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Emerging Perspectives on Diverse Nature-Oriented Sustainability Strategies

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Abstract: Increasing levels of nature-oriented sustainability strategies (NOSSs) are being recognized as offering solutions to combat climate change at scale, both through transformative infrastructure and autonomous technology innovations. This paper presents a synopsis of the mainstream literature covering the emerging trends from the last two decades across two broad trajectories of NOSS initiatives—"nature-inspired" (NI)- and "nature-based solution" (NBS)-oriented approaches. The specific scopes of these two approaches have been categorized into disciplinary fields, highlighting their peculiarities and commonalities, followed by an appreciation of their evolutionary trends based on the literature abundance over three distinct time-horizons—pre 2000, 2000–10, and 2011–2021. We find ambitious levels of sustainability-led developments are driving NOSS initiatives beyond 2010; in particular, the increased level of NI approaches in the field of chemical processing, material structure, and renewable energy. Likewise, there has been rapid growth in NBS approaches in the last decade from a systems perspective, reducing the level of grey infrastructure by offering sustainable alternatives to the ecologically destructive technologies. However, we identify some crucial red herrings to the main-streaming of NOSSs as a 'true sustainability solution', such as the inherent challenges in their scaling-up, operation and management, and in ensuring ecologically and culturally adaptive interventions across different global contexts.

Keywords: climate; nature-based; nature-inspired; strategy; sustainability

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1. Introduction

To ensure sustainability in the Anthropocene i.e., the current epoch where human activity has been the dominant influence on climate and the environment, there is growing emphasis on exploring the interconnectedness of humans, nature and technology as part of Nature-Oriented Sustainability Strategies (henceforth termed as NOSSs) [1]. Over the last two decades, this drive for sustainability has been pushing the boundary of technological innovation in either mimicking or integrating biological components of nature at scale, ranging from products to infrastructure solutions (referred to as biomimicry or biomimetics in the design literature) [2,3]. Traditional NOSSs predominantly have an ecological bearing, facilitating the interaction of the natural and the built-components from a more balanced socio-ecological perspective. They have been considered effective towards 'regenerative living cities' for simultaneously combating climate change and biodiversity loss [4]. More advanced NOSSs incorporating biomimicry, i.e., inspired by natural processes, are being increasingly considered as a useful starting point towards infrastructure resilience in an urbanizing world. These are deemed vital in all aspects of urban development for creating more holistic approaches to sustainable cities. However, while the role of biomimicry as a sustainable design methodology, aspiring to facilitate a more sustainable human–nature relation, is quite appealing at face value [5], it cannot be considered an automatic by-product of biomimetics [6]. A growing body of literature indicates that biomimetic designs are not always acclaimed to be more sustainable outcomes [7–9]. Their contribution to a more sustainable future can only be ensured if a particular ethos and respectful engagement with nature complement the technological ambitions of the practice [9].

The two overlapping aspects of NOSSs, which are invariably used in the literature are—'nature-inspired' (NI) and 'nature-based solution' (NBS)-oriented approaches. While nature-inspired (NI) developments are rather multidisciplinary concepts, which are rapidly being incorporated for disrupting technocratic solutions [10,11], NBS has a de facto natural component (biophilic/ecological) as an integral part of the solution development [2,8,12]. Both these approaches play a vital role in influencing our sustainability pathways—while NI systems have led to the development of the sustainable technology-oriented Technological Innovation System framework, NBS provide sustainability pathways for multifunctional nature-integrated spatial planning and design innovations, termed the Nature-Based Innovation System framework. An earlier study identified the commonalities and differences between the two frameworks, suggesting that market formation is more central to driving NI technological innovation, whereas the roles of place-based dynamics, agency and governance structure are more central to NBS innovation [13].

The first part of this paper takes stock of the emergence of the NOSSs concept, including different sub-categories of nature-inspired (NI) and nature-based solution (NBS)-oriented approaches. This is followed by a discussion on the evolutionary trends of some prominent disciplinary sub-categories of each of the two aspects, elaborating with examples, where possible. A discussion on their potential applications as 'true sustainability solutions' from a systems perspective is provided later, including implementation challenges with respect to their mainstreaming.

2. Research Methodology

The motivation of this study was to (1) capture the breadth of nature-oriented sustainability strategies presented in the academic literature across the two broad themes identified in this study—the nature-inspired (NI) and nature-based solution (NBS); (2) identify the usage of these approaches in different disciplinary categories for the two themes; (3) show the historical perspective and the emerging research trends in this field; (4) identify the potential limitations and operational challenges in their implementation; (5) project future research directions to address the research gap.

The study adopted a two-tiered approach to grasp the level of granularity in the published literature in this spec. As the first step, a systematic review of peer-reviewed literature was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISRMA) method within the Scopus database. This included three stages: a meta-analysis of all articles containing blanket search phrases within title, abstract and keywords. To capture the full range of literature on NI approaches in its broadest sense, the term NI was harmonized to include 'nature inspired' and 'bioinspired' solutions. Likewise, to capture the full range of literature on NBS approaches in its broadest sense, the term NB was harmonized to include 'nature based', 'green infrastructure' and 'ecosystem services'. This was followed by a detailed screening of abstract and article content, to select only those which contained a description of their application to real-world problems. Those studies which only mentioned the terms NI or NBS sporadically in the context of a wider discussion on a peripheral issue, without further description of their application/implementation, were eliminated in this step. The final step included a thorough review of the latter set of papers ,to summarize their focus and key contributions. In this manner, the volume of literature from stage 1 (capturing all articles with a mere mention of the relevant phrases in either title, abstract, keywords) to stage 2 (detailed description of their real-world applications) reduced respectively, from 16,200 to 776, an attrition of over 95%.

In the next step, a wider search was conducted in Google Scholar to scan for additional sources of project/government reports, books/book chapters and conference proceedings. Predefined inclusion criteria were applied to identify documents with either cross-over between the NI/NBS approaches or mis-representation of the terms (e.g., use of NI meant to describe NBS, or vice versa).

Both themes were classified into disciplinary categories on the basis of the semantics of the approaches and abundance of the search phrase for each category in the reviewed literature. In order to establish the evolutionary trends for each category, the following three broad time horizons were applied: pre 2000, 2000–10, and 2011–2021. Section 3 provides a synopsis of the historical perspectives on NOSSs. The outcomes of the review focusing on the emerging perspectives of NOSSs using criteria such as application areas, evolution of the disciplinary categories and their timeline based on year of publication, are described in detail in Section 4.

3. Historical Perspective on Nature-Oriented Sustainability Strategies

Nature-inspired ideas clearly predate modern times, but it is worth considering the first period when arguably the NOSS concept became particularly poignant during the ecological movement in the mid to late 20th Century, which saw technology as a way to make physical labour easier, within a context of working within (and taking inspiration from) nature [14]. A foil to nature-based and inspired thinking was neatly presented by Aldous Huxley, who took a (fictional) dystopian view, painting a picture of a world where efficiency, artificiality and rigid social order dominate [15]. Similarly, Steinbeck (in fiction, but based on events of the 1930s Great Depression) [16] and Orwell (in observation) [17], described the impacts of unsustainable farming practices and industrial pollution on people, with commentary, showing strong connections between financial, natural and human capital. John Seymour, famous for guiding many on self-sufficiency, was also a champion of sustainable development, including using natural materials and methods for growing food, construction, and working with natural materials rather than against them—an example being splitting wood to use the full grain strength rather than sawing [18]—through to wider sustainability [19]. It can be argued that, as key authors on sustainability, all have been heavily nature-inspired.

Moving on to post-industrialization, mention is appropriate of Richard Mabey, who explored the idea of nature taking over in spaces abandoned by humans [20]. Such thinking is also clear in areas where post-industrial landscapes have returned to nature, with examples including The High Line in New York, a linear park built on the site of an elevated railway, or the National Forest in the UK, much of which is grown on areas previously used for coal mining [21]. Perhaps a more famous example would be the Eden project in Cornwall, UK, a visitor attraction built in a reclaimed quarry, which is a complex biome, housing thousands of plant species [22]. It can be seen that localism and crafts, and many people growing food at home during the COVID-19 pandemic are part of this narrative, with nature-based and inspired ideas central to calls for resilience [23,24], but with wider impacts on de-growth, reduced carbon footprints, etc. In all cases, NI and NBS approaches have produced both bespoke and overlapping NOSS concepts.

4. Emerging Perspectives on Nature-Oriented Sustainability Strategies

The emergence of both 'nature-inspired' (NI) and 'nature-based solution' (NBS)-oriented approaches are discussed in this section, in terms of the peculiarities and commonalities of their contributions to the different disciplinary categories identified.

4.1. Nature-Inspired

Nature-inspired solutions, as scoped in this study, are identified as technical products (or systems) which incorporate life-like features but do not necessarily have any natural components themselves [12]. More recently, the growth in computational power and 3-D printing has pushed the boundary between living and technical systems, which has facilitated both systematic and disruptive innovation within disciplines and at inter-disciplinary boundaries. For example, drawing inspiration from living systems can improve sustainability by making efficient and economic use of materials and energy; products are meant to be fully recyclable, beyond their usable life, allowing sustainable material use and at the same time making the solution more resilient and robust [25].

Effective implementation of NI approaches requires multidisciplinary cooperation to capitalize on various attributes towards developing more sustainable and smart structural systems, such as geometry, structure, mechanism, energy, intelligence, etc. There has been rapid growth in bio-inspired architectural design, mainly towards improving sustainability potential. However, the use of the biomimetic idea in architectural design has been largely aimed at achieving visual expression, and the level of detailed adaption into structural functions is still a moot point. Recent efforts have shifted to a more engineering focus; for example, bridge engineers have adopted structural principles of trees, which provide multiple load paths to maintain a uniform load distribution in the column and tower of a bridge [26]. There is greater emphasis on adopting nature-inspired parameters and schemes for improving kinetic design in man-made artifacts with respect to their functionality and shape [27]. The emerging trends in the following NI disciplinary categories can be noted in the literature.

4.1.1. Computing/Optimization Algorithms

Soft computing, implementing a systematic approach to analyzing nature-inspired algorithms simulating different natural processes has been widely utilized to address complex meta-heuristic and evolutionary multi-objective optimization problems [28–32]. A review of more than three hundred publications dealing with nature-inspired and bio-inspired algorithms proposed two comprehensive, principle-based taxonomies to organize existing and future algorithmic developments into well-defined categories, considering the following two criteria: the source of inspiration and the behavior of each algorithm [33]. Specific nature-inspired computing algorithms include the following: genetic algorithms, swarm intelligence, ant colony optimization, particle swarm optimization, bee-inspired algorithms, bat algorithms, firefly algorithms, cuckoo searching, virus colony searching, etc. [26,34,35]. Advanced optimization algorithms are discipline-focused, to solve various complex engineering design or problems of software testing. For example, flower pollination algorithms, grey wolf optimizers, and grasshopper optimization algorithm have been applied to investigate the performance of a radial flow turbine in terms of the best angle at the blade inlet [36] and design optimization of floating offshore wind turbines [37].

The application of binary multi-objective bird swarm optimization and a hybrid of bird-swarm and cuckoo-search algorithms have been considered, to provide the optimal solution for real-time scheduling of home appliances in an energy management system [38]. The crow-search algorithm, simulating the intelligent flocking behavior of crows, has been applied to the economic-load-dispatch optimization problem in power network systems [39]. The biological interaction between predator and prey has been implemented in the form of the marine predator's algorithm in real-world engineering design problems in the areas of ventilation and building-energy performance [40]. The cuckoo search was found to be a promising cost-effective alternative to conventional color multilevel thresholding for the segmentation of colored satellite images [41], whereas a biogeography-based optimization algorithm is applied for optimal text classification [42]. Humanoid-robot control of multi-objective sunflower-optimization techniques and firefly-based artificial potential-field algorithms are applied for navigational tasks and route mapping [43,44]. The use of nature-inspired optimization has seen rapid growth in the capacity of cloud computing in the last decade [45]. More recent focus on artificial intelligence (AI) has led to its application in smart transportation systems [46].

