, and quality of life in the evolutionary process. Studies such as Rani et al. (2021) and Haque, Bhushan, & Dhiman (2022) address how technologies (AI, IoT, big data, blockchain) are integrated into the functioning of cities, as well as the opportunities and security and privacy issues that this integration brings. Bauer, Sanchez, & Song (2021) examine the integration of IoT into the smart city structure alongside the development of technological infrastructure, analysing the evolution of the concept in practical terms through application examples. This practical dimension was explored by Campisi et al. (2021) in the context of autonomous vehicles, evaluating the effects of digitalisation on spatial planning and mobility. Lai & Cole (2023), on the other hand, systematically analysed various smart city indices representing efforts to measure conceptual development, contributing to the evolutionary nature of measurement tools.

Alongside these developments, ecological planning and design (EPD) aims to design cities in a way that is compatible with natural systems, sustainable, and resilient. It is directly related to concepts such as climate change adaptation, disaster risk reduction, ecosystem service conservation, and environmental justice. However, in current smart city applications, these concepts often lag behind technological infrastructure, and nature-based solutions are reflected in urban policies to a limited extent. This situation highlights the need for new planning approaches that require the integration of EPD into smart city systems.

EPD aims to minimise the environmental impacts of urbanisation and redefine the relationship between humans and nature. Steiner and Brooks

(1981) define this approach as the systematic integration of biophysical and sociocultural knowledge into decision-making processes, outlining a seven-step comprehensive methodology for ecological planning. Building on this structural foundation, Wang, Palazzo, & Carper (2016) point to the inadequacies of approaches reduced to scientific knowledge and propose the concept of 'ecological wisdom,' suggesting a transformation in decision-making processes centred on ethics, local context, and social responsibility. Heymans et al. (2019) systematically analyse trends in the literature and present an 'ecological urban planning paradigm' consistent with sustainability principles, arguing that concepts such as ecosystem services, resilience, and green infrastructure must be integrated into this paradigm. This holistic understanding is supported by the social-ecological-technological systems (SETS) framework developed by McPhearson et al. (2022), which proposes a planning approach based on systems thinking that addresses the multidimensional complexity of nature-based solutions.

Ecological networks, an important tool for preserving ecological integrity at the urban scale, are evaluated in functional and social contexts by Ignatieva, Stewart, & Meurk (2011), who emphasise the need to support these structures with cultural and aesthetic values. This view is reinforced by Semeraro et al. (2021) through applications such as green roofs and community gardens, addressing the effects of green infrastructure on human health and well-being. The role of ecological planning in multi-scale structural development and the creation of sustainable urban forms is discussed by Bibri (2022) in the context of data-driven approaches, defining the strategic planning dynamics from eco-neighbourhoods to eco-cities. Similarly, Puchol-Salort et al. (2021) evaluate the integration of ecosystem services into planning processes using the UPSUF framework, linking it to decision support systems. Finally, McPhearson et al. (2025) provide a comprehensive synthesis of the integration of nature-based solutions into urban planning at the global scale, highlighting the need for a multi-layered strategic transformation that includes dimensions of justice, governance, and knowledge production.

In this context, the European Union supports smart city strategies with comprehensive policies such as the Green Deal, Circular Economy Action Plan, Mission Cities Initiative, and New European Bauhaus. These approaches aim to extend technological progress beyond digitalisation to areas such as environmental sustainability and social inclusiveness. The importance of interdisciplinary cooperation, multi-stakeholder governance, and nature-based solutions in achieving sustainable urbanisation goals is emphasised; in this regard, planning disciplines play important roles.

Smart city policies in Europe are developing in an integrated manner with sustainability goals; in this process, local context, governance structures, and technical capacities are decisive. In an analysis of 40 cities in Europe, Cantuarias-Villessuzanne et al. (2021) categorise cities into three groups based on their sustainability strategies and propose different strategy typologies based on core smart city competencies. This diversity demonstrates that cities develop different understandings of sustainability based on their technological capacity, social needs, and environmental context. Shamsuzzoha et al. (2021), on the other hand, compare Helsinki, Singapore, and London to highlight the contribution of multi-stakeholder, data-driven, and participatory strategies to sustainability goals in European cities.

