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Spatial Synergies: Between Humans and Non-Human Citizens: A Critical Literature Review

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Abstract

This paper addresses the historical oversight of architectural design and urban planning, where architectural and urban planning endeavors were exclusively tailored for human occupancy, often at the expense of indigenous species. This shortsighted approach has caused massive ecosystem changes, resulting in an explosive imbalance that reverberates through land, air, and water systems, culminating in the spectrum of global climate change. Focusing on the "Spatial Synergy" concept, the paper establishes a mutual dialogue between architecture and nature, underscoring their interdependence for attaining environmental justice. It explores the living cycle between humans and non-humans, emphasizing environmental and ecological impacts, and then examines psychological and economic ramifications on spatial design. This study investigates the gap between human-centric architectural designs and the needs of non-human inhabitants, aiming to develop a framework that addresses both. We identify critical knowledge gaps by analyzing historical oversights and current practices and propose a synergistic architectural approach. Methods include a comprehensive review of existing literature and case studies. Our results reveal that integrating detailed biodiversity data into design processes leads to environments that better support local ecosystems, marking a significant shift from conventional practices toward regenerative design. The implications suggest shifting from sustainable to regenerative design principles is essential for creating healthier urban landscapes.

Keywords*:* Spatial Synergy; Environmental Justice; Biodiversity; Synergistic architecture.

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1. Introduction

"*I am who I am. You perceive my existence through your own eyes, often taking me for granted and failing to grasp how vital I am to your survival. I am your neighbor who is constantly striving to provide the best for you, yet you choose to destroy me. You encroach upon my home, disrupt my climate, and misunderstand my needs. All I ask is to be treated respectfully as your neighbor, guest, and independent entity*." If nature could express its feelings in words, this might be its plea.

This reflection embodies the profound disconnection that has grown between humanity and the natural world. Since the onset of the Industrial Revolution, our relationship with nature has become increasingly fractured, from architectural design and urban planning to the intimate spaces within our homes. The era of industrialization marked a seismic shift in how we interact with our environment, with buildings and urban spaces being designed with a singular focus on human needs—often at the expense of the ecosystems they disrupted. This anthropocentric approach has resulted in significant ecological imbalances,

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manifesting in climate change, biodiversity loss, and the degradation of natural resources. Current architectural and urban planning practices, while evolving, continue to prioritize human convenience over ecological balance. Studies by Beatley & Newman (2013) and Soga & Gaston (2016) highlight the urgent need for a paradigm shift towards more inclusive and ecologically harmonious design principles. However, despite these calls, a critical gap remains in the practical implementation of such principles, particularly in the integration of non-human needs into the architectural design process.

This paper addresses this gap by exploring the concept of "spatial synergy"—a mutual dialogue between architecture and nature that underscores their interdependence, unlocking potential benefits such as enhanced biodiversity, improved human well-being, and resilient ecosystems.

“Spatial synergy is crucial for ensuring that architectural practices not only meet the needs of present generations but also contribute to the resilience and sustainability of future urban environments. By integrating natural systems into architectural design, spatial synergy offers a pathway to creating spaces that are adaptable, regenerative, and supportive of both human and ecological health.”.

Through an examination of historical oversights and contemporary practices, we seek to highlight the need for a fundamental shift in design paradigms towards nature-inclusive guidelines that respect and integrate the diversity of the natural world.

In summary, this paper argues for a reconceptualization of architectural practice that not only acknowledges but actively incorporates the needs of both human and non-human inhabitants. This study is driven by the urgent need to address the gap between human-centric architectural design and the ecological requirements of non-human species. The current environmental crisis, characterized by biodiversity loss and climate change, demands an innovative approach to urban planning. By proposing a new framework that integrates detailed biodiversity data into the design process, we aim to transform urban spaces from environments of exclusion into vibrant ecosystems that support life in all its forms. This shift, illustrated in the methodology graph (Figure 1), highlights the crucial role of biodiversity mapping, regenerative design principles, and the use of natural materials in creating adaptable and resilient environments. This transition from traditional to synergistic architecture is not just a response to the ecological crisis but a necessary step toward achieving environmental justice and sustainability in the built environment.