4.1.2. Chemical Processing

Nature-inspired reactor and catalysis engineering have captured the attributes of biological systems in chemical engineering processes (rather than mimicry), offering scalability, efficiency and robustness in structured environments, with superior catalytic performance [47]. They also offer a greener alternative to the high-energy and -resource demand, as well as the use of potentially hazardous or environmentally harmful reagents in conventional chemical processing. An extensive review of the concept of nature-inspired chemical engineering, with the acronym NICE, has proposed a systematic design methodology to solve engineering problems, based on the fundamental understanding of mechanisms that underpin the desired properties, rather than the narrow sense in which biomimetics is often applied, focusing on mimicry of the isolated features of biological organisms [48]. Nevertheless, it is acknowledged that the majority of "inspiration" from nature to date in the chemical processing spec is empirical, and there is vast opportunity for developing more fundamental approaches based on mechanistic features [49]. A nature-inspired water splitting system, comprising a multifunctional robust photocatalyst graphitic carbon nitride (g-C3N4) has been developed, with potential for application in other systems such as photoelectrochemical cells or coupled solar-cell systems [50]. Molecular docking, i.e., binding between a receptor and a ligand in chemical processing, has been optimized using three nature-inspired docking programs based on the genetic algorithm inspired by the process of natural selection; the particle swarm optimization method, based on the behavior of animal flocks; and the ant colonies algorithm [51]. Sustainable use of nature-inspired biosynthesis has been increasingly explored for the fabrication of cost-effective and environmentally friendlier chemicals, such as sulphur-bearing Fe-rich nanoparticles (SINPs) [52]; protein structures existing in nature have inspired optimization of peptide–peptide and peptide–graphene interactions for applications in bionanotechnology [53]. The Monkey—Krill Herd Hybrid (MAKHA), Intelligent Firefly Algorithm (IFA), Covariance Matrix Adaptation Evolution Strategy (CMAES), Artificial Bee Colony (ABC), Cuckoo Search (CS), Bare Bones Particle Swarm Optimization (BBPSO) and Flower Pollination Algorithms (FPA) have been applied for the prediction of critical points in multicomponent mixtures [54].

4.1.3. Material Structure

A review on smart designs for improved sustainability of nature-inspired structural materials considered their specific role in functionalities of flexible electronic devices in complex environments, including mechanical sensing, energy harvesting, physically interacting, etc., alongside their biomimetic functions [55]. A bottom-up growth strategy based on slime mold behavior in nature has been applied in the design of full-scale industrial components [56]. A nature-inspired optimization method based on sunflowers' motion is applied in complex structures, to infer structural damage detection in composite laminated plates [54]. Environmentally benign materials using nature-inspired external-to-internal design systems have been found to offer reliable, responsive and remarkable anticorrosion performance, with longer service lifetime owing to their better liquid-repellent passive surface (super hydrophobicity), ion transport control and interfacial adhesion [55]. The concept of fractal geometry is being applied to design nature-inspired structural forms in architecture and construction; for example, tree-inspired branching supports and a natural-terrain-inspired unsmooth crinkled roof have been applied to the Iterated Function System and Midpoint Displacement (Diamond-Square) algorithms, to improve strength and other surface properties [57]. Nature-inspired optimization algorithms have been applied to 3D reconstruction of porous media, using information from a single 2D thin image of the original material, which allows the phase of each porous-material point to be decided such that the resulting 3D material model shows the same statistical properties as its corresponding 2D version [27].

4.1.4. Renewable Energy

In addition to the computational application of nature-inspired meta-heuristic optimization algorithms to the specific renewable energy problems mentioned in previous sections, this section captures some direct applications of nature-inspired concepts to renewable energy innovation. For over a decade, the application of nature-inspired semiconductors has been considered in organic electronics, including some direct application of natural materials and synthetic derivatives of natural molecules for organic field-effect transistors and organic photovoltaics [58]. However, the potential for nature-inspired renewable energy has found recent prominence in solar energy harvesting, mainly within light-harvesting techniques and the utilization of bio-inspired electron-transfer pathways, used to enhance power conversion efficiency [59]; we note a recent finding that charge separation in organic solar cells is governed by quantum coherence, and may foster a new area of exploration in bio-inspired solar cells around quantum coherence [60]. Nature-inspired alternatives to commercial electrocatalysts (mostly based on expensive platinum-group metals), have been recognized as offering cost-efficient hierarchical structures appropriate for intrinsically scaling, as well as providing biological catalysts that catalyze the same reactions as in electrochemical devices [48].

4.1.5. Public Health

Nature-inspired chemical sensors have been enabling fast, relatively inexpensive, and minimally (or non-) invasive diagnostics and follow-up of health conditions through the monitoring of biomarkers and volatile biomarkers, which are excreted from one body fluid or a combination of body fluids (breath, sweat, saliva, urine, seminal fluid, nipple aspirate fluid, tears, stool, blood, interstitial fluid, and cerebrospinal fluid) [61]. Nature-inspired virtual reality simulation has been applied to reduce stress and pain levels among patients in cancer treatment, during chemotherapy infusion intravenous (IV)/port access sessions [62].

4.1.6. Fashion Technology

The fashion industry offers great opportunities for innovative and sustainable design inspired by nature. Fashion technology has two aspects to address—one, to make the product more sustainable, and two, to make the product more appealing to the (fast) fashion industry. Both can be achieved through adopting attributes of nature-inspired design, e.g., camouflage, symbiosis, and defensive mechanisms. For instance, a frilled lizard scares away enemies when being threatened, by opening its cloak. Likewise, the shape of the opened cloak could be applied to the outline of the clothing for defense against weather, etc., eco-friendly biofabric yarns have been already used to design compostable underwear using Bio Couture (fiber that can be de-composed by living beings), and self-glow garments utilizing colorful proteins often used as markers to make cells glow [62]. The prospects of sustainable textile-making using biopolymers is attracting interest in mimicking nature in the design of smart interactive apparel, through a combination of interdisciplinary engineering principles and polymer sciences [63].

Figure 1 shows the varying patterns of the constituent sub-categories, showing the relative abundance of their literature volume reflected as percentage shares over the three time-horizons chosen. It is noted that pre 2000, the NI literature was dominated by the Computing and Optimization algorithm and material structure. Post 2000, the NI literature appears to have become more diversified, with the emergence of several new sub-categories. Specifically, the literature covering biomimetic concepts has gained prominence, and new NI applications in chemical processing and the renewable-energy sector have been reported. Interestingly, literature reporting innovative NI applications to fashion technology and public health in 2000–10 and 2011–21, respectively, indicates the appetite of new disciplines for adopting NOSSs.

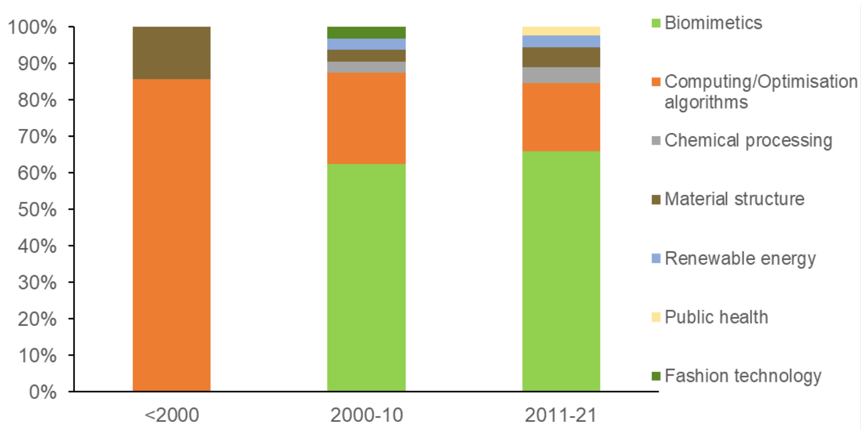

Figure 1. Patterns showing increasing number of sub-categories of nature-inspired solutions and their varying percentage share, over different time horizons.

Figure 2 shows the evolutionary pattern of the sub-categories over the three time horizons. The patterns emerging from the plot clearly show the maturity of the NI application in the fields of chemical processing, material structure, and renewable energy, with the growing spread of literature contributions from 2010 onwards. Notably, in the figure, the trend of biomimetic design adoption in modern-day applications is negligible pre 2000, and more prominent only from 2010 onwards, with rapid growth ever since. This corroborates with the recently reported trend of exponential increase in the literature studying the relationship of "biomimetics and sustainability", with a total of only 56 articles published in 2000 and 13,400 articles published by 2021, showing over 800% increase between 2010 and 2021 only [64]. Furthermore, the plot shows sporadic literature on innovative NI applications to specialist disciplines, such as fashion technology and public health disciplines, with a 100% literature share in 2000–10 and 2011–21, respectively. Interestingly, the research in the nature-inspired public-health and renewable-energy application area has dramatically grown recently, post 2019.

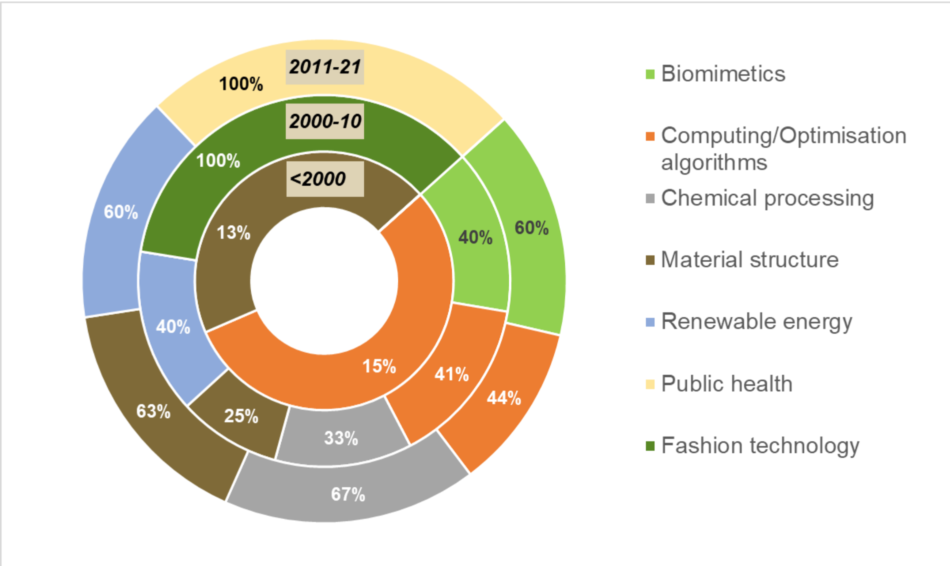

Figure 2. Timeline of evolution of different sub-categories of nature-inspired solutions.

New renewable-energy-generation approaches utilizing NI computational algorithms have been formulated and used in recent years, and some of the techniques which are used in PV–wind-hybrid-system studies are discussed in a recent review [65]. For example, ant colony algorithms aim to search for an optimal path in a graph, based on the behavior of ants seeking a path between their colony and a source of food [66]; the ant colony algorithm has been applied to improving the technical and economic performance of a small hybrid renewable-energy system in the north-western region of Iran [67]; and a graph-based ant system was proposed to minimize the total capital cost of a standalone hybrid wind/PV renewable-energy system [68].

