IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Applications of biomimicry to urban planning: interrogating the relevance of emerging approaches to design cities by inspiring from nature.

To cite this article: Sofiane Madmar *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1274** 012015

Applications of biomimicry to urban planning: interrogating the relevance of emerging approaches to design cities by inspiring from nature.

Sofiane Madmar[1], Muhammad Zaly Shah[2], Ak Mohd Rafiq Ak Matusin[2], Amil Ahmad Ilhan[3]

[1]ENTPE Lyon, 3 Rue Maurice Audin, 69120 Vaulx-en-Velin, France
[2]Center for Innovative Planning and Development (CIPD), Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Skudai, 81310, Johor, Malaysia
[3]Faculty of Engineering, Universitas Hasanuddin, Makassar, Sulawesi, Indonesia

E-mail: sofiane.mad30@gmail.com

Abstract. Cities have an important role to play in tackling the challenges of climate change and the depletion of biodiversity. The way they were built has had a significant impact on biological and terrestrial systems. In this regard, a new generation of urban planners is attempting to address this problem by inventing new urban models, especially using biomimicry to create a real paradigm shift in the discipline. Nonetheless, it introduces a fresh perspective that refrains from viewing nature merely as a supplier of resources and energy, but instead recognizes it as a rich wellspring of wisdom. This approach is now unfolding in the realm of cities and territories as intricate systems. In fact, biomimicry is seen as a means towards more virtuous development models, aiming at the regeneration and resilience of living spaces in symbiosis with the environment. Researchers and theorists have put forth diverse ideas and concepts to incorporate the principles derived from nature into urban projects. However, several challenges are raised when trying to mimic how a biological system works to plan cities which are much more complex due to human social attributes. Although there are a few current examples of biomimicry being applied to urban planning, they need to be assessed to determine if this approach is relevant, particularly in the social field. This study employs a qualitative approach whereby the narrative review of literature has been applied which focusing on the applicability and impact of biomimicry in urban systems. Six-step framework for review articles are used to address three key research questions regarding the adoption of biomimicry principles in urban contexts. We aim to summarize and categorize the variety of applications of biomimicry to urban planning by the literature review method and to initiate an inquiry into their relevance and utility in responding to contemporary urban challenges.

1. Introduction

In the face of global challenges like climate change and biodiversity loss, cities across the world find themselves grappling with the imperative to respond urgently. The way we have constructed our urban environments has had a profound influence on the delicate balance of biological and terrestrial systems, exacerbating these pressing issues. This predicament has even been described as the "Great Acceleration," as articulated by Steffen et al. [1]. It is evident that the problem at hand is systemic, demanding that our solutions be equally comprehensive and holistic in nature. Cities worldwide are struggling with the urgent need to address the interconnected challenges of climate change and biodiversity loss. Figure 1 provides a visual representation of the temporal trends spanning over a significant period, from 1750 to 2010. This comprehensive depiction showcases a diverse set of indicators that effectively capture and convey the changes occurring in the structure and functioning of the Earth System. By analyzing these indicators, we gain valuable insights into the complex and dynamic nature of our planet's ecological and environmental transformations over time.

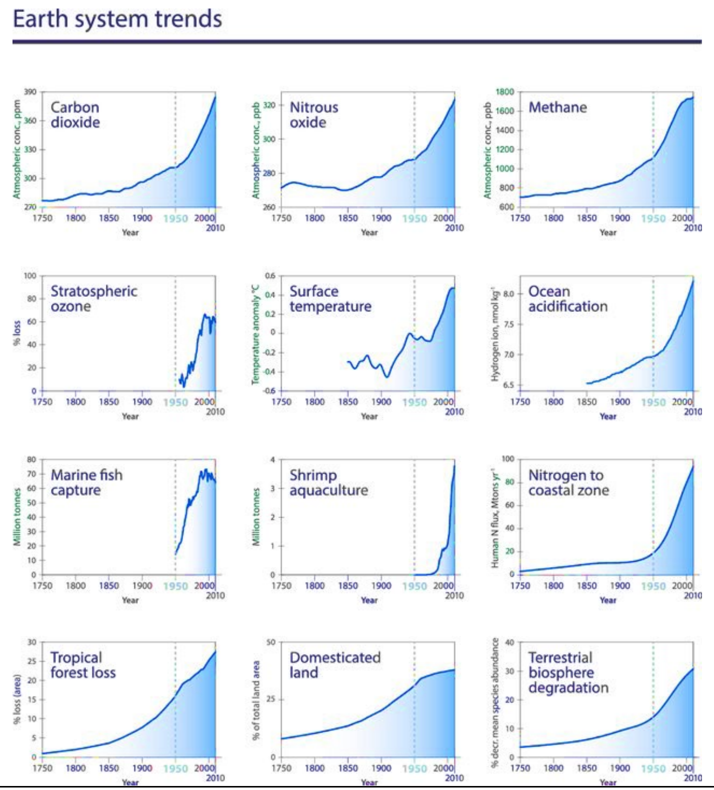

Figure 1. Trends from 1750 to 2010 in indicators for the structure and functioning of the Earth System. [1]

In order to tackle these issues, a new generation of urban planners has emerged, driven by a vision to revolutionize traditional urban models and forge a more sustainable path forward. Among the innovative approaches gaining traction, biomimicry stands out as a promising and alternative paradigm shift within the discipline.