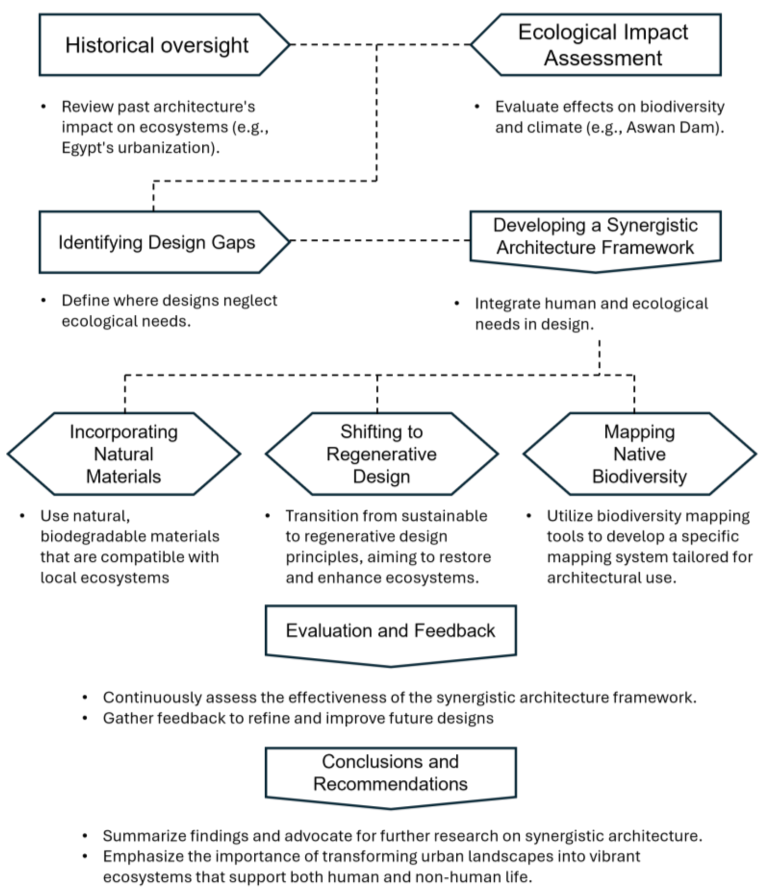

Figure 1. Research Methodology and Framework Diagram.

Following this framework, the study seeks to answer the following research questions:

1. How can architectural practices integrate the ecological needs of non-human species while fulfilling human requirements?
2. What role does biodiversity play in enhancing the sustainability and resilience of urban environments?
3. How can architectural design shift from sustainable to regenerative practices to restore ecological balance in urban areas?

A. Material & Method

2. Historical Overview: Nature's Narrative

For centuries, nature has silently observed the unfolding drama of human progress, its voice often drowned out by the relentless march of development. As humans advanced, their relationship with nature shifted from coexistence to dominance. Forests were felled, rivers were dammed, and land was stripped of vitality. This relentless exploitation has degraded ecosystems and disrupted the delicate balance that sustains all life forms.

In Egypt's case study, rapid development and urbanization have led to the degradation of green areas. Historically, Egypt was celebrated for its lush Nile Valley, a verdant ribbon of life amidst the desert. However, urban growth and industrial activities have steadily encroached upon this green expanse over the decades (Figure 2).

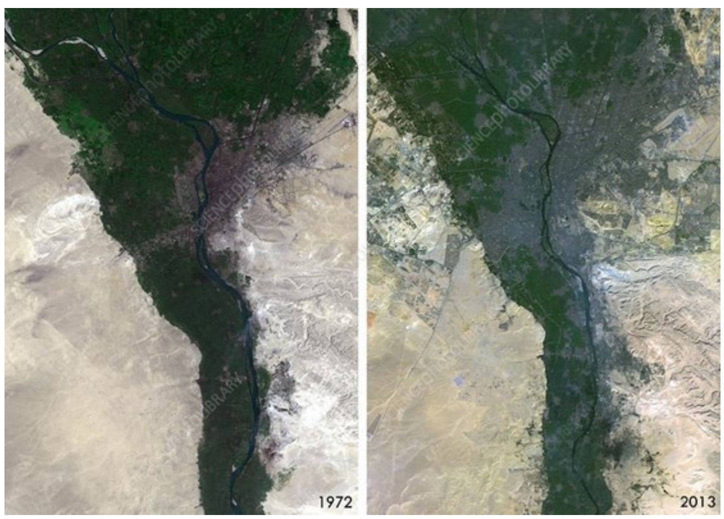

Figure 2. Satellite images of Cairo from 1972 and 2013 highlight the significant urban expansion (grey) encroaching upon the surrounding countryside (green). The Nile River (black) remains a central feature, flowing through the city centre. (Image credits to PLANETOBSERVER / SCIENCE PHOTO LIBRARY)

The construction of the Aswan High Dam in the 1960s, while a monumental achievement in controlling the Nile's flooding and generating hydroelectric power, had profound ecological consequences. El-Batrawy et al. (2014) provide additional insights into the socio-environmental impacts of dam constructions, including changes in agricultural patterns and loss of habitats. The dam disrupted the natural silt deposition that fertilized the land, leading to a decline in soil fertility and the loss of wetlands, crucial habitats for diverse species (Stevens, 2012).