Likewise, a bacterial foraging algorithm, inspired by the group-foraging behavior of bacteria such as *Escherichia coli* and *Myxococcus xanthus* (which relies on chemical gradients in the environment, and moves toward or away from specific signals), has been applied to the optimal design of an integrated wind–PV–diesel–battery system for the supply of the power demand in remote and rural areas of Ardebil, Iran [69]. An artificial bee colony, inspired by intelligent foraging behavior of a honey-bee swarm (where the position of a food source represents a possible solution to the optimization problem, and the amount of a nectar food source corresponds to the quality of the associated solution) [70], has been applied to a multi-objective artificial bee colony algorithm, to solve the distribution-system reconfiguration and hybrid (photovoltaic–wind turbine–fuel cell) energy-system sizing [71]; this has been applied to an artificial bee swarm optimization algorithm, to optimally size a hybrid energy system, based on PV–wind–fuel cell. [72].

We note attempts at developing a sustainable NI self-repairing damage-control solution, such as a plant-inspired self-healing polymer, inspired by *Delosperma cooperi* leaves; a self-sealing wax system inspired by Banksia follicles; self-healing coatings inspired by lotus leaves; self-sealing foam coating for pneumatic systems inspired by *Aristolochia*; and self-healing elastomers for dampers, inspired by latex-bearing plants. Likewise, animal-inspired self-healing polymers and composites inspired by nacre, in marine mussels (*Myrtilus* sp.); self-healing concrete, mimicking the bone healing process; self-healing composites inspired by hemostasis, etc. These are extensively reviewed in some recent publications [10,11]. Efforts in biomimetic developments are also underway in drawing inspiration from biological concepts toward developing life-like motile systems, embedding automation, such as the following: a façade shading system inspired by the bird-of-paradise flower; a façade shading system inspired by the motion of the underwater snap trap of the waterwheel plant; a cellular actuator—kinetic amplification triggered by plant-inspired motor cells; the Venus flytrap as concept generator for plant-inspired soft robots; and weather-responsive building skins with autonomous actuation, inspired by the hygroscopic movement of pine-cone scales [25,73].

4.2. Nature-Based

Increasing levels of nature-based solutions (NBSs) are being applied as a performance-based planning approach in the urban hinterlands and across cities to conserve and restore nature, as well as to develop a harmony with other built structures, working with nature. Their potential for addressing social, economic and ecological sustainability challenges, simultaneously, is recognized in research and policy communities globally, owing to the resilience of natural processes in upscaling, which will help in reducing climate-change-adaptation costs [13,74,75].

The NBSs scoped in this study are literally the progression of the prevalent concepts of green infrastructure and ecosystem services principles, albeit with a more integrative design focus on offering a ‘solution’. We adopt the literature definition as “any transition to a use of ecosystem services with decreased input of non-renewable natural capital and increased investment in renewable natural processes” [76], with its focus primarily on biophilic built space [2,8,12]. The Advisory Group Report for EU-H2020′s Societal Challenge 5 has considered NBSs, in the context of using biomimicry, to position the EU as a world leader in the development of industrial and technological solutions “inspired by, using, copying from or assisted by nature. This idea is included in the EC Expert Group on Nature-based solutions’ definition “... involve the innovative application of knowledge about nature, inspired and supported by nature” [77]. At a global policy level, 131 nations—66%

of all signatories to the Paris Agreement—include NB approaches for climate-change mitigation and adaptation in their Nationally Determined Contributions [78].

As established in Section 2, the review has considered NBS approaches in its broadest sense. This was considered appropriate for comparing the 'recent trends' in the adoption of nature-based strategies for the creation of more holistic sustainable cities, acknowledging the interconnectedness of humans, nature and technology [2]. Based on the keyword search, the following NBS disciplinary categories were identified for our analysis (in alphabetic order)—biodiversity, built environment, catchment management, chemical processing, climate change mitigation, ecotourism, pollution control, public health/therapy, urban planning. Interestingly, commonalities were found in the public-health and chemical-processing sub-categories for the NI and NBS approaches, albeit the public health contributions from NBS captured the evidence generated from the direct role of nature-based therapeutic applications. NBS contributions to chemical processing captured the evidence from the role of nature-based feed in their process chain. The following emerging trends have been noted in the literature.

4.2.1. Biodiversity

The potential and significance of NBS for biodiversity conservation and ecological restoration has been widely recognized [79]. Given the association between biodiversity loss and climate change, NB climate solutions are increasingly being embedded in biodiversity science [80,81], and are considered as a vital and transformative contributor of biodiversity in cities, mainly ecosystem-based—focusing on the protection, restoration or enhancement of the integrity, functionality, and connectivity of habitats and ecosystems. A review of 199 projects across Europe identified that a growing number of cities are taking a project-based approach (quantified, measurable actions) in implementing NBS approaches for biodiversity conservation and restoration, through a set of explicit, quantitative and measurable targets, which are tailored to the specific conditions of urban settings [82].

4.2.2. Catchment Management

Numerous NBS regenerative sustainability approaches using blue–green infrastructure have been applied in catchment management as a cost-effective alternative to conventional hard infrastructures. These mainly include a multi-functional biophilic design for river restoration, allowing resilience for tackling flash floods, and recreational opportunities as co-benefits [83–87]. One popular application of such an approach is the development of "Sponge City" in Shenzhen, China, to mitigate flood risk, tackle chronic water scarcity, and improve the urban environment, by combining water storage and infiltration facilities distributed on a large scale across the city [88,89]. A reservoir optimization approach based on the Cuckoo Search algorithm was applied to balance the trade-off between human water demand and riverine-ecosystem protection, which involved a modified percent-of-flow approach to identify the ecologically feasible region of water-resource utilization [90]. Using a hydro morphological functional-landscape approach, based on biophysical spatial criteria, NBS extent and location has been determined for implementation in river landscaping, primarily for floodplain management [91]. NBSs also offer an economically and ecologically viable solution for reducing the vulnerability of coastal communities through the dampening effect of natural defenses, such as sand dunes, saltmarsh, mangroves, seagrass and kelp beds, and coral and shellfish reefs, thereby reducing the need for (or complementing) hard-engineering defense (e.g., seawalls, breakwaters, etc.) [92].

4.2.3. Built Environment/Urban Planning

NBS interventions have been identified as serving as proactive adaptation options, and have proven to offer timely and viable solutions to urban-planning challenges, such as climate change, urban degeneration and aging infrastructures [93]. They offer 'living' and adaptable tools to boost the capacity of city landscapes to face today's critical environmental, economic and societal challenges [94]. NBSs have been found to offer a cost-effective alternative to traditional physical- and chemical-remediation technologies requiring high energy and resource input for urban contaminated-land remediation and brownfield redevelopment [95]. Contrary to traditional urban-planning approaches that aim 'to protect and preserve', NBSs consider enhancing, restoring, co-creating, and co-designing urban green networks, offering multifunctionality and connectivity [96]. In the last decade, the European Commission has made active recommendations to bring nature back into cities, by promoting systemic NBS interventions [97]. However, a synopsis of some fifteen NBS cases across eleven European cities identified the need for a multi-disciplinary approach for the success of their design in diverse settings; delivery through collaborative governance to ensure inclusivity, livability and resilience; and recognition of the place-based transformative potential which enables them to be superior to grey infrastructure [98].

Several NBS frameworks have been developed, either to identify the critical factors for designing urban nature-based innovation [13] or for their impact monitoring and evaluation, ensuring effective implementation and long-term regeneration [99]. Another approach for targeted NBS development, relying on the nexus among local urban challenges, NBS attributes, and their ecosystem services, has led to the development of a classification system for mainstreaming urban NBSs [100]. The EU-funded EKLIPSE project developed a holistic framework for assessing the co-benefits (and costs) of NBSs in urban areas, covering aspects of socio-cultural and socio-economic systems, biodiversity, ecosystems and climate [101]. A modified framework approach, conforming to the European Community standards, has been proposed for assessing the role and co-benefits of NBSs, using the structure of the DPSIR (Driver-Pressure-State-Impact-Response) model [102], which prioritizes social bearing for upholding decisions in response to environmental issues [103]. A systematic stakeholder-mapping method has been proposed to support strategic NBS co-creation, including the co-design and co-implementation [104]. Further, innovative urban-sustainability transformative efforts aim to combine multi-functional NBSs with a circular-economy principle for managing nutrients and resources within the urban biosphere, facilitating local resources and healthy environments—termed in the literature circular city [105], edible city [106], etc. However, this has its own challenges, as research has found there is a lack of a deep understanding of the underlying processes for different NBS pathways, prohibiting the identification of optimal circularity solutions for maximizing the synergies across pathways [107]. At the same time, there is recognition of the growing social disparity in the appreciation of NBSs, as well as their role as drivers in actually reinforcing inequalities or leading to new forms of social exclusion, across cityscapes [108].

4.2.4. Public Health/Therapy

Nature-based therapeutic interventions as standalone treatment programs have featured in traditional medicine in different parts of the world over centuries, but have been part of a more structured approach in the last decade [109,110]. Strong evidence for the role of NBSs in developing resilient and healthy/livable urban landscapes in a changing climate has been demonstrated, based on recent literature, showing the association between public health and natural environments, in relation to the following pathways: socio behavioral/cultural ecosystem services (e.g., stress and physical activity) and services regulating the ecosystem (e.g., heat reduction) or defining health outcomes (e.g., cardiovascular mortality) [111]. On the other hand, social prescribing as a tool for referring at-risk populations to nature-based community services, resources and activities, has been adopted to connect vulnerable populations with the broader community, to improve their mental wellbeing. There is growing recognition of integrating such prescribing into standard health-care practice, alongside the use of technologically and socially innovative strategies to track patient participation in such prescribed social practices [112]. A positive relationship between the health of children and the elderly, and urban green and blue spaces, has been reported [113], as well as positive psychophysiological and cognitive benefits associated with biophilia [114]. A qualitative assessment found that NBSs helped customers and employees improve mental health perception, emotional well-being, and loyalty in the hotel industry [115]. Nature-based stress-management intervention has been reported to reduce burnout fatigue and long-term sick leave, and improve workability among the working-age female population in Sweden [116].

4.2.5. Ecotourism

There has been increasing interest in how a nature-based tourism industry can be supported through nature protection, the sustainable management of natural resources, public infrastructure, and access policies. An analysis of nature-based tourism companies in Sweden, using a two-dimensional model of the nature-based tourism servicescape, through (a) the naturalness dimension, i.e., the level of natural environments and facilities, and (b) the access dimension, i.e., open vs. exclusive rights to natural resources, has reported the access dimension as a much more important factor in promoting NBS-based tourism [116]. Another study has identified a strong association between nature-based recreation and spirituality (including spiritual experiences and spiritual well-being) [117]. However, intensive nature-based tourism in vulnerable regions has led to rising tension between commercial development and ecological protection, leading to a call for stringent spatial-regulation strategies. To address such a dilemma, a Chinese study has developed an indicator of conflict tendency between nature-based tourism development and ecological protection (ICTP), based on the combination of landscape attractiveness and ecological sensitivity [118]. Based on qualitative analysis of relatively new and emerging NBS-based tourism products in Norway, a framework has been developed for identifying and managing natural resources which are important to the NBS-based tourism sector [119].

4.2.6. Hydro-Meteorological Hazard Protection and Pollution Control

A classification scheme for designing NBSs for mitigating the adverse impacts of key hydro-meteorological hazards, such as floods, storm surges, landslides, droughts, and heatwaves, has identified that their effectiveness depends on the location, architecture, typology, green species and environmental conditions [120]. The majority of NBS interventions (blue, green and hybrid infrastructures) are applied to such hazard protection work on a scale ranging from soil solutions to landscape solutions. The former enhances the soil resilience and soil functions, through which local ecosystem services are maintained or restored. The latter reduces flood risk, drought and erosion problems by avoiding the transfer of rainfall into runoff [121]. However, most of the evidence base to date is from a limited number of field studies, and there is a need for real-world demonstrators in order to promote their upscaling and replication in order to consider them as mainstream solutions [122]. This has led to foresight on how cities can effectively mainstream nature-based solutions to mitigate and adapt to the negative effects of climate change, and, conversely, on what future role urban science can play in coproducing nature-based solutions [123].

