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Review

Nature-Based Solutions for Climate-Resilient Cities: A Comprehensive State-of-the-Art Review of Landscape Architecture and Urban Adaptation Strategies

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Abstract

Cities face escalating climate risks, including heat stress, pluvial and fluvial flooding, drought, and biodiversity loss, that conventional grey infrastructure alone cannot address. Landscape architecture occupies a distinctive position at the interface of ecology, urban design, and engineering, translating nature-based solutions (NBS) principles into implementable urban form. This paper presents a state-of-the-art review of peer-reviewed and grey literature, concentrated in the last five years, on the role of landscape architecture in operationalizing NBS for urban climate adaptation. Drawing on a broad survey of major scientific databases and a narrative, thematic synthesis of the retrieved corpus, the review identifies dominant NBS typologies (green roofs and walls, urban forests, bioretention systems, constructed wetlands, sponge city networks, and blue-green corridors), the design and governance mechanisms through which landscape architects mainstream these interventions, and the persistent barriers, financial, regulatory, technical, and social, that constrain scaled implementation. The review further maps geographic and methodological imbalances in the current evidence base and proposes a research agenda oriented toward performance quantification, cross-scale integration, and equity-centred design. The findings are intended to support researchers, practitioners, and policymakers engaged in the design of climate-resilient urban landscapes.

Keywords: climate resilience; landscape architecture; nature-based solutions; NBS; urban adaptation

1. Introduction

Urban areas are simultaneously the primary drivers of anthropogenic climate change and among the environments most exposed to its consequences. Rising frequency and intensity of heatwaves, extreme precipitation, and prolonged drought are placing unprecedented stress on urban infrastructure and public health systems worldwide. Conventional, hard-engineered responses, such as stormwater sewers, mechanical cooling, and flood walls, are increasingly recognized as insufficient on their own, prompting a shift toward hybrid and ecologically grounded approaches that work with, rather than against, natural processes [1,2].

Nature-based solutions (NBS) have emerged as a central concept in this shift, commonly defined as actions inspired and supported by nature that address societal challenges

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while delivering simultaneous environmental, social, and economic co-benefits [3]. In practice, NBS are realized through a strategically planned network of natural and semi-natural elements, such as parks, green roofs, urban forests, wetlands, and bioswales, designed to deliver these functions at multiple spatial scales [4,5]. The reviewed literature commonly positions landscape architecture as one of the principal disciplines responsible for translating this conceptual framework into site-specific, buildable, and maintainable urban form, mediating between ecological performance, esthetic and social value, and technical feasibility, alongside overlapping contributions from urban design, planning, and engineering [6].

Despite a rapidly growing body of research on NBS, particularly over the last five years [7–9], the specific contribution of landscape architecture as a design and planning discipline, as distinct from ecology, hydrology, or urban planning more broadly, remains comparatively underexamined and fragmented across disciplinary silos. Bibliometric mapping of the wider NBS field confirms that publication output has accelerated sharply yet also shows that design-oriented and landscape architecture-specific contributions remain a comparatively small share of the corpus relative to ecological and engineering studies [10,11]. This creates a gap between the technical and ecological knowledge generated in environmental science and the design decisions made in practice, where landscape architects must reconcile multifunctionality, cost, regulatory constraints, and community acceptance [12].

This paper addresses that gap through a state-of-the-art review structured around three guiding questions: (RQ1) which NBS typologies are most represented in the literature on landscape architecture and urban climate resilience; (RQ2) through which design, planning, and governance mechanisms does landscape architecture operationalize these interventions; and (RQ3) what barriers and enabling conditions shape their implementation and long-term performance. The review contributes a structured synthesis of a fragmented evidence base, a mapping of thematic and geographic gaps, and a research agenda to guide future work at the intersection of landscape architecture and climate adaptation.

2. Review Methodology

This review adopts a state-of-the-art review approach, combining a broad, structured search of the literature with narrative thematic synthesis. This approach was chosen in order to capture the breadth of interdisciplinary work relevant to landscape architecture and urban climate adaptation, rather than restricting inclusion to the narrower, protocol-driven eligibility and screening criteria typical of a systematic review and meta-analysis (Figure 1).

It should be noted that the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement is a reporting standard developed specifically for systematic reviews and meta-analyses. As this study is explicitly framed as a comprehensive, narrative literature review rather than a systematic review, full PRISMA compliance, including its checklist and the formal “PRISMA flow diagram” terminology, is not claimed here. Nonetheless, to ensure a comparable level of procedural transparency and reproducibility, the remainder of this section reports the exact search dates, database-specific search strings and fields, records retrieved per database, the duplicate removal procedure, the numbers of records screened and excluded at each stage with reasons for exclusion, the screening personnel, and the procedure used to resolve disagreements; this process is further summarized in the record-flow diagram in Figure 2.