This urbanization has exacerbated environmental problems such as air pollution, water scarcity, and heat islands. Reducing green areas has also diminished vegetation's natural cooling effect, leading to higher temperatures and reduced air quality in urban centers. These environmental changes directly impact Egypt's urban population's natural and human health and well-being, highlighting the intricate link between human and ecological health.

Egypt's case is one among many others that are mere examples of how disconnection from nature can cause problems. However, the question remains: What is the main issue behind this?

3. The Gap: Nature’s Perspective

The disconnection between nature and architecture in contemporary cities is primarily driven by a critical gap rooted in criticism of the one-way human perspective. This perspective, which focuses solely on human needs and desires, neglects nature's essential requirements, impacts, and effects. Human-centered designs often ignore the ecological and environmental aspects crucial for sustainable living. Although, in some design movements, nature, as a green element, is considered in the design, it is not considered part of the prime focus of design.

The relentless urban expansion and the prioritization of economic growth over ecological balance have exacerbated this issue, leading to degraded green spaces and biodiversity loss (Beatley & Newman, 2013; Soga & Gaston, 2016). Research by Seto et al. (2012), further illustrates how urban land expansion globally contributes to significant biodiversity loss (Figure 3). Their study projects that urban areas will triple in size by 2030, with the most extensive growth occurring in biodiversity hotspots such as Southeast Asia, South America, and sub-Saharan Africa. This expansion threatens over 10% of all known species, particularly in regions that are rich in species but poor in protected areas. The research highlights that nearly 60% of the projected urban expansion will occur in these biodiversity hotspots, potentially leading to the extinction of many endemic species if current trends continue. This narrow viewpoint has resulted in a built environment that marginalizes nature, treating it as an afterthought rather than an integral component. If given a voice, nature would criticize human architecture for failing to incorporate natural elements and ecosystems as fundamental parts of its structure, emphasizing that this oversight has significantly widened the gap between urban development and ecological harmony.

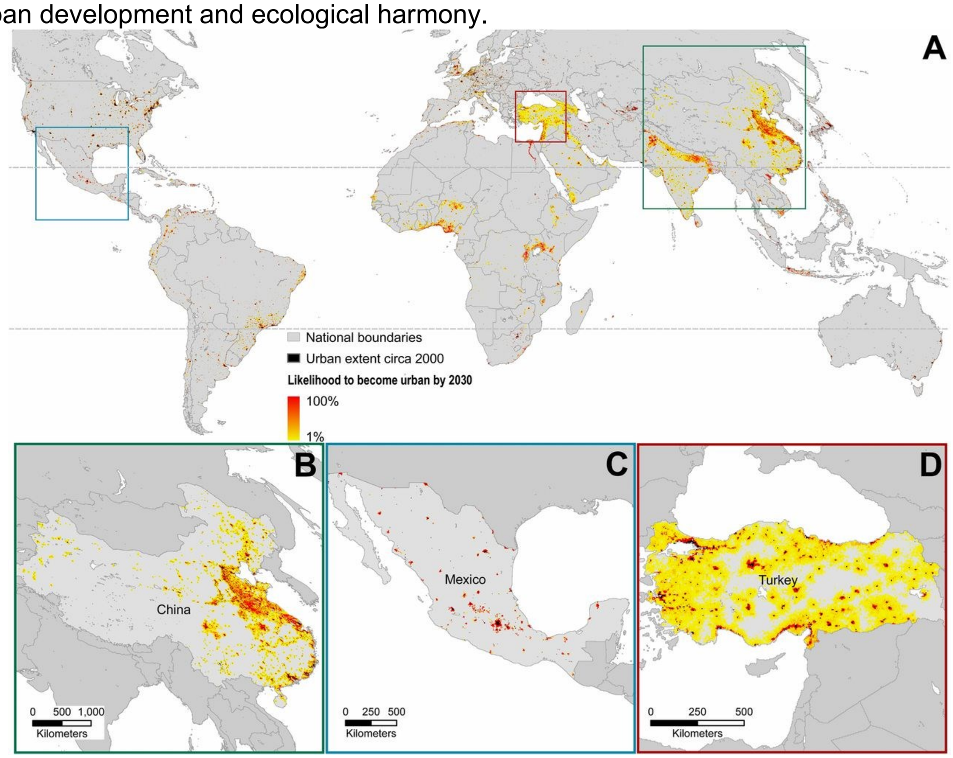

Figure 3. Projected Urban Expansion and its Impact on Biodiversity Hotspots by 2030. (by K. C. Seto, B. Güneralp, and L. R. Hutyra, 2012).