Adopting a system perspective and a multi-sectoral approach, a study has analyzed the potential of NBSs to achieve several UN Sustainable Development Goals (SDGs) by promoting the delivery of bundles of ecosystem services, alongside reducing the negative effects of water-related hazards [124]. Applying a multi-criteria analysis as a basis for integrated valuation, a multi-purpose green infrastructure (a series of constructed wetlands) was shown to perform equal to, or even better than, the grey infrastructure alternative for water purification and flood protection, along with additional co-benefits (e.g., wildlife support, recreation, health and well-being, etc.), [125]. A number of NBS applications for grey water treatments, ranging from traditional constructed wetlands to more advanced building-integrated designs (e.g., green roofs and green walls) have shown their environmental, economic, and energetic benefits in terms of hydraulic design parameters, to guarantee high removal performance [126].

Figure 3 presents the varying patterns of constituent NBS disciplinary categories over the three time-horizons, with the relative abundance of the volume of literature on this reflected as percentage shares. We note that NBSs represent a relatively young science; the pre 2000 literature is found to be limited mainly to three conventional topics—pollution control, climate-change mitigation and eco-tourism. However, beyond 2000, the NBS literature has grown rapidly; the number of sub-categories has diversified into nine, with the majority of applications associated with urban planning (as shown by the different slices in the second and third columns of figure 3). NBS applications to biodiversity, catchment management and climate-change mitigation have overlapping incentives, which have largely been driven by the ecosystem services agenda of the Millennium Ecosystem Assessment framework [127].

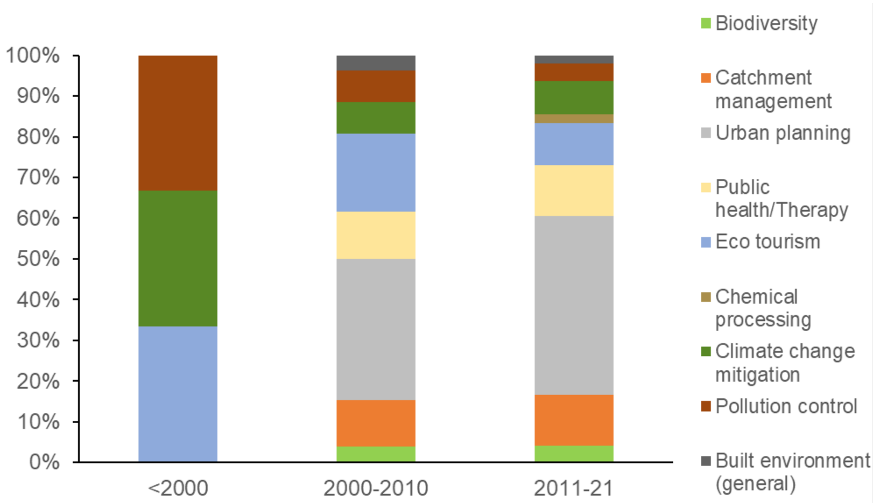

Figure 3. Pattern showing increasing number of sub-categories of nature-based solutions and their varying percentage share over different time-horizons.

Figure 4 shows the evolutionary timeline of some prominent sub-categories of NBSs from our literature review. Based on the abundance of the sub-categories over the three time-horizons (shown as percentages), the majority of work-themed NBSs have been reported in the last 10 years. The key sub-categories associating NBS with sustainability seem to have acquired maturity from 2010 onwards, and are shown in the growing percentage share for these categories from 2000 to 0 and from 2011 to 21. These mainly include the following: biodiversity, catchment management, urban planning, climate change mitigation, and public health/therapy. Other NBS categories have maintained a consistent literature presence, such as pollution control, ecotourism and built-environment applications. The application of NBS to sustainable chemical processing is found to be an emerging area, reported only in 2011–21.

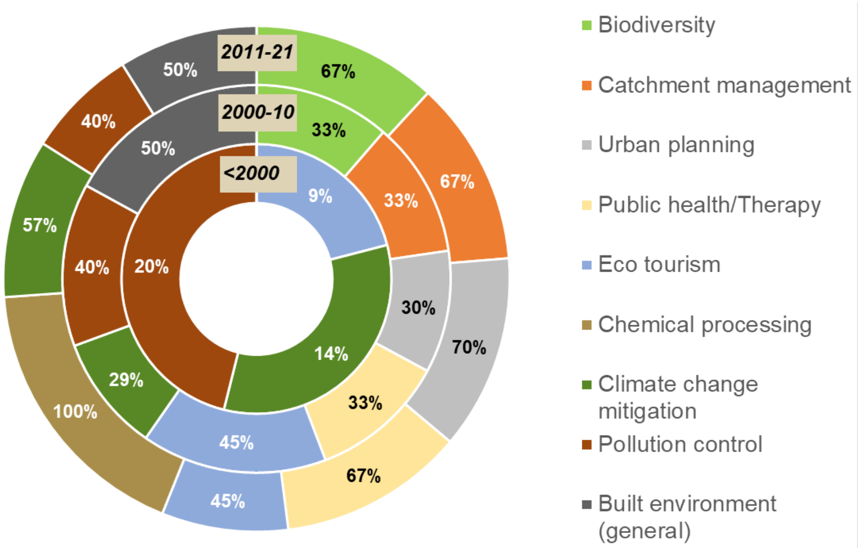

Figure 4. Timeline of evolution of different sub-categories of nature-based solutions.

5. NOSS Application from a Systems Perspective

Nature-oriented sustainability strategies are emerging as an alternative to the ecologically destructive technologies, systems, and approaches of the current industrial age, which define the current unsustainable human–nature relations [128]. It takes "nature as a model to meet the challenges of sustainable development" [5]; specifically, ecosystem-level biomimicry is considered to facilitate more sustainable designs, distinguishing between the mimicry of ecosystem functions and ecosystem processes [9,129].

The modeling of environmental systems allows us to understand more clearly whether solutions are nature-based or nature-inspired (or, ostensibly, a mixture). Other issues which may arise include the strength of connectivity between entities, albeit connections changing over time, and the formation of new issues, entities or connections. Issues of intrinsic scale must also be considered, both in terms of the solution proposed, which could range from large-scale nature-based land management [130] and food production using pest control [131], to nature-inspired black-water treatment [132], down to the use of biotechnology for the deposition of metals for electronics [133]. However, it is useful to model a selection of concepts within a framework bounded by the issues discussed in this paper. This is presented in Figure 5, to illustrate interconnectivities, but this is by no means exhaustive.

Figure 5. Connected entities representing a selection of nature-inspired/based solutions.

Some patterns emerge immediately from this initial thought experiment. Firstly, NBSs appear to be more interconnected than the NI approaches, whereas both tend to be broadly separate. As mentioned in the previous section, there is some crossover, as would be expected, for energy and water, where a mix of system-scale sustainability solutions and technologies may exist, although a deeper disaggregation for each area can be expected to produce more clarity. Interconnectivity between many entities and green spaces, and plants and trees (connections here are multiplexed for clarity) appear to be prominent. Some issues of urbanism also map onto green spaces; these are largely nature-based, although built-environment solutions may be nature-inspired, as well. Architecture and the built environment are intertwined with both NI- and NBS-design approaches, so consideration of specific cases may prompt a deeper discussion.

6. Implementation Challenges for Mainstreaming NOSSs

6.1. Scaling-up Issues

Nascent NI or NBS innovations often involve cross-disciplinary science, which poses scaling-up challenges for making them commercially viable. The paradox of a reliance on nature could be that the nature itself works at specific scales, whereas the human aspiration is to extend this to the scale of each person’s preference. NBSs, which have been operating already at meso- to macro-scale, therefore have greater potential for providing returns on economy at scale [79]. Within renewable energy, the diffuse nature of energy sources can produce suboptimal outcomes for the connection to electricity grids and fuel refineries. Miscanthus grown for bioenergy, for example, has scalability issues; these are not in terms of the level of demand on land, as projections are based mainly on utilizing marginal land and, indeed, for biofuels grown on land unsuitable for food production [134], but the main issue is the demand of concentrating the resource on the development of the required level of feedstock intensity, and the associated transportation. Another example would be the lead times for grid connection for UK renewables (wind and solar), whereby sources and sinks do not correlate strongly (notwithstanding issues such as planning and electricity market structure); the timely construction of wind and solar farms is limited by the arrival of a suitable grid connection, thus limiting scale and efficiency. For example, current innovation in bio-inspired solar-cell technology, while offering a viable resource to sustain human energy demands, still faces major fabrication and performance concerns [27].

Often, these initiatives are marred by the overriding focus of an organization and country on current financial performance indicators, e.g., the GDP, annual turnover, or assets vs. liabilities. Unfortunately, to date, the returns from the nature-based capital are not routinely adequately captured in the management costs of the performance metrics. There is a growing call to support large-scale NBS implementation in cities, by bringing them onto the local urban agenda [135] and hybrid (or multi-actor) governance has been identified as appropriate for upscaling urban NBS initiatives, combining scientific expertise with bottom-up consultation procedures [104].

Flexibility of scaling (e.g., scaling up) is also an issue, which can form an extra dimension for subsequent environmental-systems modeling; for example, a solution which is suitable for a building may not be suitable for a whole city [136]. In many cases, engineers are aware of a bio-inspired method, but they are not capable of finding tangible resources that could revolutionize their designs at scale [26]. Specifically, the tendency of modern processing to scale up nature-inspired solutions has posed some challenges for the scaling up. As the majority of these are still in their infancy, promising technologies have only been proven to work at a micro-scale level, leading to questions on their potential application on an industrial scale.

6.2. Management Challenges

Proponents of nature-oriented sustainability solutions acknowledge a nuanced relationship between biomimicry and sustainability, essentially reflecting its infancy and complexity. One of the main limitations of the case studies available in the literature to date is that the evaluations are mostly dominated by ecological parameters, and the narrative is thin with regard to practice and management aspects [137,138]. NOSSs can be critiqued, as they do not necessarily involve nature, but in some cases, focus rather on the technological limitations of nature (such as biomimicry, or hard-engineered stormwater storage structures). For example, the dominance of keywords such as ‘solutions’ and ‘services’ in NBS discourse and practices has a strong performative effect on our thinking. As such, speaking of solutions or services will focus our (scientific) quest, and may explicitly or implicitly downplay attention to nature’s contributions or processes that are not seen as a solution or a service. The adaption of reflexive approaches, by bringing together new networks of society, nature-based solution ambassadors, and practitioners, has been recommended for overcoming the governance challenges in implementing nature-based solutions [93]. A wider context here is that funding may be less available for conservation than it is for an increased turnover, even when resource efficiency may lead to improved profits (or, amongst policy-makers, a heavy centering on economic growth). This is likely to change; indeed, EU energy policy now gives energy conservation equal weight to production. However, financial capital remains arguably over-emphasized.

NBSs with an accepted level of operational issues are mainly those which require regular maintenance of nature-based interventions, such as the Sponge city watershed management, which involves the large-scale maintenance of vegetation health. The governance of the ‘true sustainability solutions’ of NBSs has led to several conflicting opinions in the literature. Lately, sustaining NBs in the context of austerity has oriented public policy towards a more encompassing reliance upon the private and non-for-profit sectors in the design, production, and maintenance of public goods [139].