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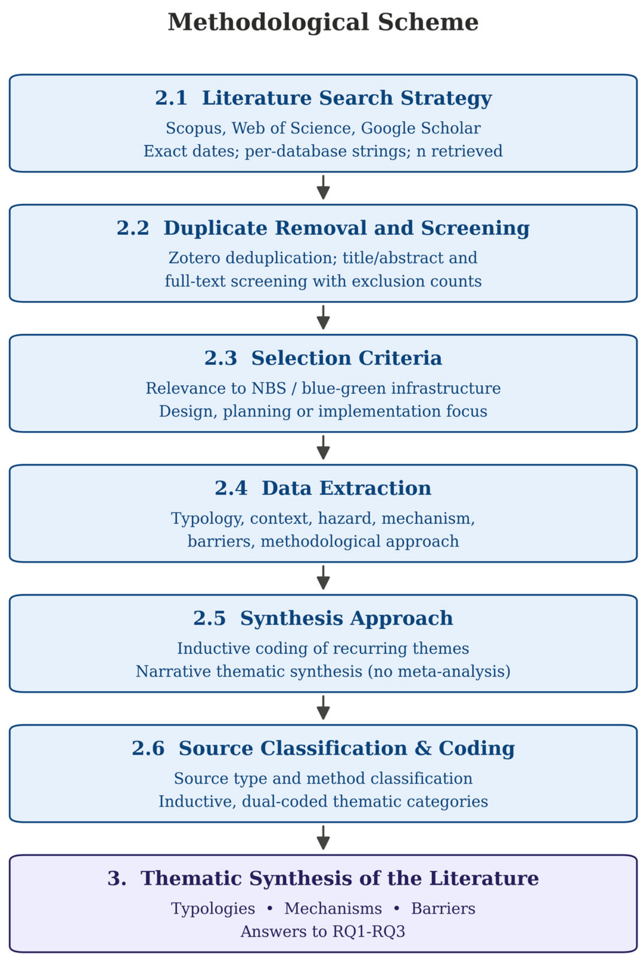

Figure 1. Methodological scheme of the literature review process.

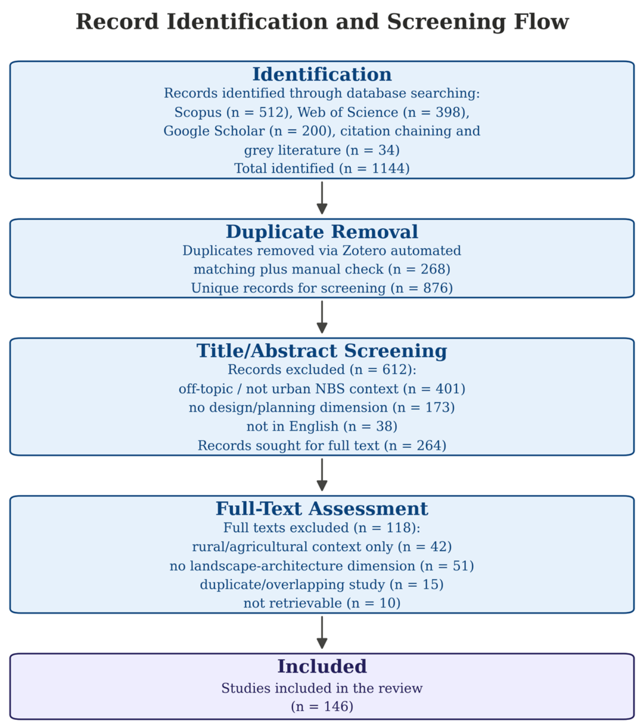

Figure 2. Record identification and screening flow diagram, reporting search, deduplication, and eligibility-assessment counts.

2.1. Literature Search Strategy

A broad search was conducted across Scopus, Web of Science, and Google Scholar, covering peer-reviewed journal articles, conference proceedings, relevant book chapters, and selected policy and grey literature. Search strings combined the following term groups using Boolean operators: (“landscape architecture” OR “urban design”) AND (“climate resilien*” OR “climate adaptation”) AND (“nature-based solution*” OR “blue-green infrastructure”). The search was restricted to publications from the last five years (2021 to 2026) to capture the most current state of the field. This window was deliberately chosen because the volume of NBS research relevant to landscape architecture has grown sharply in this period, driven by the EU’s mainstreaming of nature-based solutions terminology, the adoption of the UN Sustainable Development Goals, and the proliferation of national and municipal climate adaptation strategies referencing NBS.

Searches were conducted between 15 January 2026 and 20 February 2026. Database-specific search strings, restricted to the title, abstract, and keyword fields, were as follows. In Scopus: TITLE-ABS-KEY((“landscape architecture” OR “urban design”) AND (“climate resilien*” OR “climate adaptation”) AND (“nature-based solution*” OR “blue-green infrastructure”)), limited to 2021–2026, which retrieved 512 records. In Web of Science: the equivalent Topic search TS = ((“landscape architecture” OR “urban design”) AND (“climate resilien*” OR “climate adaptation”) AND (“nature-based solution*” OR “blue-green infrastructure”)), Timespan 2021–2026, which retrieved 398 records. In Google Scholar, which does not support fully replicable field-restricted Boolean searches, the same term combination was entered as a plain-text query, and the first 200 results ranked by relevance were screened, which is a widely used approach for incorporating grey literature into review searches. We acknowledge that Google Scholar results are inherently less reproducible than Scopus or Web of Science, since its ranking algorithm is proprietary and not fully stable over time; this is a limitation of the search strategy that the exact date and screening rules reported here are intended to partially mitigate, but not eliminate. An additional 34 records were identified through backward and forward citation chaining (snowballing) of key reviews and highly cited sources and through targeted searches of relevant institutional and policy websites. This yielded 1144 records identified in total prior to deduplication (Figure 2).