3.1. The Boundaries: Nature's Prison

Nature's first and most significant issue with our architecture is the imposition of boundaries and limitations. As human beings, our instinct to protect ourselves manifests in creating barriers and boundaries, which is evident even in our personal and psychological spaces. We set invisible boundaries between each other and within ourselves, forming limits we do not cross (Altman, 1975). Consequently, it is no surprise that we construct boundaries in architecture, urban spaces, and cities, prioritizing barriers even in public spaces. For example, gated communities and urban zoning laws illustrate how architecture often segregates and restricts access, contrasting sharply with ecosystems' open and interconnected nature (Newman & Kenworthy, 1999).

In contrast, nature operates without such confines. Natural ecosystems have no rigid boundaries. Each organism depends on others in an open symbiotic cycle. This symbiotic cycle involves mutual dependencies where plants, animals, and microorganisms interact and support each other's growth and survival. For example, trees provide oxygen and animal habitats, aiding pollination and seed dispersal and contributing to biodiversity and ecological balance (Margulis & Sagan, 1986). Nature's capacity to grow and adapt is limitless, constantly evolving in shape, colors, and form. Unlike human architecture's static and segmented nature, natural environments demonstrate resilience and flexibility, with ecosystems constantly adapting to changes and disturbances. This fundamental difference creates a dissonance between human architectural practices and the inherent fluidity of natural systems, leading to conflicts and environmental degradation.

3.2. Human-Centric Design: Nature's Exclusion

(The second issue is the exclusivity of architecture to humans, which, while understandable given that humans are the primary users of these spaces, often neglects the needs of non-human inhabitants. Architectural designs are meticulously tailored to meet human needs and comfort, yet this anthropocentric focus overlooks the requirements of other species. For instance, the rise of sustainable and green architecture that fosters coexistence with nature has led to the inclusion of green habitats within built environments. However, these efforts often fall short because they fail to consider the specific needs of these habitats. Materials used in green architecture frequently inhibit natural growth, restricting roots and stems and limiting the potential for proper ecological integration (Beatley, 2016; Kellert et al., 2008).

An example of this oversight is the implementation of green roofs and vertical gardens. While these innovations are steps towards integrating nature into urban spaces, they often use materials not conducive to long-term plant health. The shallow soil depths and restrictive root environments can stunt plant growth and reduce biodiversity, turning what should be thriving ecosystems into decorative yet ecologically sterile features (Oberndorfer et al., 2007). Moreover, the design of these green spaces sometimes prioritizes aesthetics over functionality, choosing plants based on visual appeal rather than ecological suitability, further undermining their effectiveness (Dunnett & Kingsbury, 2008).

Another example is the creation of urban parks and green corridors intended to provide habitats for wildlife within cities. However, the fragmented and isolated nature of these green spaces often fails to support sustainable populations of many species. Without proper connectivity, these areas can become ecological traps, where animals are attracted to habitats that are ultimately unsuitable for long-term survival (Forman, 2014).

We miss opportunities to create genuinely symbiotic environments supporting all life forms by viewing these spaces through a purely human lens. This compartmentalization results in environments that resemble divided plates, where different elements coexist without interaction or connection, undermining the holistic benefits of biodiversity (Thompson & Sorvig, 2018).

3.3 The Disconnection: Nature's Abandonment

The third significant issue is the lack of connection and communication between humans and non-humans, both physically and emotionally or psychologically. This relationship is typically one-sided, heavily favouring humans, while non-humans are expected to continuously provide benefits without receiving anything in return. This dynamic reflects a lack of respect for non-human entities' natural existence and needs. For instance, urban planning and architecture often disregard the habitats of local wildlife, leading to fragmented ecosystems and diminished biodiversity (Bettencourt & Kaur, 2011). Psychological disconnection is equally troubling, as the diminishing interaction with nature has been linked to a phenomenon known as "nature-deficit disorder," which can lead to a range of adverse mental health outcomes (Louv, 2008).

The physical disconnection is evident in the way modern cities are designed. Green spaces are often isolated pockets rather than integrated parts of the urban fabric, limiting the opportunities for humans to engage meaningfully with nature. For example, in many different urban environments, parks and natural reserves are designed more for human recreation than ecological sustainability, often resulting in manicured lawns and ornamental plants that provide little ecological value (Beatley, 2016).