Emphasising the decisive role of local context in policy-making, Esposito et al. (2021) reveal how different socio-economic structures are reflected in smart city narratives using the examples of Brussels and Wallonia, arguing that these narratives guide strategy preferences. In terms of institutional capacity and organisational structures, Gasco-Hernandez et al. (2022) highlight the impact of leadership, collaboration, and European Union funds on the success of digital transformation in the cities of Barcelona, Milan, and Munich. Similarly, Masik, Sagan, & Scott (2021) analyse the transformative effects of infrastructure investments and EU funds on governance culture in Polish cities.

At the implementation level, sustainable urban mobility plans (SUMP) and mobility as a service (MaaS) models are considered strategic transformation tools for European cities. Russo and Rindone (2023) highlight the role these plans play in policy-making aligned with the 2030 Agenda, while Savastano et al. (2023) examine in detail the impact of digital mobility applications on user perceptions and service quality using the example of Milan. In evaluating electric mobility policies, Ruggieri et al. (2021) measure policy impacts through air quality indicators in cities such as London, Hamburg, & Milan and document their contribution to carbon neutrality goals. Razmjoo et al. (2021) evaluate the sustainability contributions of smart cities through performance indicators developed specifically for green buildings and electric vehicles, identifying technical, governance, and social barriers and proposing solutions. In another analysis specific to the tourism sector, Ivars-Baidal et al. (2023) draw attention to the theoretical and practical gaps in the integration of sustainable tourism indicators into smart city policies. This diversity demonstrates that smart city policies in Europe are shaped not only by technology but also by a multi-layered understanding of sustainability in social, managerial, and environmental dimensions.

In this context, this book chapter evaluates the integration of EPD into smart city frameworks, referencing the EPD-Net: Filling the Gap project, which is supported by the European Union's Erasmus+ Programme and is currently ongoing. The project aims to strengthen the role of the EPD approach in creating disaster-resilient and sustainable cities; to this end, an AI-based smart education module is being developed, and a multi-stakeholder learning network is being established across Europe. In this section, the main objectives and approach of EPD-Net will be introduced, and it will be discussed how European-level collaborations in the context of the ongoing project process can contribute to the institutionalisation of EPD in smart city planning.

2. EPD Approaches in the Context of European Cooperation

The European Union's sustainable development policies encourage the adoption of nature-friendly, multi-scale, and multi-stakeholder approaches in urban planning. In this context, EPD is considered not only an environmental sensitivity but also a strategic transformation area associated with innovative urban governance models. EU directives, strategies, and funding mechanisms support the transformation of cities in an integrated manner with technological infrastructure and ecological systems. In this context, the EPD approach enables nature-based solutions, ecosystem services and green infrastructure to be institutionally integrated into urban planning processes. Developing strategies for sustainable urbanisation in Europe are based on transnational network structures involving public actors, universities, civil society organisations, the private sector, and local communities. Such multi-stakeholder structures enhance the applicability of holistic approaches such as EPD by prioritising interdisciplinary cooperation in knowledge production and sharing. Programmes such as Horizon Europe, Erasmus+, Interreg, and URBACT, in particular, ensure the institutionalisation of these collaborations and the dissemination of good practice examples. Eco-neighbourhoods, green infrastructure strategies, and nature-based climate adaptation projects developed across Europe are among the concrete outcomes of this collaboration. The EPD-Net: Filling the Gap project, developed and currently being implemented within this framework, represents a model consortium structure established on the basis of European cooperation. The EPD-Net project is being implemented through a multidisciplinary and multi-sector partnership model comprising universities, municipalities, NGOs, and private sector representatives from Belgium, Italy, Poland, Spain, and Turkey (Figure 1).