6.3. Adapting to Global Ecological and Cultural Diversity

The main struggle for NOSS developers so far has been in terms of engaging with the community, to generate a stake in the welfare of the project and its ownership [136,140]. For example, the majority of the effort in developing NBSs has been invested in the multifunctionality and better quality, whereas the action towards supporting citizens in using it is a moot point [135]. Also, while a multi-functional NI/NBS intervention can be attractive to a cluster of beneficiaries, it is not the most beneficial option for individual actors [87], potentially leading to a social dilemma regarding its acceptability and upkeep.

A recent review of NBS projects reported a distinct lack of protection and application of traditional knowledge in conservation practices, which were found to be undervalued in current urban NBS practices, despite evidence of indigenous knowledge in biodiversity conservation [82]. One-size-fits-all initiatives to sustain NBSs without wider public and policy support have come to represent an increasing challenge [141]. To address this challenge, the EU has supported an international stakeholder community to obtain a wider understanding of the gaps arising from global ecological and cultural diversity within the exchange of good practices [97]. Targeted NBS development suiting the local context, including the causal relationships among NBSs, ecosystem services and local urban challenges, has been identified as key to sustainable and resilient urban planning [100].

On the other hand, the skepticism regarding the level of success of NI innovations compared to conventional approaches has been the key barrier to greater stakeholder participation [142]. An example of the context may include the lack of take-up for natural (and traditional) mitigation, such as night cooling and solar shading (drapes and trees), during recent UK heat waves, with a market pull for air conditioning. Another factor has been that the majority of these innovations are still at the institutional level, leading to ignorance on the part of the stakeholders (such as the cross-sectoral industry representatives, policy-makers, regulators, etc.), on the rapid progress and technological development that has already been made over the past decade. In addition, the lack of regulatory and policy instruments to persuade a wider uptake of such solutions against the backdrop of the commercial motive of companies has overshadowed the interest of consumer groups [79].

7. Conclusions

This study applied evidence from the literature to provide a synopsis of the emerging trends from the last two decades across two broad trajectories of nature-oriented sustainability strategies (NOSS), including "nature-inspired" (NI)- and "nature-based solution" (NBS)-oriented approaches. Interesting evolutionary patterns of the different sub-categories of each have been identified over three distinct time-horizons: pre 2000, 2000–10, and 2011–2021, as follows. Pre 2000, the NI literature was dominated by computing and optimization algorithms and material-structure applications. Post 2000, the NI literature appears to have become more diversified, with the emergence of several new sub-categories. Specifically, the literature covering biomimetic concepts has gained prominence, and new NI applications in chemical processing and the renewable-energy sector have been reported. Interestingly, the literature reporting the innovative NI application to fashion technology and public health in 2000–10 and 2011–21, respectively, indicates the appetite of new disciplines for adopting NOSSs. Our results show the maturity of NI application in the field of chemical processing, material structure, and renewable energy, with a growing spread of literature contributions from 2010 onwards.

We note that NBSs represent a relatively young science. The pre 2000 literature is found to be limited mainly to three conventional topics—pollution control, climate-change mitigation, and ecotourism. However, since 2000, the NBS literature has grown rapidly; the number of sub-categories has diversified into nine, with the majority of applications associated with urban planning. Based on the abundance of the sub-categories for the three time-horizons, we find that the majority of the NBS-themed work has been reported in the last 10 years. This mainly includes biodiversity, catchment management, urban planning, climate-change mitigation, and public health/therapy. Other NBS disciplinary categories have maintained a consistent literature presence, such as pollution control, ecotourism, and built-environment applications. NBS application to sustainable chemical processing is found to be an emerging area, reported only in 2011–21.

At the system scale, NBSs appear to be more interconnected than the NI approaches. Architecture and the built environment are intertwined with both NI- and NBS-design approaches, so a consideration of specific cases may prompt a deeper discussion. For example, some crossover exists for energy and water systems, where there is a mix of technological and sustainability solutions, respectively, on the scale of the system, incorporating both the NI and NBS approaches, in an overlap.

It is noteworthy that the geographical contexts of the NI and NBS work are not explicitly analyzed in this study, and the references surveyed are centered in origin on the Global North, with a perennial emphasis on subjects, as outlined above. However, there is room for nuance, should we disaggregate NI and NBS; there remains an issue of origin, publication, and application. Subjects such as computing, for example, may be currently centered on industrial nations/regions, but it is less advisable to draw firm conclusions on geographical context for all topics considered. The literature surveyed with a potential global focus constitutes the overwhelming majority, and while much research originates from North America, Europe, and Asia (in that order), the short-term impacts of the research itself remain, broadly, evenly distributed between the Global North and the Global South. A subset of solutions will require greater wealth and industrialization to realize, and, as such, will gain traction sooner in, e.g., North America and Europe. Further, as the Global South is expected to be impacted more aggressively by the imminent threats of climate change and resource scarcity, the higher impact of acquiring evidence-based knowledge-transfer capability from Global North actions on sustainability will mean the fast-tracking of their potential for global implementation.

Going forward, we have identified the three key focus areas of further research to ensure the successful implementation of NI and NBS approaches. These include (a) a consideration of inherent issues in their scaling up; (b) the management and governance of a 'true sustainability solution' of NOSSs; and (c) ensuring delivery of ecologically and culturally adaptive NOSSs across different global contexts.

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References

1. McPhearson, T.; Raymond, C.M.; Gulsrud, N.; Albert, C.; Coles, N.; Fagerholm, N.; Nagatsu, M.; Olafsson, A.S.; Soininen, N.; Vierikko, K. Radical changes are needed for transformations to a good Anthropocene. *npj Urban Sustain.* **2021**, *1*, 5. https://doi.org/10.1038/s42949-021-00017-x.
2. Randrup, T.B.; Buijs, A.; Konijnendijk, C.C.; Wild, T. Moving beyond the nature-based solutions discourse: introducing nature-based thinking. *Urban Ecosyst.* **2020**, *23*, 919–926. https://doi.org/10.1007/s11252-020-00964-w.
3. Bar-Cohen, Y. Nature as a Model for Mimicking and Inspiration of New Technologies. *Int. J. Aeronaut. Space Sci.* **2012**, *13*, 1–13. https://doi.org/10.5139/ijass.2012.13.1.1.
4. Zari, M.P.; MacKinnon, M.; Varshney, K.; Bakshi, N. Regenerative living cities and the urban climate-biodiversity-wellbeing nexus. *Nat. Clim. Change* **2022**, *12*, 601–604. https://doi.org/10.1038/s41558-022-01390-w.
5. Ilieva, L.; Ursano, I.; Traista, L.; Hoffmann, B.; Dahy, H. Biomimicry as a Sustainable Design Methodology—Introducing the 'Biomimicry for Sustainability' Framework. *Biomimetics* **2022**, *7*, 37. https://doi.org/10.3390/biomimetics7020037.
6. Speck, O.; Speck, T. Functional morphology of plants—A key to biomimetic applications. *New Phytol.* **2021**, *231*, 950–956. https://doi.org/10.1111/nph.17396.

7. Kennedy, E.; Fecheyr-Lippens, D.; Hsiung, B.-K.; Niewiarowski, P.H.; Kolodziej, M. Biomimicry: A Path to Sustainable Innovation. *Des. Issues* **2015**, *31*, 66–73. https://doi.org/10.1162/desi_a_00339.
8. Helmrich, A.M.; Chester, M.V.; Hayes, S.; Markolf, S.A.; Desha, C.; Grimm, N.B. Using Biomimicry to Support Resilient Infrastructure Design. *Earths Future* **2020**, *8*, e2020EF001653. https://doi.org/10.1029/2020ef001653.
9. MacKinnon, R.B.; Oomen, J.; Zari, M.P. Promises and Presuppositions of Biomimicry. *Biomimetics* **2020**, *5*, 33. https://doi.org/10.3390/biomimetics5030033.
10. Speck, O.; Langer, M.; Mylo, M.D. Plant-inspired damage control—An inspiration for sustainable solutions in the Anthropocene. *Annu. Rev. Anthropol.* **2021**, *9*, 220–236. https://doi.org/10.1177/20530196211018489.
11. Speck, O.; Speck, T. An Overview of Bioinspired and Biomimetic Self-Repairing Materials. *Biomimetics* **2019**, *4*, 26. https://doi.org/10.3390/biomimetics4010026.
12. Bar-Cohen, Y. *Biomimetics: Nature-Based Innovation*; CRC Press: Boca Raton, FL, USA, 2011.
13. van der Jagt, A.P.N.; Raven, R.; Dorst, H.; Runhaar, H. Nature-based innovation systems. *Environ. Innov. Soc. Transit.* **2020**, *35*, 202–216. https://doi.org/10.1016/j.eist.2019.09.005.
14. Casement, W. William Morris on Labor and Pleasure. *Soc. Theory Pract.* **1986**, *12*, 351–382. https://doi.org/10.5840/soctheorpract19861235.
15. Huxley, A. *Brave New World*; Vintage: New York, NY, USA, 1931.
16. Steinbeck, J. *The Grapes of Wrath*; The Viking Press: New York, NY, USA, 1939.
17. Orwell, G. *The Road to Wigan Pier*; Victor Gollancz: London, UK, 1937.
18. Seymour, J. *The Forgotten Crafts*; Portland House, Distributed by Outlet Books Co.: New York, NY, USA, 1984.
19. Seymour, J.; Girardet, H. *Blueprint for a Green Planet*; Dorling Kindersley: London, UK, 1987.
20. Mabey, R.; Sinclair, I. *The Unofficial Countryside*; Collins: London, UK, 1973.
21. Cloke, P.; Milbourne, P.; Thomas, C. From wasteland to wonderland: Opencast mining, regeneration and the English National Forest. *Geoforum* **1996**, *27*, 159–174. https://doi.org/10.1016/0016-7185(96)00006-1.
22. Jones, H. The Eden Project: A Synopsis around Sustainable Enterprise. *J. Corp. Citizsh.* **2008**, *30*, 133–137.
23. Bisoffi, S.; Ahrné, L.; Aschemann-Witzel, J.; Báldi, A.; Cuhls, K.; DeClerck, F.; Duncan, J.; Hansen, H.O.; Hudson, R.L.; Kohl, J.; et al. COVID-19 and Sustainable Food Systems: What Should We Learn Before the Next Emergency. *Front. Sustain. Food Syst.* **2021**, *5*, 53. https://doi.org/10.3389/fsufs.2021.650987.
24. Buheji, M.; Korže, A.V.; Eidan, S.; Abdulkareem, T.; Perepelkin, N.A.; Mavric, B.; Preis, J.; Bartula, M.; Ahmed, D.; Buheji, A.; et al. Optimising Pandemic Response through Self-Sufficiency—A Review Paper. *Am. J. Econ.* **2020**, *10*, 277–283. https://doi.org/10.5923/j.economics.20201005.02.
25. Speck, T.; Poppinga, S.; Speck, O.; Tauber, F. Bio-inspired life-like motile materials systems: Changing the boundaries between living and technical systems in the Anthropocene. *Annu. Rev. Anthropol.* **2021**, *9*, 237–256. https://doi.org/10.1177/20530196211039275.
26. Hu, N.; Feng, P.; Dai, G. The Gift from Nature: Bio-Inspired Strategy for Developing Innovative Bridges. *J. Bionic Eng.* **2013**, *10*, 405–414. https://doi.org/10.1016/s1672-6529(13)60246-2.
27. Persiani, S. *Biomimetics of Motion: Nature-Inspired Parameters and Schemes for Kinetic Design*; Springer International Publishing: Berlin/Heidelberg, Germany, 2018.
28. Bozorg-Haddad, O. (Ed.). *Advanced Optimization by Nature-Inspired Algorithms*; Springer Science and Business Media LLC: Dordrecht, The Netherlands, 2018; ISBN: 3540306765.
29. Figueira, J.R.; Talbi, E.-G. Emergent nature inspired algorithms for multi-objective optimization. *Comput. Oper. Res.* **2013**, *40*, 1521–1523. https://doi.org/10.1016/j.cor.2013.01.020.
30. Abdel-Basset, M.; Hessin, A.-N.; Abdel-Fatah, L. A comprehensive study of cuckoo-inspired algorithms. *Neural Comput. Appl.* **2018**, *29*, 345–361. https://doi.org/10.1007/s00521-016-2464-8.
31. Viana, F.A.C.; Steffen, V.; Butkewitsch, S.; De Freitas Leal, M. Optimization of aircraft structural components by using nature-inspired algorithms and multi-fidelity approximations. *J. Glob. Optim.* **2009**, *45*, 427–449. https://doi.org/10.1007/s10898-008-9383-x.
32. Zang, H.; Zhang, S.; Hapeshi, K. A Review of Nature-Inspired Algorithms. *J. Bionic Eng.* **2010**, *7*, S232–S237. https://doi.org/10.1016/s1672-6529(09)60240-7.
33. Molina, D.; Poyatos, J.; Del Ser, J.; García, S.; Hussain, A.; Herrera, F. Comprehensive Taxonomies of Nature- and Bio-inspired Op-timization: Inspiration Versus Algorithmic Behavior, Critical Analysis Recommendations. *Cognit. Comput.* **2020**, *12*, 897–939. https://doi.org/10.1007/S12559-020-09730-8/METRICS.
34. Li, M.D.; Zhao, H.; Weng, X.W.; Han, T. A novel nature-inspired algorithm for optimization: Virus colony search. *Adv. Eng. Softw.* **2016**, *92*, 65–88. https://doi.org/10.1016/j.advengsoft.2015.11.004.
35. Maraveas, C.; Asteris, P.G.; Arvanitis, K.G.; Bartzanas, T.; Loukatos, D. Application of Bio and Nature-Inspired Algorithms in Agricultural Engineering. *Arch. Comput. Methods Eng.* **2023**, *30*, 1979–2012. https://doi.org/10.1007/S11831-022-09857-X/FIGURES/8.
36. Mehrnia, S.; Miyagawa, K.; Kusaka, J.; Nakamura, Y. Radial turbine optimization under unsteady flow using nature-inspired algorithms. *Aerosp. Sci. Technol.* **2020**, *103*, 105903. https://doi.org/10.1016/j.ast.2020.105903.
37. Saad, A.E.H.; Dong, Z.; Karimi, M. A Comparative Study on Recently-Introduced Nature-Based Global Optimization Methods in Complex Mechanical System Design. *Algorithms* **2017**, *10*, 120. https://doi.org/10.3390/a10040120.