Emotionally and psychologically, this disconnection manifests in undervaluing nature's intrinsic worth. Studies have shown that exposure to nature can significantly enhance human well-being, reducing stress and improving mental health (Capaldi et al., 2015). However, when the natural world is only seen as a resource to be exploited, its role in supporting human emotional and psychological health is ignored. The anthropocentric viewpoint overlooks the mutual benefits of a balanced relationship, where humans and nature coexist and support each other.

Reflecting on the case of Egypt, the intersection of boundaries, human-centric decisions, and nature disconnection has profoundly shaped the current environmental challenges. The relentless expansion of urban areas, as evidenced by the dramatic increase in Cairo's urban footprint from 1972 to 2013, illustrates the imposition of rigid boundaries that fragment and degrade natural habitats. This urban sprawl has encroached upon valuable green spaces and disrupted the delicate ecological balance, significantly losing biodiversity and ecosystem services. Human-centric architectural practices further exacerbate this issue by prioritizing human needs and comfort while neglecting the needs of non-human citizens. For example, the construction of the Aswan High Dam, while providing significant benefits for agriculture and hydroelectric power, resulted in the displacement of communities and wildlife, altering the natural flow of the Nile and leading to substantial ecological consequences (Scudder, 2016; Stanley & Warne, 1993). Additionally, ongoing settlement expansion over fertile agricultural lands reduces Egypt's already scarce arable land, exacerbating food security issues and diminishing natural habitats (Attia, 2009; Shalaby & Tateishi, 2007). The psychological and physical disconnection from nature, driven by a lack of integrated green spaces and a predominant focus on human utility, has diminished appreciation for nature's intrinsic value and critical role in human well-being.

Given these challenges and the pressing need to address the ecological imbalances created by traditional practices, this paper proposes a framework for synergistic architecture that integrates the needs of both human and non-human inhabitants.

B. Analysis and Findings

4. Shifting narratives: Turning tables to the Favor of nature

"*What we, nature, really need from architecture is respect and understanding for our diverse nature and needs*." On behalf of Nature.

This call to action emphasizes the necessity for integrating the diverse needs of nature into architectural design as a prime element. The manifestation of new guidelines where architects and designers move beyond authoritarian thinking and embrace complex systems thinking is essential to creating a synergy between humans and non-humans. This approach, termed "synergistic architecture," is defined as architecture for the ecosystem, representing the interlocking missing piece between human architecture and "non-human architecture" (Ewida, 2021).

Synergistic architecture prioritizes the ecosystem's needs, ensuring that designs are sustainable and regenerative, fostering an environment where both humans and non-humans can thrive. Recent work by Kellert and Calabrese (2015) highlights the importance of biophilic design in fostering human-nature connections in built environments. Their research emphasizes that biophilic design not only improves the psychological well-being of individuals by reducing stress and enhancing mood but also contributes to physical health by improving air quality, natural lighting, and indoor vegetation. These elements mimic natural environments, helping to restore a sense of connection to nature that is often lost in urban settings. Furthermore, Kellert and Calabrese demonstrate that biophilic design can enhance cognitive function and creativity, making it a critical component of workspaces, educational environments, and healthcare facilities. By integrating natural forms, materials, and spaces into architectural design, biophilic design fosters a deeper, more meaningful connection between humans and their environment, ultimately contributing to both environmental sustainability and human well-being. This shift necessitates a fundamental change in design strategies, guidelines, and materials. Respect and understanding of the diversity of nature and its needs must become central to architectural practice. To achieve this, we need to address the important role that biodiversity in enhancing sustainability by understanding the surrounding ecology, native organisms, and their current states. This can be facilitated by mapping out the native flora and fauna to become part of the project analysis and a prime parameter in the design. Second, there is a need to shift from sustainable to regenerative thinking processes to accommodate the added parameters. Lastly, to fully accommodate native nature within complex integration systems, we must transition from traditional building materials and construction methods to more liveable natural biomaterials and intelligent construction methods.

4.1. Mapping Native Nature

Integrating native nature into architectural design necessitates a robust mapping system to effectively understand and incorporate diverse ecological elements. One of the most renowned systems for biodiversity mapping is the Global Biodiversity Information Facility (GBIF). GBIF is an international network and data infrastructure funded by the world's governments, aimed at providing open access to data about all types of life on Earth. It enables users to search and download information on where and when species have been recorded globally, making it an invaluable tool for biodiversity research and conservation (GBIF, 2023).

GBIF aggregates data from numerous sources, including natural history collections, research projects, and citizen science observations. It allows for the comprehensive mapping of species distributions and can identify critical habitats and biodiversity hotspots. Similar systems include the Biodiversity Heritage Library (BHL) and the Encyclopaedia of Life (EOL), both of which compile extensive biodiversity data from various sources to aid in research and conservation efforts (BHL, 2023; EOL, 2023).