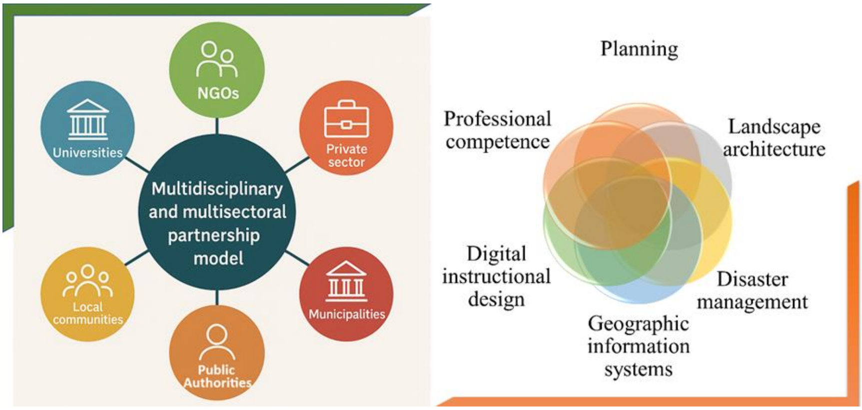

Figure 1. Multi-disciplinary and Multi-sector Partnership Model

The main objective of the project is to develop an innovative learning network and digital training module to support the systematic application of ecological principles in the planning of disaster-resilient and sustainable cities. Through activities such as knowledge exchange, methodology development, pilot implementation tailored to local contexts, and multilingual resource production among partners, the aim is to disseminate EPD principles across Europe (Table 1).

Table 1. EPD Strategy and Dissemination Potential Matrix

Strategic Area	Recommended Strategies	Potential for Dissemination
Institutional Structures	Strengthening multi-level governance mechanisms, developing inter-institutional coordination tools	Medium - high
Education and Capacity Development	Supporting professional transformation with multilingual, contextual educational content	High
Policy Integration	Creating guidelines, indicators, and criteria for integrating EPD principles into planning legislation	High
Digital Infrastructure	Integrating CBS, digital twins, and AI-based decision support tools into planning systems	Medium
Dissemination and Networks	Sharing best practice examples on open platforms, increasing interaction between local government networks	Very high

The structure of the EPD-Net project is important in that it demonstrates how ecological transformation policies in Europe are being implemented through multi-level governance structures. The project aims not only to produce academic outputs but also to develop decision support tools for implementation through municipalities and local governments, as well as to offer integrated solutions for education and capacity development processes. In this regard, the project lays the groundwork for a unique EPD model developed within the framework of European cooperation that can be replicated in different contexts.

2.1. Partnership Model and Consortium Structure within the Scope of the EPD-Net Project

The EPD-Net: Filling the Gap project is a multi-stakeholder European cooperation initiative that aims to strengthen its strategic role in the process of building disaster-resilient and sustainable cities. The project is supported by the European Union's Erasmus+ Programme and is being carried out with the participation of various institutions and organisations from European Union countries and Turkey (Figure 2). The consortium is based on a multidisciplinary and multi-sectoral structure that includes universities, local governments, private sector representatives, civil society organisations, and implementing agencies.