38. Khan, Z.A.; Khalid, A.; Javaid, N.; Haseeb, A.; Saba, T.; Shafiq, M. Exploiting Nature-Inspired-Based Artificial Intelligence Techniques for Coordinated Day-Ahead Scheduling to Efficiently Manage Energy in Smart Grid. *IEEE Access* **2019**, *7*, 140102–140125. https://doi.org/10.1109/access.2019.2942813.
39. Sheta, A.; Faris, H.; Braik, M.; Mirjalili, S. Nature-Inspired Metaheuristics Search Algorithms for Solving the Economic Load Dispatch Problem of Power System: A Comparison Study. *Appl. Nat. Inspired Comput. Algorithms Case Stud.* **2020**, 199–230. https://doi.org/10.1007/978-981-13-9263-4_9.
40. Faramarzi, A.; Heidarinejad, M.; Mirjalili, S.; Gandomi, A.H. Marine Predators Algorithm: A nature-inspired metaheuristic. *Expert Syst. Appl.* **2020**, *152*, 113377. https://doi.org/10.1016/j.eswa.2020.113377.
41. Bhandari, A.; Kumar, A.; Chaudhary, S.; Singh, G.K. A novel color image multilevel thresholding based segmentation using nature inspired optimization algorithms. *Expert Syst. Appl.* **2016**, *63*, 112–133. https://doi.org/10.1016/j.eswa.2016.06.044.
42. Khurana, A.; Verma, O.P. Novel approach with nature-inspired and ensemble techniques for optimal text classification. *Multimedia Tools Appl.* **2020**, *79*, 23821–23848. https://doi.org/10.1007/s11042-020-09013-2.
43. Kashyap, A.K.; Parhi, D.R.; Pandey, A. Multi-objective optimization technique for trajectory planning of multi-humanoid robots in cluttered terrain. *ISA Trans.* **2022**, *125*, 591–613. https://doi.org/10.1016/j.isatra.2021.06.017.
44. Kashyap, A.K.; Pandey, A.; Parhi, D.R. Route Mapping of Multiple Humanoid Robots Using Firefly-Based Artificial Potential Field Algorithm in a Cluttered Terrain. *New Adv. Soc. Artif. Intell. Ind. Internet Things Paradig*. **2022**, 323–350. https://doi.org/10.1002/9781119884392.CH15.
45. Nayak, J.; Naik, B.; Jena, A.K.; Barik, R.K.; Das, H. Nature Inspired Optimizations in Cloud Computing: Applications and Challenges. *Stud. Big Data* **2018**, *39*, 1–26. https://doi.org/10.1007/978-3-319-73676-1_1/COVER.
46. Mchergui, A.; Moulahi, T.; Zeadally, S. Survey on Artificial Intelligence (AI) techniques for Vehicular Ad-hoc Networks (VANETs). *Veh. Commun.* **2022**, *34*, 100403. https://doi.org/10.1016/j.vehcom.2021.100403.
47. Coppens, M.-O. A nature-inspired approach to reactor and catalysis engineering. *Curr. Opin. Chem. Eng.* **2012**, *1*, 281–289. https://doi.org/10.1016/j.coche.2012.03.002.
48. Trogadas, P.; Coppens, M.-O. Nature-inspired electrocatalysts and devices for energy conversion. *Chem. Soc. Rev.* **2020**, *49*, 3107–3141. https://doi.org/10.1039/c8cs00797g.
49. Trogadas, P.; Nigra, M.M.; Coppens, M.-O. Nature-inspired optimization of hierarchical porous media for catalytic and separation processes. *New J. Chem.* **2016**, *40*, 4016–4026. https://doi.org/10.1039/c5nj03406j.
50. Martin, D.J.; Reardon, P.J.T.; Moniz, S.J.A.; Tang, J. Visible light-driven pure water splitting by a nature-inspired organic semi-con-ductor-based system. *J. Am. Chem. Soc.* **2014**, *136*, 12568–12571. https://doi.org/10.1021/JA506386E/SUPPL_FILE/JA506386E_SI_001.PDF.
51. Čechová, P.; Kubala, M. Comparison of three nature inspired molecular docking algorithms. *Int. J. Bio Inspired Comput.* **2021**, *17*, 34–41. https://doi.org/10.1504/ijbic.2021.113362.
52. O'Connor, D.; Hou, D.; Liu, Q.; Palmer, M.R.; Varma, R.S. Nature-inspired and sustainable synthesis of sulfur-bearing fe-rich nano-particles. *ACS Sustain. Chem. Eng*. **2020**, *8*, 15791–15808. https://doi.org/10.1021/ACSSUSCHEMENG.0C03401/ASSET/IMAGES/MEDIUM/SC0C03401_0016.GIF.
53. No, Y.H.; Kim, N.H.; Gnapareddy, B.; Choi, B.; Dugasani, S.R.; Lee, O.-S.; Kim, K.-H.; Ko, Y.-S.; Lee, S.; Lee, S.W.; et al. Nature-Inspired Construction of Two-Dimensionally Self-Assembled Peptide on Pristine Graphene. *J. Phys. Chem. Lett.* **2017**, *8*, 3734–3739. https://doi.org/10.1021/acs.jpclett.7b00996.
54. Gomes, G.F.; da Cunha, S.S., Jr.; Ancelotti, A.C. A sunflower optimization (SFO) algorithm applied to damage identification on laminated composite plates. *Eng. Comput.* **2019**, *35*, 619–626. https://doi.org/10.1007/s00366-018-0620-8.
55. Liu, Y.; He, K.; Chen, G.; Leow, W.R.; Chen, X. Nature-Inspired Structural Materials for Flexible Electronic Devices. *Chem. Rev.* **2017**, *117*, 12893–12941. https://doi.org/10.1021/acs.chemrev.7b00291.
56. Nagy, D.; Zhao, D.; Benjamin, D. Nature-Based Hybrid Computational Geometry System for Optimizing Component Structure. In *Humanizing Digital Reality: Design Modelling Symposium Paris*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 167–176. https://doi.org/10.1007/978-981-10-6611-5_15.
57. Rian, I.M.; Asayama, S. Computational Design of a nature-inspired architectural structure using the concepts of self-similar and random fractals. *Autom. Constr.* **2016**, *66*, 43–58. https://doi.org/10.1016/j.autcon.2016.03.010.
58. Glowacki, E.D.; Leonat, L.; Voss, G.; Bodea, M.; Bozkurt, Z.; Irimia-Vladu, M.; Bauer, S.; Sariciftci, N.S. Natural and nature-inspired semiconductors for organic electronics. In Proceedings of the Organic Semiconductors in Sensors and Bioelectronics IV, San Diego, CA, USA, 24–25 August 2011; Volume 8118, pp. 78–87. https://doi.org/10.1117/12.892467
59. Soudi, N.; Nanayakkara, S.; Jahed, N.M.; Naahidi, S. Rise of nature-inspired solar photovoltaic energy convertors. *Sol. Energy* **2020**, *208*, 31–45. https://doi.org/10.1016/j.solener.2020.07.048.
60. Bian, Q.; Ma, F.; Chen, S.; Wei, Q.; Su, X.; Buyanova, I.A.; Chen, W.M.; Ponseca, C.S.; Linares, M.; Karki, K.J.; et al. Vibronic coherence contributes to photocurrent generation in organic semiconductor heterojunction diodes. *Nat. Commun.* **2020**, *11*, 1–9. https://doi.org/10.1038/s41467-020-14476-w.
61. Broza, Y.Y.; Zhou, X.; Yuan, M.; Qu, D.; Zheng, Y.; Vishinkin, R.; Khatib, M.; Wu, W.; Haick, H. Disease Detection with Molecular Biomarkers: From Chemistry of Body Fluids to Nature-Inspired Chemical Sensors. *Chem. Rev.* **2019**, *119*, 11761–11817. https://doi.org/10.1021/acs.chemrev.9b00437.
62. Scates, D.; Dickinson, J.I.; Sullivan, K.; Cline, H.; Balaraman, R. Using Nature-Inspired Virtual Reality as a Distraction to Reduce Stress and Pain Among Cancer Patients. *Environ. Behav.* **2020**, *52*, 895–918. https://doi.org/10.1177/0013916520916259.