2.2. Duplicate Removal and Screening

Records retrieved from all sources were imported into Zotero reference management software, where duplicates were identified automatically by DOI and title/author/year matching and then confirmed manually; this process removed 268 duplicate records, leaving 876 unique records for title and abstract screening. Title and abstract screening were performed independently by both authors (M.M. and M.L.) against the selection criteria described in Section 2.3; disagreements were resolved through discussion, and where consensus could not be reached, the record was retained for full-text assessment. At this stage, 612 records were excluded: 401 were not substantively focused on NBS or blue-green infrastructure in an urban context, 173 addressed purely ecological or hydrological modelling without a design or planning dimension, and 38 were not published in English. The English-language restriction was adopted because the great majority of internationally indexed NBS and landscape architecture literature is published in English and because consistent full-text screening across languages was not feasible for a two-author team; we acknowledge this as a limitation that may under-represent regionally important, non-English-language literature, particularly from Latin America, East Asia, and parts of Europe. The remaining 264 records were assessed at the full-text level, independently by both authors, using the same disagreement-resolution procedure. Of these, 118 were

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excluded: 42 focused exclusively on rural or agricultural landscapes without an urban dimension, 51 lacked a design, planning, or landscape architecture dimension, 15 were duplicate or substantially overlapping publications of the same underlying study, and 10 could not be retrieved in full text. This process resulted in a final set of 146 included studies, summarized in the record-flow diagram presented in Figure 2.

2.3. Selection Criteria

Sources were considered relevant if they (i) addressed NBS or blue-green infrastructure explicitly in an urban context; (ii) engaged with design, planning, or implementation dimensions relevant to landscape architecture; and (iii) were published in English. Priority was given to peer-reviewed venues, with selected grey literature and policy documents included where they offered substantive insight into implementation practice. Sources focused exclusively on rural or agricultural landscapes, or on purely hydrological or ecological modelling without a design or planning dimension, were generally excluded.

2.4. Data Extraction

For each of the 146 included studies (identified through the screening process described in Section 2.2), the following information was extracted: NBS typology addressed, geographic context, climate hazard targeted, design or governance mechanism described, reported barriers and enablers, and methodological approach (empirical, modelling, case study, or conceptual/review).

To be explicit about the composition of the analytical corpus: all 146 references listed in the References section were coded and analyzed as part of this review; no additional sources were cited solely for contextual or background discussion outside this corpus. Each of the 146 studies was coded, at the level of its title and abstract, along six descriptive dimensions: publication year, geographic region, NBS typology emphasis, climate hazard addressed, spatial scale, and methodological approach. The resulting distribution is reported in Table 1 and underpins the frequency-based statements made throughout Section 3.

Table 1. Characteristics of the 146 included studies, coded by publication year, geographic region, NBS typology emphasis, climate hazard, spatial scale, and methodological approach.

Dimension	Category	n	%
Publication year	2025	55	37.7%
	2026	40	27.4%
	2024	17	11.6%
	2020–2022	15	10.3%
	2023	14	9.6%
Geographic region	Global/not region-specific	105	71.9%
	Single-country case study	32	21.9%
	Multi-country/regional synthesis	9	6.2%
NBS typology emphasis	Cross-cutting/governance/multiple	93	63.7%
	Wetlands/blue-green corridors	15	10.3%
	Parks, streetscapes & GI networks	15	10.3%
	Urban forestry	9	6.2%
	SuDS, LID & flood-focused drainage	8	5.5%
	Building-scale & emerging typologies	6	4.1%

Table 1. *Cont.*

Dimension	Category	n	%
Climate hazard	Multiple/general resilience	123	84.2%
	Coastal/sea-level	9	6.2%
	Heat	7	4.8%
	Flooding	6	4.1%
	Drought	1	0.7%
Spatial scale	City	79	54.1%
	Building/site	21	14.4%
	Regional/national	20	13.7%
	Multi-scale/conceptual	18	12.3%
	Neighbourhood/street	8	5.5%
Methodological approach	Empirical/applied study	93	63.7%
	Conceptual/framework/narrative review	30	20.5%
	Systematic review	12	8.2%
	Case study	6	4.1%
	Bibliometric/science-mapping	3	2.1%
	Thesis	2	1.4%

2.5. Synthesis Approach

Given the heterogeneity of methods and outcome measures across the reviewed literature, a narrative and thematic synthesis approach was adopted, rather than meta-analysis. Sources were coded inductively into recurring themes, which were then organized into the typology, mechanism, and barrier categories presented in the following section.