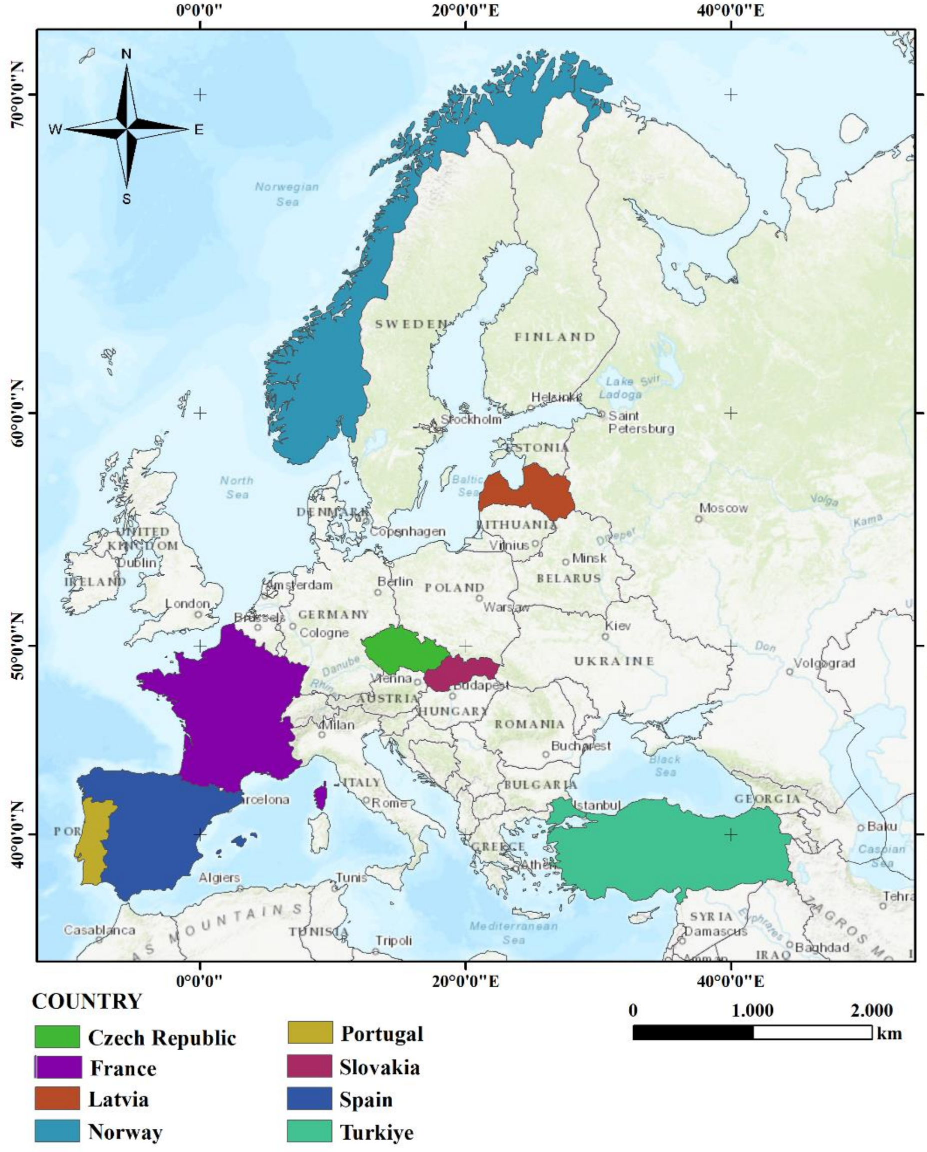

Figure 2. EPD-Net Project Partner Countries

The partnership model aims to effectively implement the EPD approach at both theoretical and practical levels by bringing together the knowledge, experience, and capacity contributions of actors working at different scales. Universities play a role in academic research, pedagogical design, and educational module development processes. NGOs ensure that social participation, environmental justice, and local sensitivities are integrated into the project, while private sector actors contribute to the development of innovative technologies and data-driven solutions. This consortium structure is based not only on task distribution but also on a culture of collaborative production. Interaction between partners is carried out based on the principles of horizontality and flexibility in decision-making processes. The development, testing, and dissemination stages are shaped through mutual feedback mechanisms. Thus, both the applicability of EPD-based learning models is increased, and scalable solutions can be developed in different contexts. EPD-Net's partnership structure serves as an example of collaboration models developed in the field of sustainable urban planning at the European level. The consortium dynamics of the project aim not only to produce an educational module but also to create a multi-actor knowledge and impact network that will support the institutionalisation of the EPD approach in European cities. In this respect, the project presents a successful example of an interdisciplinary and multi-level strategic partnership model.

3. The Future of EPD Applications in Smart Cities

Smart cities are multi-layered systems shaped not only by technological infrastructure but also by environmental sustainability, social inclusivity, and governance models. In this context, the integration of EPD into smart city strategies not only produces environmentally friendly urban solutions but also offers a comprehensive planning approach that serves long-term resilience, climate adaptation, and social justice goals. The integration of

EPD principles into strategic policy documents, professional capacity building, and the development of decision support systems are of great importance for the systematic application of EPD principles. The smart education module to be developed within the scope of the EPD-Net project aims to establish the knowledge infrastructure for this transformation. The module offers a multidisciplinary learning framework covering topics such as nature-based solutions, SETS, disaster resilience, climate change mitigation, and digital planning tools. This content has a flexible and modular structure that can be used in the professional development processes of educational institutions, public employees, and local government experts. Thanks to an AI-supported guidance system, the aim is to provide a learning experience that can be adapted to the individual needs and contexts of users.

For EPD applications to be successful in the future, not only technical knowledge but also governance tools that enable the transformation of institutional structures are needed. The EPD-Net project aims to produce multilingual resources and a common terminology framework that will support the development of a common language and approach among practitioners across Europe. This will enable stronger coordination between European-level strategic documents and local implementation tools.