63. Singh, A.V.; Rahman, A.; Kumar, N.S.; Aditi, A.; Galluzzi, M.; Bovio, S.; Barozzi, S.; Montani, E.; Parazzoli, D. Bio-inspired approaches to design smart fabrics. *Mater. Des.* **2012**, *36*, 829–839. https://doi.org/10.1016/j.matdes.2011.01.061.
64. Speck, O.; Möller, M.; Grießhammer, R.; Speck, T. Biological Concepts as a Source of Inspiration for Efficiency, Consistency, and Sufficiency. *Sustainability* **2022**, *14*, 8892. https://doi.org/10.3390/su14148892.
65. Sinha, S.; Chandel, S. Review of recent trends in optimization techniques for solar photovoltaic-wind based hybrid energy systems. *Renew. Sustain. Energy Rev.* **2015**, *50*, 755–769. https://doi.org/10.1016/j.rser.2015.05.040.
66. Dorigo, M.; Birattari, M.; Stutzle, T. Ant colony optimization. *IEEE Comput. Intell. Mag.* **2006**, *1*, 28–39. https://doi.org/10.1109/mci.2006.329691.
67. Menshsari, A.; Ghiamy, M.; Mousavi, M.M.; Bagal, H.A. Optimal design of hybrid water-wind-solar system based on hydrogen storage and evaluation of reliability index of system using ant colony algorithm. *International Res. J. Appl. Basic. Sci.* **2013**, *4*, 3582–3600.
68. Xu, D.; Kang, L.; Cao, B. Graph-Based Ant System for Optimal Sizing of Standalone Hybrid Wind/PV Power Systems. In Proceedings of the International Conference on Intelligent Computing, Kunming, China, 16–19 August 2006; pp. 1136–1146.
69. Passino, K.M. Biomimicry of bacterial foraging for distributed optimization and control. *IEEE Control Syst. Mag.* **2002**, *22*, 52–67. https://doi.org/10.1109/mcs.2002.1004010.
70. Karaboga, D.; Basturk, B. A powerful and efficient algorithm for numerical function optimization: artificial bee colony (ABC) algorithm. *J. Glob. Optim.* **2007**, *39*, 459–471. https://doi.org/10.1007/s10898-007-9149-x.
71. Nasiraghdam, H.; Jadid, S. Optimal hybrid PV/WT/FC sizing and distribution system reconfiguration using multi-objective artificial bee colony (MOABC) algorithm. *Sol. Energy* **2012**, *86*, 3057–3071. https://doi.org/10.1016/j.solener.2012.07.014.
72. Maleki, A.; Askarzadeh, A. Artificial bee swarm optimization for optimum sizing of a stand-alone PV/WT/FC hybrid system considering LPSP concept. *Sol. Energy* **2014**, *107*, 227–235. https://doi.org/10.1016/j.solener.2014.05.016.
73. Speck, O.; Speck, T. Bridging the Gap: From Biomechanics and Functional Morphology of Plants to Biomimetic Developments. *Biomimetics* **2021**, *6*, 60. https://doi.org/10.3390/biomimetics6040060.
74. Escobedo, F.J.; Giannico, V.; Jim, C.Y.; Sanesi, G.; Lafortezza, R. Urban forests, ecosystem services, green infrastructure and nature-based solutions: Nexus or evolving metaphors? *Urban For. Urban Green.* **2019**, *37*, 3–12. https://doi.org/10.1016/j.ufug.2018.02.011.
75. Xing, Y.; Jones, P.; Donnison, I. Characterization of Nature-Based Solutions for the Built Environment. *Sustainability* **2017**, *9*, 149. https://doi.org/10.3390/su9010149.
76. Potschin, M.; Kretsch, C.; Haines-Young, R.; Furman, E.; Berry, P.; Baró, F. Nature-Based Solutions. In *OpenNESS Ecosystem Services Reference*; Potschin, M., Jax, K., Eds.; EC FP7 Grant Agreement no. 308428; IPBES Secretariat: Bonn, Germany, 2016.
77. European Commission. *Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-Naturing Cities*; European Commission: Brussels, Belgium, 2015. https://doi.org/10.2777/765301.
78. Seddon, N.; Daniels, E.; Davis, R.; Chausson, A.; Harris, R.; Hou-Jones, X.; Huq, S.; Kapos, V.; Mace, G.M.; Rizvi, A.R.; et al. Global recognition of the importance of nature-based solutions to the impacts of climate change. *Glob. Sustain.* **2020**, *3*, e15. https://doi.org/10.1017/sus.2020.8.
79. Cohen-Shacham, E.; Andrade, A.; Dalton, J.; Dudley, N.; Jones, M.; Kumar, C.; Maginnis, S.; Maynard, S.; Nelson, C.R.; Renaud, F.G.; et al. Core principles for successfully implementing and upscaling Nature-based Solutions. *Environ. Sci. Policy* **2019**, *98*, 20–29. https://doi.org/10.1016/j.envsci.2019.04.014.
80. Seddon, N.; Turner, B.; Berry, P.; Chausson, A.; Girardin, C.A.J. Grounding nature-based climate solutions in sound biodiversity science. *Nat. Clim. Change* **2019**, *9*, 84–87. https://doi.org/10.1038/s41558-019-0405-0.
81. Mori, A.S. Advancing nature-based approaches to address the biodiversity and climate emergency. *Ecol. Lett.* **2020**, *23*, 1729–1732. https://doi.org/10.1111/ele.13594.
82. Xie, L.; Bulkeley, H. Nature-based solutions for urban biodiversity governance. *Environ. Sci. Policy* **2020**, *110*, 77–87. https://doi.org/10.1016/j.envsci.2020.04.002.
83. Blau, M.L.; Luz, F.; Panagopoulos, T. Urban River Recovery Inspired by Nature-Based Solutions and Biophilic Design in Albufeira, Portugal. *Land* **2018**, *7*, 141. https://doi.org/10.3390/land7040141.
84. Martin, E.G.; Costa, M.M.; Máñez, K.S. An operationalized classification of Nature Based Solutions for water-related hazards: From theory to practice. *Ecol. Econ.* **2019**, *167*, 106460. https://doi.org/10.1016/j.ecolecon.2019.106460.
85. Vera-Puerto, I.; Valdes, H.; Correa, C.; Agredano, R.; Vidal, G.; Belmonte, M.; Olave, J.; Arias, C. Proposal of competencies for engineering education to develop water infrastructure based on "Nature-Based Solutions" in the urban context. *J. Clean. Prod.* **2020**, *265*, 121717. https://doi.org/10.1016/j.jclepro.2020.121717.
86. Krauze, K.; Wagner, I. From classical water-ecosystem theories to nature-based solutions—Contextualizing nature-based solutions for sustainable city. *Sci. Total. Environ.* **2019**, *655*, 697–706. https://doi.org/10.1016/j.scitotenv.2018.11.187.
87. Janssen, S.; Vreugdenhil, H.; Hermans, L.; Slinger, J. On the nature based flood defence dilemma and its Resolution: A game theory based analysis. *Sci. Total. Environ.* **2020**, *705*, 135359. https://doi.org/10.1016/j.scitotenv.2019.135359.
88. Luo, K.; Wang, Z.; Sha, W.; Wu, J.; Wang, H.; Zhu, Q. Integrating Sponge City Concept and Neural Network into Land Suitability Assessment: Evidence from a Satellite Town of Shenzhen Metropolitan Area. *Land* **2021**, *10*, 872. https://doi.org/10.3390/land10080872.
89. Lancia, M.; Zheng, C.; He, X.; Lerner, D.N.; Andrews, C.; Tian, Y. Hydrogeological constraints and opportunities for "Sponge City" development: Shenzhen, southern China. *J. Hydrol. Reg. Stud.* **2020**, *28*, 100679. https://doi.org/10.1016/j.ejrh.2020.100679.

90. Ren, K.; Huang, S.; Huang, Q.; Wang, H.; Leng, G.; Cheng, L.; Fang, W.; Li, P. A nature-based reservoir optimization model for resolving the conflict in human water demand and riverine ecosystem protection. *J. Clean. Prod.* **2019**, *231*, 406–418. https://doi.org/10.1016/j.jclepro.2019.05.221.
91. Guerrero, P.; Haase, D.; Albert, C. Locating Spatial Opportunities for Nature-Based Solutions: A River Landscape Application. *Water* **2018**, *10*, 1869. https://doi.org/10.3390/w10121869.
92. Morris, R.L.; Konlechner, T.M.; Ghisalberti, M.; Swearer, S.E. From grey to green: Efficacy of eco-engineering solutions for nature-based coastal defence. *Glob. Change Biol.* **2018**, *24*, 1827–1842. https://doi.org/10.1111/gcb.14063.
93. Kabisch, N.; Frantzeskaki, N.; Pauleit, S.; Naumann, S.; Davis, M.; Artmann, M.; Haase, D.; Knapp, S.; Korn, H.; Stadler, J.; et al. Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecol. Soc.* **2016**, *21*. https://doi.org/10.5751/es-08373-210239.
94. Lafortezza, R.; Chen, J.; van den Bosch, C.K.; Randrup, T.B. Nature-based solutions for resilient landscapes and cities. *Environ. Res.* **2018**, *165*, 431–441. https://doi.org/10.1016/j.envres.2017.11.038.
95. Song, Y.; Kirkwood, N.; Maksimović, Č.; Zheng, X.; O'Connor, D.; Jin, Y.; Hou, D. Nature based solutions for contaminated land remediation and brownfield redevelopment in cities: A review. *Sci. Total Environ.* **2019**, *663*, 568–579. https://doi.org/10.1016/j.scitotenv.2019.01.347.
96. Dushkova, D.; Haase, D. Not Simply Green: Nature-Based Solutions as a Concept and Practical Approach for Sustainability Studies and Planning Agendas in Cities. *Land* **2020**, *9*, 19. https://doi.org/10.3390/land9010019.
97. Faivre, N.; Fritz, M.; Freitas, T.; de Boissezon, B.; Vandewoestijne, S. Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environ. Res.* **2017**, *159*, 509–518. https://doi.org/10.1016/j.envres.2017.08.032.
98. Frantzeskaki, N. Seven lessons for planning nature-based solutions in cities. *Environ. Sci. Policy* **2019**, *93*, 101–111. https://doi.org/10.1016/j.envsci.2018.12.033.
99. Dumitru, A.; Frantzeskaki, N.; Collier, M. Identifying principles for the design of robust impact evaluation frameworks for nature-based solutions in cities. *Environ. Sci. Policy* **2020**, *112*, 107–116. https://doi.org/10.1016/j.envsci.2020.05.024.
100. Almenar, J.B.; Elliot, T.; Rugani, B.; Philippe, B.; Gutierrez, T.N.; Sonnemann, G.; Geneletti, D. Nexus between nature-based solutions, ecosystem services and urban challenges. *Land Use Policy* **2021**, *100*, 104898. https://doi.org/10.1016/j.landusepol.2020.104898.
101. Raymond, C.M.; Frantzeskaki, N.; Kabisch, N.; Berry, P.; Breil, M.; Nita, M.R.; Geneletti, D.; Calfapietra, C. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environ. Sci. Policy* **2017**, *77*, 15–24. https://doi.org/10.1016/j.envsci.2017.07.008.
102. Lafortezza, R.; Sanesi, G. Nature-based solutions: Settling the issue of sustainable urbanization. *Environ. Res.* **2019**, *172*, 394–398. https://doi.org/10.1016/j.envres.2018.12.063.
103. Gregory, A.J.; Atkins, J.P.; Burdon, D.; Elliott, M. A problem structuring method for ecosystem-based management: The DPSIR modelling process. *Eur. J. Oper. Res.* **2013**, *227*, 558–569. https://doi.org/10.1016/j.ejor.2012.11.020.
104. Toxopeus, H.; Kotsila, P.; Conde, M.; Katona, A.; van der Jagt, A.P.; Polzin, F. How 'just' is hybrid governance of urban nature-based solutions? *Cities* **2020**, *105*, 102839. https://doi.org/10.1016/j.cities.2020.102839.
105. Langergraber, G.; Pucher, B.; Simperler, L.; Kisser, J.; Katsou, E.; Buehler, D.; Mateo, M.C.G.; Atanasova, N. Implementing nature-based solutions for creating a resourceful circular city. *Blue-Green Syst.* **2020**, *2*, 173–185. https://doi.org/10.2166/bgs.2020.933.
106. Sartison, K.; Artmann, M. Edible cities—An innovative nature-based solution for urban sustainability transformation? An explorative study of urban food production in German cities. *Urban For. Urban Green.* **2020**, *49*, 126604. https://doi.org/10.1016/j.ufug.2020.126604.
107. Colléony, A.; Shwartz, A. Beyond Assuming Co-Benefits in Nature-Based Solutions: A Human-Centered Approach to Optimize Social and Ecological Outcomes for Advancing Sustainable Urban Planning. *Sustainability* **2019**, *11*, 4924. https://doi.org/10.3390/su11184924.
108. Tozer, L.; Hörschelmann, K.; Anguelovski, I.; Bulkeley, H.; Lazova, Y. Whose city? Whose nature? Towards inclusive nature-based solution governance. *Cities* **2020**, *107*, 102892. https://doi.org/10.1016/j.cities.2020.102892.
109. Stigsdotter, U.; Palsdottir, A.; Burls, A.; Chermaz, A.; Ferrini, F.; Grahn, P. Nature-based Therapeutic Interventions. In *Forests, Trees and Human Health*; Nilsson, K., Sangster, M., Gallis, C., Hartig, T., de Vries, S., Seeland, K., Schipperijn, J., Eds.; Springer: Berlin, Germany, 2011; pp. 309–342.
110. Segal, D.; Harper, N.J.; Rose, K. *Outdoor Therapies: An Introduction to Practices, Possibilities, and Critical Perspectives*; Routledge: New York, NY, USA, 2020; pp. 95–107. https://doi.org/10.4324/9780429352027.
111. Van den Bosch, M.; Ode Sang, Å. Urban natural environments as nature-based solutions for improved public health—A systematic review of reviews. *Environ. Res.* **2017**, *158*, 373–384. https://doi.org/10.1016/j.envres.2017.05.040.
112. Leavell, M.A.; Leiferman, J.A.; Gascon, M.; Braddick, F.; Gonzalez, J.C.; Litt, J.S. Nature-Based Social Prescribing in Urban Settings to Improve Social Connectedness and Mental Well-being: a Review. *Curr. Environ. Heal. Rep.* **2019**, *6*, 297–308. https://doi.org/10.1007/s40572-019-00251-7.
113. Kabisch, N.; van den Bosch, M.; Lafortezza, R. The health benefits of nature-based solutions to urbanization challenges for children and the elderly—A systematic review. *Environ. Res.* **2017**, *159*, 362–373. https://doi.org/10.1016/j.envres.2017.08.004.