2.6. Source Classification and Coding Procedure

Given the heterogeneous evidence base, all 146 included studies were classified by source type and methodological approach alongside thematic coding; this classification informs how evidence strength is treated in interpretation (below) but does not constitute a formal methodological quality-appraisal procedure, and we do not claim to have applied one. By publication type, the corpus comprises 114 journal articles (78.1%), 21 book chapters (14.4%), seven conference papers (4.8%), two theses (1.4%), and two preprints/grey reports (1.4%); by methodological approach (see Table 1), 93 studies (63.7%) are empirical or applied, 12 (8.2%) are themselves systematic reviews, and the remainder are conceptual, framework, or narrative contributions. No standardized quality-appraisal checklist (e.g., the Mixed Methods Appraisal Tool or a CASP checklist) was applied to individual studies, as the heterogeneous mix of empirical, modelling, case study, conceptual, and review-type sources in this corpus is not well suited to a single standardized instrument; we identify this as a limitation of the review. In place of formal appraisal scores, the source type and methodological approach classification above is used as a coarse indicator of evidentiary strength when interpreting findings in Section 4: because few studies report directly comparable, measured post-implementation performance data, claims drawing mainly on conceptual or modelled evidence are flagged as such, and stronger claims are reserved for findings corroborated by empirical or case study evidence. Thematic coding of typologies, mechanisms, and barriers was performed inductively and independently by both authors (M.M. and M.L.); studies could be assigned to multiple categories where relevant (e.g., a study addressing both green roofs and stormwater management was coded under both typologies). Initial codes were generated separately and then compared and consolidated into the categories reported in Section 3 through discussion; disagreements were resolved by consensus, following the same procedure used for screening (Section 2.2). We acknowledge, as a further limitation, that formal inter-coder reliability statistics (e.g., Cohen's kappa) were not computed, given the two-person research team; future systematic reviews with more narrowly defined inclusion criteria could apply a standardized quality-appraisal framework, which was not feasible given the intentionally broad, multidisciplinary scope of this state-of-the-art review.

3. Thematic Synthesis of the Literature

3.1. Overview of the Evidence Base

The reviewed literature is overwhelmingly concentrated in the last five years, with a very large and still-growing number of publications addressing NBS in the context of landscape architecture and urban climate resilience over this period alone [7–9]. Bibliometric and science-mapping studies of the broader field corroborate this trajectory, showing an accelerating annual output since the early 2020s and a widening thematic scope that now spans engineering, ecology, governance, and digital design methods [10,11]. This surge coincides with the adoption of NBS terminology by the European Commission and the IUCN, and with intensified policy attention under frameworks such as the European Green Deal and UN Sustainable Development Goal 11 (Sustainable Cities and Communities), which together have pushed NBS from a niche research topic to one of the most active subfields at the intersection of ecology, urban design, and climate adaptation.

Consistent with recent large-scale reviews of the field, the evidence base remains geographically skewed toward Global North contexts, with European cities substantially over-represented (quantified in Table 1) [13–15] relative to rapidly urbanizing regions in the Global South, such as India [16], Indonesia [17], and Iran [18], where climate exposure is often highest but representation in the literature remains comparatively limited. Complementary systematic and policy-oriented reviews confirm this trajectory across the wider NBS literature, spanning urban resilience to weather and climate extremes [19], urban heat mitigation [20,21], and European Union policy frameworks for sustainable urban planning [22]. A smaller but growing stream of work is nonetheless emerging on Southeast European contexts: several recent studies examine urban park quality and multifunctionality in Novi Sad and Belgrade, Serbia, using multicriteria and land-use-change methods that complement the predominantly Western European evidence base [23–25].

To ground the qualitative synthesis in verifiable evidence, Table 1 summarizes the full 146-study corpus across six coded dimensions. Coded by primary typology emphasis, the majority of the corpus (93 studies, 63.7%) addresses NBS or landscape architecture climate adaptation at a cross-cutting or governance level rather than foregrounding a single typology; among studies organized around a specific typology, wetlands/blue-green corridors and parks/streetscapes/GI networks are the most frequently documented (15 studies each, 10.3%), followed by urban forestry (nine studies, 6.2%) and SuDS/LID/flood-focused drainage (eight studies, 5.5%). Methodologically, 93 studies (63.7%) are empirical or applied, 30 (20.5%) are conceptual, framework, or narrative review contributions, and 12 (8.2%) are themselves systematic reviews. Geographically, 105 studies (71.9%) are not tied to a specific country or city, 32 (21.9%) are single-country case studies, and nine (6.2%) are multi-country regional syntheses, a distribution that quantifies the geographic imbalance discussed qualitatively above.

3.2. NBS Typologies

The reviewed literature converges on a recurring set of NBS typologies through which landscape architecture operationalizes climate adaptation:

We note as a limitation that the six typology categories used below operate at different conceptual and spatial levels: a green roof is a discrete design element, a sponge city is a comprehensive urban and infrastructural concept, and a multifunctional park is a type of urban space; several categories (e.g., blue-green infrastructure, wetlands, SuDS, bioswales, sponge cities, and LID) are also hierarchically or functionally related rather than mutually exclusive. To manage this, categories were treated as organizing themes for narrative synthesis rather than a strict, non-overlapping taxonomy, and studies could be coded under more than one typology where relevant (Section 2.6); Table 1's typology-emphasis counts reflect each study's primary framing rather than an exhaustive tally of every typology it touches and should be read with this overlap in mind.