3.1. Strategies for Integration into Policy and Planning Processes

In order to redesign smart city strategies in line with sustainability and resilience goals, nature-based and holistic planning approaches beyond technological infrastructure are needed. EPD provides a robust framework that addresses this need, integrating principles such as ecosystem services, green infrastructure, and environmental justice into spatial decision-making processes. Although European cities' policy documents include such concepts, sectoral fragmentation, institutional barriers, and governance deficiencies at the implementation level limit the full integration of EPD into planning (Heymans et al., 2019; McPhearson et al., 2022). Developing system-focused models is important to overcome these limitations. The SETS approach proposed by McPhearson et al. (2025) emphasises the need to integrate nature-based solutions into planning processes using systems thinking in order to respond to complex urban problems. Similarly, Puchol-Salort et al. (2021) demonstrate that decision support systems play a critical role in integrating ecosystem services into decision-making processes through the UPSUF model. Good examples of promoting the institutionalisation of such strategic models can be observed across Europe in transport planning and carbon-neutral city targets. For example, integrated solutions such as SUMP and MaaS are effective applications that bring together urban planning and environmental goals. Russo and Rindone (2023) discuss the transformative role these plans play in policy-making in line with the 2030 Agenda, while Ruggieri et al. (2021) assess how mobility policies can be measured through environmental indicators and their impact on reducing carbon emissions.

Within this framework, the EPD-Net project has set the development of practical tools that will transform policy and planning processes as one of its primary objectives. The consortium, formed with the participation of partners from different countries, enables comparative analysis of various legal, institutional, and cultural contexts. The strategies developed in line with these analyses reveal how EPD principles can be adapted to various urban planning systems. At the same time, the smart education module developed within the scope of the project serves to strengthen the EPD perspective in decision-making processes by providing knowledge-based guidance for planning professionals. In this regard, the integration of EPD into smart city planning is considered a multidimensional transformation area that goes beyond the conceptual level and needs to be supported by measurable, applicable, and context-sensitive tools.

3.2. EPD-Compliant Smart City Model with European Partnerships

Achieving sustainability and resilience goals in European cities increasingly requires structures based on multi-stakeholder, multi-level, and interdisciplinary partnerships. In this context, an EPD-compliant smart city approach is taking shape through integrated models supported by transnational partnerships, rather than relying solely on local initiatives. The European Commission's initiatives, such as the Green Deal, Horizon Europe, and New European Bauhaus present a strategic vision that combines technological innovation with nature-based principles.

Mutual learning processes and joint strategy development play an important role in the development of an EPD-compliant smart city model. Cantuarias-Villessuzanne et al. (2021) point out that there are striking differences between European cities' approaches to sustainability and suggest that these differences can be harmonised through mechanisms based on shared knowledge. At this point, multi-stakeholder collaborations have the potential to both produce solutions sensitive to local needs and disseminate good practice examples at the European level. Shamsuzzoha et al. (2021) show that data-driven and participatory management practices implemented in cities such as Helsinki, London, and Singapore provide suitable infrastructures for the EPD approach.

The EPD-Net project brings together institutions from different countries and sectors under one roof by concretising this type of cooperation model. The partnership structure not only enables the sharing of knowledge and experience, but also allows for joint content development, the creation of adaptable solutions, and strategic adaptations that take contextual differences into account. The AI-supported digital education platform goes beyond targeting individual capacity development and provides tools that will facilitate the spread of a common understanding of EPD across Europe. This model offers a replicable framework for implementing EPD principles in European cities. The developed digital infrastructure and network-based structure both facilitate the incorporation of an ecological dimension into local policymakers' strategy documents and enable the creation of practical models that can be reproduced in different contexts. The project's multilingual and culturally sensitive structure supports an inclusive approach that encourages access to information and participation. This Europe-centric collaborative model contributes to the integration of EPD's planning, governance, and education dimensions, thereby establishing a strategic foundation for the realisation of a sustainable and resilient city vision.

4. Conclusion and Suggestions

EPD stands out as a fundamental approach to achieving sustainability and resilience goals in smart cities in terms of environmental, social and administrative dimensions. This approach offers a comprehensive vision of transformation shaped by nature-based solutions, system-oriented spatial strategies, and multi-stakeholder governance principles. European Union initiatives such as the Green Deal, Mission Cities, and New European Bauhaus provide holistic frameworks supporting this transformation, enabling urban policies to be reimagined not only through digitalisation but also through an environmental adaptation perspective.

The EPD-Net project serves as a unique platform in this transformation process, strengthening the knowledge infrastructure, providing guidance at the implementation level, and increasing professional capacity. The interaction between the consortium's stakeholders from different geographical, institutional, and cultural contexts is producing important findings on how the EPD approach can be diversified and made applicable across Europe. The digital learning network created with the AI-supported training module developed within the scope of the project facilitates the dissemination of this information and its customisation according to local contexts.