114. Ryan, C.O.; Browning, W.D.; O Clancy, J.; Andrews, S.L.; Kallianpurkar, N.B. Biophilic Design Patterns: Emerging Nature-Based Parameters for Health and Well-Being in the Built Environment. *J. Archit. Res.* **2014**, *8*, 62–76. https://doi.org/10.26687/archnet-ijar.v8i2.436.
115. Han, H.; Hyun, S.S. Green indoor and outdoor environment as nature-based solution and its role in increasing customer/employee mental health, well-being, and loyalty. *Bus. Strat. Environ.* **2019**, *28*, 629–641. https://doi.org/10.1002/bse.2269.
116. Sahlin, E.; Ahlborg, G.; Matuszczyk, J.V.; Grahn, P. Nature-Based Stress Management Course for Individuals at Risk of Adverse Health Effects from Work-Related Stress—Effects on Stress Related Symptoms, Workability and Sick Leave. *Int. J. Environ. Res. Public Health* **2014**, *11*, 6586–6611. https://doi.org/10.3390/ijerph110606586.
117. Heintzman, P. Nature-Based Recreation and Spirituality: A Complex Relationship. *Leis. Sci.* **2009**, *32*, 72–89. https://doi.org/10.1080/01490400903430897.
118. Yuxi, Z.; Linsheng, Z. Identifying conflicts tendency between nature-based tourism development and ecological protection in China. *Ecol. Indic.* **2020**, *109*, 105791. https://doi.org/10.1016/j.ecolind.2019.105791.
119. Fossgard, K.; Fredman, P. Dimensions in the nature-based tourism experiencescape: An explorative analysis. *J. Outdoor Recreat. Tour.* **2019**, *28*, 100219. https://doi.org/10.1016/j.jort.2019.04.001.
120. Debele, S.E.; Kumar, P.; Sahani, J.; Marti-Cardona, B.; Mickovski, S.B.; Leo, L.S.; Porcù, F.; Bertini, F.; Montesi, D.; Vojinovic, Z.; et al. Nature-based solutions for hydro-meteorological hazards: Revised concepts, classification schemes and databases. *Environ. Res.* **2019**, *179*, 108799. https://doi.org/10.1016/j.envres.2019.108799.
121. Sahani, J.; Kumar, P.; Debele, S.; Spyrou, C.; Loupis, M.; Aragão, L.; Porcù, F.; Shah, M.A.R.; Di Sabatino, S. Hydro-meteorological risk assessment methods and management by nature-based solutions. *Sci. Total. Environ.* **2019**, *696*, 133936. https://doi.org/10.1016/j.scitotenv.2019.133936.
122. Ruangpan, L.; Vojinovic, Z.; Di Sabatino, S.; Leo, L.S.; Capobianco, V.; Oen, A.M.P.; McClain, M.E.; Lopez-Gunn, E. Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. *Nat. Hazards Earth Syst. Sci.* **2020**, *20*, 243–270. https://doi.org/10.5194/nhess-20-243-2020.
123. Frantzeskaki, N.; McPhearson, T.; Collier, M.J.; Kendal, D.; Bulkeley, H.; Dumitru, A.; Walsh, C.; Noble, K.; van Wyk, E.; Ordóñez, C.; et al. Nature-Based Solutions for Urban Climate Change Adaptation: Linking Science, Policy, and Practice Communities for Evidence-Based Decision-Making. *BioScience* **2019**, *69*, 455–466. https://doi.org/10.1093/biosci/biz042.
124. Gómez Martín, E.; Giordano, R.; Pagano, A.; van der Keur, P.; Máñez Costa, M. Using a system thinking approach to assess the contribution of nature based solutions to sustainable development goals. *Sci. Total Environ.* **2020**, *738*, 139693. https://doi.org/10.1016/j.scitotenv.2020.139693.
125. Liquete, C.; Udias, A.; Conte, G.; Grizzetti, B.; Masi, F. Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits. *Ecosyst. Serv.* **2016**, *22*, 392–401. https://doi.org/10.1016/j.ecoser.2016.09.011.
126. Boano, F.; Caruso, A.; Costamagna, E.; Ridolfi, L.; Fiore, S.; Demichelis, F.; Galvão, A.; Pisoeiro, J.; Rizzo, A.; Masi, F. A review of nature-based solutions for greywater treatment: Applications, hydraulic design, and environmental benefits. *Sci. Total. Environ.* **2020**, *711*, 134731. https://doi.org/10.1016/j.scitotenv.2019.134731.
127. Raskin, P.D. Global Scenarios: Background Review for the Millennium Ecosystem Assessment. *Ecosystems* **2005**, *8*, 133–142. https://doi.org/10.1007/s10021-004-0074-2.
128. Blok, V.; Gremmen, B. Ecological Innovation: Biomimicry as a New Way of Thinking and Acting Ecologically. *J. Agric. Environ. Ethics* **2016**, *29*, 203–217. https://doi.org/10.1007/s10806-015-9596-1.
129. Pedersen Zari, M. *Regenerative Urban Design and Ecosystem Biomimicry*, 1st ed.; Taylor and Francis: London, UK, 2018; p. 260. https://doi.org/10.4324/9781315114330.
130. Keesstra, S.; Nunes, J.; Novara, A.; Finger, D.; Avelar, D.; Kalantari, Z.; Cerdà, A. The superior effect of nature based solutions in land management for enhancing ecosystem services. *Sci. Total Environ.* **2018**, *610–611*, 997–1009. https://doi.org/10.1016/j.scitotenv.2017.08.077.
131. Hutchins, S.H. Natural products for crop protection: Evolution or intelligent design. *ACS Symp. Ser.* **2015**, *1204*, 55–62. https://doi.org/10.1021/BK-2015-1204.CH005.
132. Paulo, P.L.; Galbiati, A.F.; Filho, F.J.C.M.; Bernardes, F.S.; Carvalho, G.A.; Boncz, M. Evapotranspiration tank for the treatment, disposal and resource recovery of blackwater. *Resour. Conserv. Recycl.* **2019**, *147*, 61–66. https://doi.org/10.1016/j.resconrec.2019.04.025.
133. Loo, L.; Guenther, R.H.; Basnayake, V.R.; Lommel, S.A.; Franzen, S. Controlled Encapsidation of Gold Nanoparticles by a Viral Protein Shell. *J. Am. Chem. Soc.* **2006**, *128*, 4502–4503. https://doi.org/10.1021/ja057332u.
134. Hastings, A.; Clifton-Brown, J.; Wattenbach, M.; Mitchell, C.P.; Stampfl, P.; Smith, P. Future energy potential of *Miscanthus* in Europe. *GCB Bioenergy* **2009**, *1*, 180–196. https://doi.org/10.1111/j.1757-1707.2009.01012.x.
135. Zwierzchowska, I.; Fagiewicz, K.; Poniży, L.; Lupa, P.; Mizgajski, A. Introducing nature-based solutions into urban policy—Facts and gaps. Case study of Poznań. *Land Use Policy* **2019**, *85*, 161–175. https://doi.org/10.1016/j.landusepol.2019.03.025.
136. Seddon, N.; Chausson, A.; Berry, P.; Girardin, C.A.J.; Smith, A.; Turner, B. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philos. Trans. R. Soc. B Biol. Sci.* **2020**, *375*, 20190120. https://doi.org/10.1098/rstb.2019.0120.
137. Tiwary, A.; Godsmark, K.; Smethurst, J. Field evaluation of precipitation interception potential of green façades. *Ecol. Eng.* **2018**, *122*, 69–75. https://doi.org/10.1016/j.ecoleng.2018.07.026.

138. Himeur, Y.; Rimal, B.; Tiwary, A.; Amira, A. Using artificial intelligence and data fusion for environmental monitoring: A review and future perspectives. *Inf. Fusion* **2022**, *86-87*, 44–75. https://doi.org/10.1016/j.inffus.2022.06.003.
139. Sekulova, F.; Anguelovski, I.; Kiss, B.; Kotsila, P.; Baró, F.; Palgan, Y.V.; Connolly, J. The governance of nature-based solutions in the city at the intersection of justice and equity. *Cities* **2021**, *112*, 103136. https://doi.org/10.1016/j.cities.2021.103136.
140. Nunes, N.; Björner, E.; Hilding-Hamann, K.E. Guidelines for Citizen Engagement and the Co-Creation of Nature-Based Solutions: Living Knowledge in the URBiNAT Project. *Sustainability* **2021**, *13*, 13378. https://doi.org/10.3390/su132313378.
141. Kotsila, P.; Anguelovski, I.; Baró, F.; Langemeyer, J.; Sekulova, F.; Connolly, J.J. Nature-based solutions as discursive tools and contested practices in urban nature's neoliberalisation processes. *Environ. Plan. E Nat. Space* **2020**, *4*, 252–274. https://doi.org/10.1177/2514848620901437.
142. Wamsler, C.; Alkan-Olsson, J.; Björn, H.; Falck, H.; Hanson, H.; Oskarsson, T.; Simonsson, E.; Zelmerlow, F. Beyond participation: When citizen engagement leads to undesirable outcomes for nature-based solutions and climate change adaptation. *Clim. Change* **2020**, *158*, 235–254. https://doi.org/10.1007/s10584-019-02557-9.