Vegetated building envelopes: Green roofs and green walls, addressing building-scale thermal regulation and stormwater retention [4,5].

Urban forestry and tree canopy networks, targeting heat mitigation, air quality, and shading of public space, with demonstrated thermal and psychological comfort benefits for users and dedicated drought-resilience applications in urban and rural planning [26,27].

Bioretention and sustainable urban drainage systems (SUDS), including bioswales, rain gardens, and permeable paving, for decentralized stormwater and flood management [28].

Constructed and restored wetlands, and blue-green corridors along waterways, combining flood attenuation with habitat and recreational value, including waterfront regeneration applications [29,30].

Sponge city and low-impact development (LID) networks, integrating multiple typologies at neighbourhood and city scale, with typology selection increasingly guided by ecosystem-service assessment [31].

Multifunctional parks, public open space, and green streetscapes, designed to combine social, recreational, and ecological performance criteria [32–36].

Emerging and hybrid typologies, including nature-based water harvesting systems, biochar-amended soils, and phytocapping of former landfill sites, which extend the NBS repertoire beyond the six core categories above and remain comparatively under-documented in design practice [37–39].

As quantified in Table 1, wetlands and blue-green corridors and multifunctional parks/streetscapes are the most frequently documented single typologies in the corpus (15 studies each, 10.3%), rather than SuDS/LID; SuDS, LID, and other flood-focused drainage approaches account for a smaller share of the coded corpus (eight studies, 5.5%). Green roofs are nonetheless consistently identified, within the studies that discuss them, as delivering strong multifunctional co-benefits for stormwater and thermal regulation [5,29]. Blue-green infrastructure networks are additionally reported to deliver multifunctional value beyond flood attenuation in rapidly urbanizing Asian contexts, including cooling and recreational co-benefits documented in Chinese cities [40], while urban parks specifically are increasingly assessed through dedicated multicriteria and cooling-performance frameworks rather than treated as a residual open space category [23,36]. A further set of design-specific applications diversifies the typological landscape, including green and smart building façades with innovative cultivation systems, climate-resilient schoolyards, and the revegetation of abandoned or peri-urban land for thermal comfort [41–43]. At a broader systems level, NBS are also positioned as building blocks for circular-city water management and for climate-resilient food systems, extending the typological frame beyond individual site interventions to metabolic and agricultural systems [44–46], while dedicated reviews continue to map the effectiveness and evidence base of nature-based flood-risk infrastructure specifically [47–50]. Additional technical and typological contributions address urban heat island mitigation through blue-green and low-carbon infrastructure [51–55], the integration of NBS with renewable energy systems and green corridors within smart city frameworks [56–58], landscape-scale flagship concepts such as the "sponge city" as nature-based infrastructure beyond concrete [59], and school-based co-design of nature-based climate solutions [60].

3.3. Design and Governance Mechanisms

Across the reviewed literature, landscape architecture engages with climate adaptation through several recurring mechanisms: (i) spatial planning integration, embedding NBS networks into municipal and regional plans to achieve connectivity and multifunctionality rather than isolated interventions [12,31]; (ii) design stage performance criteria, incorporating stormwater, thermal, and biodiversity metrics directly into site and landscape design processes, often formalized through implementation models [6,61]; (iii) stakeholder co-design and participatory processes, particularly in projects seeking social legitimacy and long-term maintenance buy-in from residents, as illustrated in case studies integrating NBS with urban infrastructure [62]; (iv) pilot and demonstration projects, used both as proof-of-concept and as a vehicle for regulatory and financial learning ahead of wider rollout, exemplified by Copenhagen's climate-resilient design programme and Indonesia's new capital city development [14,17]; and (v) institutional and policy governance structures, including dedicated NBS policy frameworks and cross-departmental coordination mechanisms identified as prerequisites for mainstreaming rather than one-off implementation [63–65].

A more recent, digitally enabled strand of practice is also emerging, in which landscape architects and planners increasingly draw on digital twin models and simulation platforms to test NBS performance before construction and on AI-supported tools to optimize site selection, planting design, and carbon-sequestration outcomes [66–68]. While still a minority strand relative to conventional design and planning mechanisms, this reflects a broader trend toward evidence-based, simulation-supported decision-making in NBS design. Several recent design-driven frameworks formalize these mechanisms explicitly, including a multi-level spatial strategy for enhancing urban climate governance in Copenhagen [69], design-driven regeneration frameworks for climate-adaptive streetscapes [70,71], and adaptive management frameworks for improving coastal resiliency in highly urbanized settings [72]. Cross-cutting technical mechanisms, such as geotechnical considerations for climate-adaptive buildings and multi-hazard, life-cycle design frameworks bridging engineering, ecology, and policy, further extend the mechanism repertoire beyond spatial planning and participatory design alone [73,74]. The parallel governance-oriented literature emphasizes institutional and planning law mechanisms specifically, including systematic reviews of urban climate governance and planning [75], conceptual treatments of adapting to climate change through NBS [76], Strategic Environmental Assessment as a vehicle for embedding NBS into land-use plans [77], and broader challenges and opportunities frameworks for NBS-based urban adaptation [78–80]. Dedicated urban-shelter and equity-oriented mechanisms are also documented, including nature-based urban climate shelters [81], ecologically just design processes [82], and planning dimension frameworks tailored to Global South cities [83], alongside comparative and integrative design mechanisms for urban resilience and regeneration [84–91].