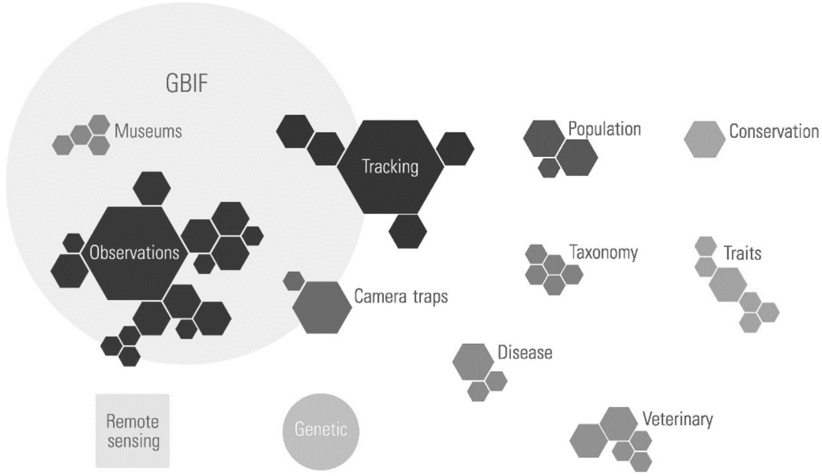

Figure 4. Illustration Major components of the Internet of Animals (IoA) are now online. (By R. Kays, 2023)

The figure above (Figure 4) illustrates the various components and data sources that feed into GBIF, such as museums, observations, tracking systems, camera traps, and taxonomic studies. These interconnected elements contribute to a holistic understanding of biodiversity by providing diverse and comprehensive data points. Drawing inspiration from these systems, we propose a specific mapping system designed for architectural use. This system would serve as a vital tool for architects and designers, providing detailed data on native flora and fauna to guide the integration of natural elements into built environments. Given the limitations on which organisms can be directly incorporated into architectural designs, this system would help identify which species can be included and how they interact with other organisms in a symbiotic manner. For example, a design might include a habitat for a specific organism that produces food or has a symbiotic relationship with another species, thereby creating a diverse and interconnected ecological network within the architectural framework. To streamline this process, we advocate integrating data from GBIF and similar platforms with Materiom, a biomaterial exploration platform (Materiom, 2023). This innovative AI-aided analytical platform would continuously update, analyze, and match data from these sources. It simplifies access to biodiversity data for architects and designers, providing insights into selected organisms' biology, needs, and requirements. Moreover, the platform suggests suitable bio-building materials tailored to each organism, considering regional climate conditions and other analytical parameters crucial in the pre-design stage for concept generation (Figure 5).

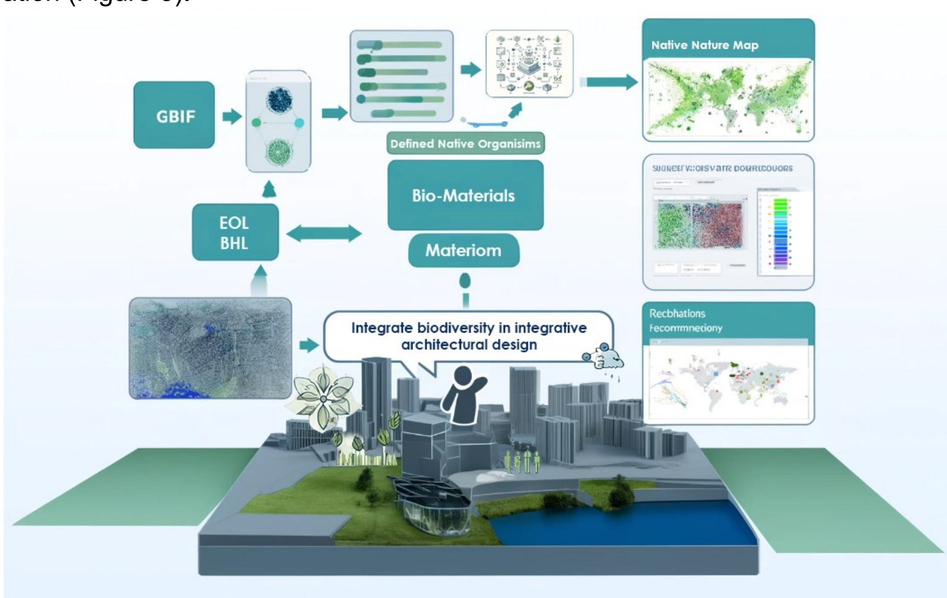

Figure 5. AI-Aided Platform Interface for Integrating Biodiversity into Architectural Design (Figure generated using AI ChatGPT-4o, 2024) .