Findings show that the functional implementation of environmental sustainability and resilience principles in smart city planning requires the holistic integration of EPD into systems. The success of implementation is closely related to inter-institutional coordination, data-driven decision support systems, flexible strategy production, and contextual adaptation capabilities, beyond theoretical frameworks. From this perspective, the collaboration model and content strategy developed by the EPD-Net project create an effective reference area that offers examples applicable to different contexts.

Looking ahead, supporting interdisciplinary research, restructuring professional education content around the EPD axis, and strengthening the technical capacity of local governments are critical to the widespread adoption of the EPD approach. Additionally, addressing ecosystem services, nature-based solutions, and environmental justice concepts in planning systems in a measurable, applicable, and locally appropriate manner will strengthen the institutionalisation process. In this context, the EPD-Net project offers an innovative model for shaping the sustainable and resilient cities of the future with its multidimensional approach that combines digitalisation, ecological sensitivity, and governance.

4.1. Strategic Recommendations and Dissemination Potential

In order for smart city strategies to develop in line with EPD principles, multi-layered, scalable, and context-sensitive strategies are needed. EPD is not merely an approach to the organisation of the physical environment, but also a planning paradigm that aims to integrate environmental information, social equity, and resilience principles into decision-making processes. Strategies developed in this direction should cover multidimensional areas of transformation, such as strengthening institutional capacity, restructuring professional education and making governance mechanisms more flexible.

Findings from the EPD-Net project indicate that interdisciplinary learning networks, decision support systems, and digital content offer important leverage points for institutionalising EPD in European cities. In this context, the use of digital modules in local government capacity development processes should be encouraged, and multilingual and contextually adaptable training materials should be developed for public employees, planning experts, and students. Such materials should not only provide theoretical knowledge but also be designed to guide professional practices with practical examples.

As a strategic recommendation, guidance documents, indicator sets, and performance criteria should be developed to facilitate the integration of EPD principles into national and local planning legislation. These tools will enable decision-makers to reflect on nature-based solutions more systematically in policy documents. In addition, it is recommended that urban data infrastructures be organised to respond to EPD-focused planning needs, and that GIS, digital twins, and AI-supported analysis tools be integrated into planning processes.

To increase the potential for dissemination, it is necessary to share good practice examples through open access platforms, strengthen knowledge transfer between similar projects, and encourage the active participation of local government networks. In this context, EPD-Net's multi-national and multi-sector partnership model offers the opportunity to increase both adaptability to different contexts and the capacity for widespread impact. The project's digital outputs and training modules can be evaluated as an expandable application pool after being tested in different cities and countries.

4.2. Future Research and Application Areas

The integration of EPD into smart city policies is still an emerging interdisciplinary field of research and application. Therefore, there is a need to develop new methodological approaches at the interface between EPD and smart technologies, increase field-based applications, and strengthen impact assessment mechanisms. The SETS framework is increasingly prominent in the literature. However, more empirical data is needed on how this framework can be adapted to local contexts and integrated into decision-making processes using which tools (McPhearson et al., 2022; 2025).

In future research, the impact of EPD approaches on planning processes should be evaluated not only through expert opinions but also through stakeholder-based participation. Research on integrating elements such as community representation, social justice, and local knowledge systems into planning models will contribute to the democratisation of this approach. On the other hand, the potential contribution of technologies such as artificial intelligence and big data analytics to the EPD process has not yet been fully revealed. How data management, algorithmic decision support systems, and visualisation tools can be aligned with ecological planning awaits further exploration as an interdisciplinary research area.

At the application level, priority should be given to comparative case studies showing how the EPD approach works in different climate zones and socio-cultural contexts. In this context, multi-stakeholder projects such as EPD-Net have great potential in terms of creating an information infrastructure for pilot applications to be tested at various geographical scales. Additionally, increasing the number of applications focused on spatial justice and reducing environmental inequalities will provide an opportunity to assess the social impacts of nature-based solutions, not just their physical ones.

Future work should focus on the integration of EPD principles into planning education curricula, their relationship with national planning standards, and their compatibility with the technical capacities of local governments. It is considered a strategic priority for both academia and practice that the conceptual model supporting EPD should not remain abstract but should be supported by measurable, applicable, and socially relevant content.

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The article complies with national and international research and publication ethics.

Ethics Committee approval was not required for the study.

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Author Contribution and Conflict of Interest Declaration Information

1st Author 50%, 2nd Author 25%, 3rd Author 25% contributed.

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