3.4. Barriers to Implementation

The reviewed literature identifies persistent, cross-cutting barriers to scaled implementation of NBS through landscape architecture practice: financial barriers, including higher upfront costs relative to conventional grey infrastructure, unclear long-term maintenance funding, and a persistent adaptation-finance gap that limits scaled deployment even where cost–benefit evaluations favour NBS over conventional infrastructure [3,92,93]; regulatory heterogeneity, where building codes, drainage standards, and land-use regulations were developed for conventional infrastructure and do not readily accommodate multifunctional green systems, as documented in policy-perspective assessments such as that of New York City [94]; technical and capacity barriers, including limited standardized performance data and a shortage of specialized design and maintenance expertise [2,95]; and social and governance barriers, including fragmented responsibility across municipal departments and uneven community engagement, which several studies link to inequitable distribution of NBS benefits across neighbourhoods of differing socioeconomic status [1,96,97]. A dedicated cross-comparative study of implementation barriers across multiple cities confirms that these four barrier categories, rather than any single dominant constraint, jointly determine whether pilot-stage NBS projects are ultimately scaled into standard practice [98]. Beyond these categories, an emerging strand of work highlights attitudinal and behavioural barriers, examining how residents' perceptions of blue-green infrastructure shape acceptance and long-term stewardship [99], while other studies explore advanced decision-support techniques, including quantum-computing and AI-assisted planning tools, as prospective means of overcoming persistent data and capacity constraints [100].

3.5. Geographic and Regional Perspectives

Beyond the general Global North/Global South imbalance noted in Section 3.1, the reviewed literature reveals distinct regional research clusters. Coastal and deltaic cities feature prominently in Global South scholarship, including Mumbai, India [101], the Nile Delta and North Coast cities of Egypt [102,103], and blue-infrastructure strategies documented more broadly across Global South cities [104]. The MENA region is represented through both country-level and regional syntheses [105,106], while African contexts appear through systematic reviews and country case studies in Ethiopia and Nigeria [107,108] and adaptation planning gap analyses in Windhoek, Namibia [109]. Latin American and Caribbean perspectives are represented through urban and peri-urban agriculture frameworks [110] and country-specific lessons from Mexico [111]. Within Europe, a growing body of Southeast European research, including multicriteria assessments of urban parks and land-use transformation studies in Novi Sad and Belgrade, Serbia [23–25,112,113], indicates that landscape architecture-led NBS research is expanding beyond the Western and Northern European cities that dominate the broader evidence base, though this regional strand remains considerably smaller than its Western European counterpart.

The regional evidence base extends further still. Northern European contexts are represented through flood-protection planning in Gothenburg, Sweden [114], resilient-waterfront strategies for Sweden's changing coastline [115], and comparative climate adaptation planning in Rotterdam, Netherlands, and Antwerp, Belgium [116]. Southern and Central European case studies include a resilience-thinking approach applied in Valencia [117], a multifunctional green infrastructure assessment in Izmir's Konak District [118], and a neighbourhood-scale nature-based adaptation planning approach for Turkish metropolises [119], alongside systematic reviews of Mediterranean flood and urban heat island strategies [120] and of urban heat islands and climate inequality across European cities more broadly [121]. South Asian scholarship is particularly dense, spanning green infrastructure indicator frameworks in Pakistan [122], green infrastructure planning guidance for Indian cities [123], deltaic adaptation strategies in India [124,125], flood mitigation in Kochi [126], and a critical analysis of NBS integration into urban design practice in Bangladesh [127,128]. Southeast Asian contributions include green open space research supporting sustainable urban planning in Indonesia [129] and nature-based solutions strengthening climate resilience in Central Vietnam [130]. A residual set of studies further broadens this regional and thematic picture without fitting neatly into a single country cluster: these include a systematic review of urban green space benefits, most likely spanning African urban contexts [131], an integrative treatment of sustainable cities blending nature-based principles with smart technologies [132], a proposed framework for urban ecological landscape design [133], and innovative environmental practices for climate adaptation in urban landscapes more generally [134]. Sector- and topic-specific contributions include climate-resilient strategies for the tourism built environment [135], grand-challenge framings of urban greening for climate-resilient cities [136], nature-based tourism and ageing-population vulnerability in protected urban and natural areas [137], sustainable streetscape implementation [138], transition pathways in nature-based solutions [139], the integration of urban planning with IPCC-like city climate assessments [140], and the incidental public exposure to invasive forest pests through mainstream media, a reminder that urban forestry-based NBS interact with ecological risks beyond climate adaptation alone [141]. This regionally dispersed but individually thin body of country-level evidence reinforces the pattern already noted in Section 3.1: NBS research is genuinely global in reach yet remains unevenly deep, with most non-European and non-North American contexts represented by only one or two studies each. Cross-tabulating the coded dimensions in Table 1 by region shows genuine, if modest, differences rather than a uniform pattern: single-country case studies address coastal/sea-level hazards proportionally more often (six of 32, 18.8%) than the corpus as a whole (nine of 146, 6.2%), consistent with the deltaic and coastal cities noted above (Egypt, India, Bangladesh, Vietnam), whereas globally framed studies are more heat-focused (5 of 105) and design-generic. Single-country studies also skew toward regional/national and city scales (nine and 15 of 32, respectively) rather than the building-scale or purely conceptual framings common among globally framed studies (18 and 14 of 105, respectively), suggesting that geographically specific work tends to engage more directly with governance-relevant scales of implementation. Among the 32 single-country studies, India (6) and Serbia (4) are the two most represented countries; the Serbian cluster therefore reflects a genuine, if small, concentration within the coded corpus rather than a disproportionate emphasis relative to other single-country contexts and is discussed accordingly rather than as a distinct regional focus of the review.