By leveraging a nature mapping system tailored for architecture, designers can ensure that their projects effectively support and enhance local biodiversity. This data-driven approach informs decisions on species inclusion, habitat creation, and material selection, facilitating the harmonious integration of nature into architectural projects that meet human and ecological needs.

4.2. From Sustainable to Regenerative Thinking

After understanding and mapping nature, the next crucial step is shifting from sustainable to regenerative thinking. Nature is inherently unpredictable, with an extraordinary ability to adapt and shift according to continuous changes. Therefore, focusing on the design process rather than the final shape is essential. Architects, planners, and designers must move beyond the prescriptive way of thinking they have learned and embrace complex systems thinking. This approach comprehends how natural systems work and aligns with the regenerative design process, providing a solid starting point for innovative, adaptable designs.

Sustainable architecture, while beneficial, often focuses primarily on reducing negative impacts—aiming to make buildings 'less bad' by minimizing resource use and reducing waste. However, this approach can fall short because it typically aims for a zero-impact outcome, which, as illustrated below (Figure 6), means merely mitigating harm rather than creating a positive impact. Sustainable design, represented in the left part of the diagram, strives to reduce the negative impacts of a project as much as possible. However, it does not necessarily contribute positively to the environment.

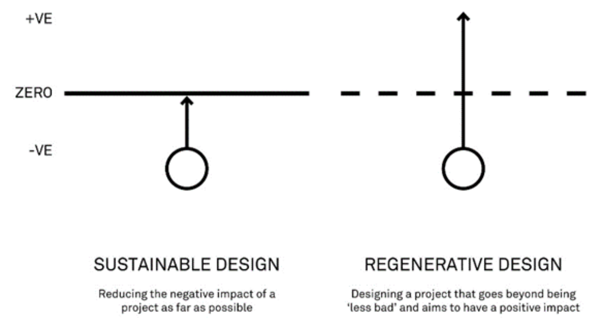

Figure 6. Illustration showing the key difference between sustainable design limitations and how they could be overcome with regenerative design (by Tate + co "What is regenerative design?").

In contrast, regenerative design takes a more comprehensive approach, aiming to create positive impacts beyond sustainability. Regenerative thinking bridges the gap by fostering systems that restore, renew, and revitalize their sources of energy and materials. It focuses on the dynamic interplay between the built environment and natural systems, ensuring that the final output is adaptable to all changes. This adaptability is critical to regenerative design, as it allows the built environment to evolve with natural systems, thereby maintaining ecological balance and promoting resilience.

For example, regenerative design might incorporate biomaterials and native flora elements where applicable. These elements promote coexistence and foster symbiotic relationships between humans and nature. By using locally sourced biomaterials, buildings can reduce their carbon footprint and support local ecosystems. Additionally, integrating native plants into the design can enhance biodiversity, improve air quality, and create local wildlife habitats, fostering a healthier and more sustainable environment (Mang & Reed, 2012; Lyle, 1994).

To truly integrate regenerative principles, the design process must be fluid, iterative, and deeply rooted in understanding natural systems. This means architects and designers must continuously interact with the environment, learning and adapting their methods to create structures that coexist with nature and enhance it. By doing so, they can develop buildings and spaces that are resilient, self-sustaining, and beneficial to all forms of life.

4.3. From Artificial to Natural

Shifting from artificial to natural materials is critical in creating bio-inclusive architecture. To ensure the perfect synergy between human and non-human inhabitants, switching to materials catering to both parties' needs is vital. This shift involves a comprehensive understanding of the compatibility of materials with native organisms, land ecology, climate, and the broader ecosystem. With the help of the AI-aided bioanalytical platform and considering all the mentioned factors, architects can ensure their projects' natural sustainability and adaptability, effectively transforming "dead concrete jungles" into livable forests.

Incorporating biomaterials—such as mycelium-based composites, bamboo, and other locally sourced natural materials—supports the growth of native flora and fauna. These materials are biodegradable, renewable, and often have lower embodied energy than traditional construction materials like concrete and steel. For instance, mycelium composites can be used to create building insulation or interior panels that are not only environmentally friendly but also promote the growth of fungi, which in turn supports a range of other organisms (Jones et al., 2020).

One notable project that manifests livable architecture and the integration of natural materials is the "Bio-Integrated Design Lab" from the University College London (UCL). This project exemplifies how bio-integrated design can synergize human-made structures and natural ecosystems.