4. Discussion

4.1. Answers to the Research Questions

RQ1—Which NBS typologies are most represented? As quantified in Table 1, the majority of the corpus (93 studies, 63.7%) addresses NBS at a cross-cutting or governance level without foregrounding a single typology. Among studies organized around a specific typology, wetlands/blue-green corridors and multifunctional parks/streetscapes are the most frequently documented (15 studies each, 10.3%), followed by urban forestry (9 studies, 6.2%) and SuDS/LID/flood-focused drainage (8 studies, 5.5%); building-scale and emerging typologies (green roofs and walls, water harvesting, biochar, phytocapping) remain the smallest coded group (six studies, 4.1%) [5,28,29,31,32,36]. Emerging typologies such as water harvesting systems, biochar-amended soils, and phytocapping remain represented by only a handful of studies each, indicating an active but still-narrow frontier of the typological repertoire [37–39].

RQ2—Through which mechanisms does landscape architecture operationalize NBS? Five recurring mechanisms structure practice: integration of NBS networks into formal spatial planning; the embedding of performance criteria at the design stage, often via structured implementation models; participatory, stakeholder-driven co-design; pilot or demonstration projects that de-risk wider rollout by generating regulatory and financial learning; and, in an emerging strand of practice, institutional/policy governance structures increasingly supported by digital twin and AI-assisted design tools [6,12,14,17,62,64,66]. Collectively, these five mechanisms draw on 36 distinct studies across the coded corpus (Section 3.3), providing a traceable evidence base rather than narrative judgement alone, though most individual studies illustrate only one mechanism at a time and no study systematically compares all five.

RQ3—What barriers and enabling conditions shape implementation? Financial constraints (upfront cost, unclear maintenance funding, and a broader adaptation-finance gap), regulatory heterogeneity (codes built for grey infrastructure), technical and data limitations (absent standardized performance metrics), and social/governance fragmentation (dispersed municipal responsibility and uneven, inequitable distribution of benefits) consistently emerge as the primary barriers, and a dedicated cross-comparative study confirms that these categories operate jointly rather than singly in determining whether pilot projects scale into standard practice [1–3,92,94,96–98]. Participatory governance, standardized performance metrics, and dedicated financing mechanisms, increasingly supported by cost–benefit evidence favouring NBS over conventional infrastructure, are the most frequently cited enabling conditions [93]. These four barrier categories are jointly supported by 12 distinct studies in the coded corpus (Section 3.4); this is a modest evidentiary base relative to the corpus as a whole, and the barrier categories should accordingly be read as recurring themes in the available literature rather than as statistically dominant patterns.

4.2. Interpretation

Within the reviewed corpus, landscape architecture is frequently positioned as a central translational discipline between ecological and hydrological science, on one hand, and buildable, governable urban form, on the other; because the search strategy included "urban design" alongside "landscape architecture", and much of the retrieved literature also originates from planning, architecture, engineering, and environmental management venues, this positioning reflects a recurring framing within the literature rather than a disciplinary attribution independently verified by this review. Its distinctive contribution lies less in generating new ecological knowledge than in resolving the multifunctionality problem: reconciling stormwater performance, thermal comfort, biodiversity, esthetic quality, cost, and long-term maintainability within a single, site-specific design solution.

We note, as a limitation, that this conclusion is partly a consequence of how the review sample was constructed: because the search strategy explicitly included the terms "landscape architecture" and "urban design", the corpus was predisposed to retrieve and foreground literature that already frames these disciplines centrally, rather than independently establishing their relative importance against planning, architecture, engineering, or environmental management.

At the same time, the review surfaces a significant gap between conceptual and typological maturity, which is well established, and the maturity of implementation evidence, which is still comparatively thin. Much of the literature remains descriptive or case study-based, with limited longitudinal performance data on how NBS interventions perform once realized, maintained, and subjected to real climate stress over multi-year timescales [2]. This constrains the ability of practitioners and policymakers to make evidence-based design and investment decisions with confidence.

The pronounced geographic imbalance toward Global North contexts is a second key limitation of the current evidence base. Cities in the Global South, and particularly those facing compound climate and rapid urbanization pressures, are simultaneously the most exposed to climate risk and the least represented in the literature guiding design practice [16–18], a gap with direct implications for the transferability and equity of existing design guidance.