The Bio-Integrated Design Lab focuses on integrating living organisms into architectural structures to enhance ecological performance and sustainability. One of their flagship projects involves using algae to create bio-facades (Figure 7). These facades provide insulation and aesthetic appeal and contribute to air purification and energy generation through photosynthesis. The algae panels absorb CO2 and produce oxygen, turning buildings into living, breathing entities that interact positively with their environment (Evans et al., 2020).

Figure 7. 3D Printed Algae Panels showcasing an innovative approach to bio-integrated architectural design that supports biodiverse sustainability (by The Bio integrated lab UCL, 2023)

Incorporating such innovative bio-integrated designs supports the growth of native flora and fauna. These materials are biodegradable, renewable, and often have lower embodied energy than traditional construction materials like concrete and steel. For instance, mycelium composites can be used to create building insulation or interior panels that are not only environmentally friendly but also promote the growth of fungi, which in turn supports a range of other organisms (Jones et al., 2020).

By adopting natural materials, architects can create buildings more attuned to the local environment, providing habitats for various species and enhancing the overall ecological resilience of urban areas. This approach benefits the environment and creates healthier and more engaging spaces for human inhabitants, fostering a deeper connection with nature.

5. Conclusions

This paper highlights the critical need to bridge the gap between human-centric architectural designs and the ecological requirements of non-human inhabitants. We began by exploring how architectural practices can integrate the ecological needs of non-human species alongside human requirements. This was addressed through the incorporation of biodiversity mapping and ecological analysis into the design process, which allows architects to create spaces that serve both humans and local ecosystems. From there, we examined the role of biodiversity in enhancing the sustainability and resilience of urban environments. By fostering biodiversity within architectural designs, urban spaces can become more adaptable and resistant to environmental pressures such as climate change, thereby promoting long-term sustainability. Finally, we considered how architectural practices can shift from sustainability to regeneration, where designs not only minimize harm but actively restore ecological balance. This transition is made possible using regenerative materials and design approaches that prioritize the rejuvenation of natural systems. Each of these interconnected findings supports the broader goal of developing synergistic architectural practices that foster harmony between human and non-human species, ensuring the resilience and sustainability of urban environments.

5.1. Key insights from this study include:

1. **Historical Impact**: The shift from coexistence to domination in human-nature relationships has led to significant ecological consequences, such as biodiversity loss and climate change. These findings support the hypothesis that human-centric design practices have been detrimental to ecological balance.
2. **Identified Gaps**: The disconnect between architecture and nature is primarily driven by human-centric designs that neglect ecological needs. This oversight has resulted in environments that

marginalize nature, leading to degraded ecosystems and a diminished capacity for ecological resilience.

3. **Proposed Solutions**: It is crucial to adopt synergistic architecture, which incorporates the needs of both humans and non-humans. This involves mapping native flora and fauna, shifting from sustainable to regenerative design principles, and using natural materials compatible with local ecosystems. By integrating detailed biodiversity data into the design process, architects can create dynamic, adaptable environments that support and enhance local biodiversity. The transition from artificial to natural materials further ensures that architectural projects sustain and rejuvenate ecosystems.

5.2. Practical Implications: To ensure the successful implementation of the proposed synergistic architecture framework in real-world scenarios, it is crucial to integrate these concepts into existing urban planning and architectural workflows. Urban planners and architects should leverage biodiversity mapping tools, as discussed in Section 4.1, and collaborate with ecological experts to identify and preserve critical habitats within development sites. Moreover, updating building codes and sustainability standards to include regenerative materials and construction practices can facilitate the widespread adoption of these principles. By embedding these strategies into the fabric of urban development, the framework not only becomes a theoretical ideal but also a practical approach to fostering sustainable and resilient built environments.

5.3. Contribution to Literature: This study contributes to the existing body of knowledge by challenging the traditional human-centric approach in architecture and advocating for a paradigm shift toward nature-inclusive design principles. The proposed framework for synergistic architecture offers a practical solution for integrating ecological considerations into the architectural design process, thereby advancing the field of synergistic architecture. Unlike previous studies that primarily focus on sustainable design, this study emphasizes a shift towards regenerative practices that actively restore and enhance ecosystems, setting a new direction for synergistic architecture.

5.4. Suggestions for Future Research: Future research should explore the application of this framework across various geographic and climatic contexts to evaluate its adaptability and effectiveness. Additionally, studies could investigate the long-term ecological and social impacts of implementing synergistic architecture on a broader scale. Research might also focus on refining methods for mapping native species and developing innovative biomaterials that better integrate with local ecosystems.

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Conflicts of interest
The Authors declare that there is no conflict of interest.

Data availability statement
The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding authors/s.

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