Finally, the review highlights that barriers to implementation are rarely purely technical; they are as often institutional and social, rooted in fragmented governance responsibility and regulatory frameworks poorly suited to multifunctional green systems [94,96]. This suggests that advancing the field requires landscape architecture to engage as much with planning law, financing mechanisms, and participatory governance as with ecological design itself.

5. Future Research Directions

The recommendations below are tied directly to gaps quantified in Table 1, rather than reflecting unstructured researcher interest: emerging and building-scale typologies such as water harvesting, biochar, and phytocapping are recommended for further study because they remain the smallest coded typology group (six studies, 4.1%); digital and AI-supported design tools are recommended because they were identified only within the small, emerging mechanism strand described in Section 3.3, rather than in a substantial share of the 146-study corpus. Future research should prioritize longitudinal, post-occupancy performance monitoring of realized NBS projects in order to build the quantitative evidence base that is currently missing from case study-dominated literature [2]. Equally important is expanded research coverage of Global South and rapidly urbanizing contexts, including arid and deltaic cities facing compound climate risk [16,18]. Further, standardized, cross-comparable performance metrics for multifunctional NBS interventions are needed, enabling design decisions to be benchmarked across typologies and climates, potentially informed by urban-metabolism frameworks [142]. Considerable potential also lies in the integration of digital and AI-supported tools, including GIS-based suitability modelling, digital twin simulation, and AI-assisted landscape design, to support evidence-based site selection and design optimization [66,68,143–146]. Research on financing and governance models that address maintenance funding gaps and institutional fragmentation, identified as primary implementation barriers, is likewise needed, drawing on emerging adaptation-finance and cost–benefit frameworks [3,92,93]. Equity-focused research should examine the distribution of NBS benefits across neighbourhoods of differing socioeconomic status to inform more just adaptation planning [1,97]. The typological repertoire itself also warrants extension beyond the six core categories to cover emerging applications such as nature-based water harvesting, biochar-amended soils, phytocapping, and NBS integration with peri-urban agriculture, which remain thinly documented from a design perspective [37–39,110]. Finally, comparative, cross-regional research is needed to connect the Southeast European evidence base, including Serbian case studies, with the more extensive Western European literature in order to test the transferability of design guidance across differing institutional and climatic contexts [23–25]. Behavioural and attitudinal research is similarly needed to understand how residents perceive and steward blue-green infrastructure over time, complementing the design- and policy-focused literature reviewed here [99].

6. Conclusions

This state-of-the-art review suggests that landscape architecture is commonly positioned, within the reviewed literature, as playing a central, translational role in operationalizing nature-based solutions for urban climate resilience, converting ecological and hydrological knowledge into implementable, multifunctional urban form; given the multidisciplinary composition of the corpus, this finding should be read as a pattern in how the literature frames the discipline's role rather than as an independently verified disciplinary attribution. Drawing on a rapidly expanding evidence base concentrated in the last five years, the review identified six core NBS typologies, from green roofs and sustainable urban drainage systems to sponge city networks and multifunctional streetscapes, together with an emerging frontier of hybrid applications, including water harvesting systems, biochar-amended soils, and phytocapping, that remain thinly documented from a design perspective [37–39].

We emphasize that this paper should be read primarily as a broad narrative and thematic synthesis of the recent literature, organized to help researchers and practitioners orient themselves within a fragmented field, rather than as a quantitative determination of which NBS typologies, mechanisms, or barriers are objectively the most important; the frequency counts reported in Table 1 describe the composition of the reviewed corpus itself, not the prevalence of these phenomena in practice or in the wider literature beyond the corpus.

The synthesis further shows that landscape architecture operationalizes these typologies through five recurring mechanisms: spatial planning integration, design stage performance criteria, participatory co-design, pilot and demonstration projects, and, increasingly, institutional governance structures supported by digital twin and AI-assisted design tools [6,12,62,66]. Implementation, however, remains constrained by four persistent and interacting barrier categories, financial, regulatory, technical, and social/governance, that jointly determine whether pilot-stage projects scale into standard practice, alongside emerging attitudinal and behavioural barriers only beginning to receive sustained research attention [98,99].

The evidence base, while expanding rapidly, remains constrained by limited longitudinal performance data, a pronounced geographic imbalance toward Global North contexts, and persistent financial, regulatory, and institutional barriers to scaled implementation. This imbalance is not merely a gap in coverage but a gap in design guidance itself: cities in the Global South and in under-represented European regions, including the Southeast European and Serbian contexts highlighted in Section 3.5, are simultaneously among the most climate-exposed and the least served by transferable, evidence-based design guidance [16,17,23]. Addressing these gaps through standardized performance monitoring, expanded geographic coverage, governance- and finance-oriented research, and closer attention to how communities perceive and steward NBS over time will be essential to realizing the full climate-adaptive potential of landscape architecture in cities worldwide. As NBS research continues to mature from a predominantly typological and conceptual literature toward one grounded in longitudinal performance evidence, landscape architecture, among other built environment disciplines engaged in this literature, appears well positioned to contribute to the translation of that evidence into resilient, equitable, and place-specific urban form.

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