Derived from the Greek roots' "bio" meaning life, and "mimesis" meaning imitation, biomimicry refers to drawing inspiration from living organisms or nature to find innovative solutions to human problems. According to Benyus [2], biomimicry is the conscious emulation of the genius of living organisms. It is not about copying without reason what nature looks like, nor is it about bio-utilization, which means using elements of nature as they are. The emulation in biomimicry is conscious, meaning that the process of abstraction or analogy between a natural element and a technological solution is intentional. The genius of nature, as described by Benyus, includes organisms, processes, or ecosystem functioning principles that work and endure over time. Biomimics, practitioners of biomimicry, search what works in nature and, most importantly, what endures. Lessons provided by nature, strategies developed and refined over billions of years, remained scientific curiosities unrelated to our respective existences. Thus, biomimicry is based on the hypothesis that everything in nature is the result of optimization that would allow humans to save time in research and development by drawing inspiration from living solutions. Mimesis, according to Benyus, is desirable and sought after to bring the technosphere and the biosphere into symbiosis or at least compatibility. Nature, imaginative by necessity, has already solved the problems we strive to solve. Our challenge is to resonate these ideas, which have stood the test of time, in our own lives [2],[3].

The foundations of biomimicry can be summarized in three main principles: (i) "Nature as model," which establishes the study of nature's patterns and their imitation as a basis for meeting human needs; (ii) "Nature as measure," which establishes ecological criteria as the measuring instrument to validate or reject the model; and (iii) "Nature as mentor," which presents nature as a teacher with whom we must act with humility. These three principles sufficiently describe biomimicry theoretically. Benyus also presents a typology of possible applications, including inspiration from forms, processes, and ecosystems. Biomimicry distinguishes itself from other approaches and ecological design in several aspects. In the field of problem-solving, exposure to biological examples has been suggested to increase the novelty of generated solutions, unlike those designed by humans, which reduce variety and innovation. This difference can be explained by the high level of abstraction required in analogizing with living systems, as well as the intrinsic characteristics of biology-inspired design. These characteristics include inherent transdisciplinarity, involving collaboration between biologists and design engineers to find innovative solution approaches. Communication between these two domains can present challenges due to their different languages and working methods. Furthermore, biomimicry is characterized by multifunctional and interdependent designs. Inspired by natural systems, it promotes the creation of designs that integrate multiple interconnected functions, resembling ecosystems. In summary, biomimicry stands out for its transdisciplinary vision, search for innovative solutions, consideration of interconnections, and pursuit of sustainability, distinguishing it from other approaches in the fields of design and ecology. However, the most evident distinction lies in its epistemology compared to other "bios" approaches [2],[4],[5].

When applied to cities and territories as systems, biomimicry is seen as a means to strive towards more virtuous models of development, aiming for the regeneration and resilience of living spaces in a reciprocal relationship with the living world [3],[5],[6]. Although few, current experiences of ecosystem-level biomimicry tend to show that drawing inspiration from living organisms in territorial planning are from two different types:

- Assimilation of ecosystem principles in the design and management of territorial projects, sometimes referred to as ecomimicry. For example, it can involve drawing inspiration from the symbiosis between living organisms to justify the implementation of more cooperative governance models.
- Representing the territory as a global ecosystem, that is, the association of an environment and living organisms contributing to the reproduction of that environment. This second type involves drawing inspiration from ecosystem exchanges, the socio-ecological processes and the ecosystem biophysical structure to design an urban project [7].

After doing a short epistemic analysis of Benyus's theories, this work proposes a discussion about the systemic approach in biomimicry which could help urban planners and designers to address sustainability. It will help to understand the benefits and inconveniences of urban biomimicry.

2. The concept of Biomimicry

In this section, we present a short historical context of Biomimicry apparition, and we explain its deeper epistemology which distinguishes itself from other ecological design approaches.

2.1. Historical context of Biomimicry

In the quest to address the challenges of ecological transition, some actors are turning to approaches that are both innovative and captivating. Biomimicry has found its place among the many new concepts and approaches. The history of biomimicry dates back thousands of years when humans observed and learned valuable lessons from nature to solve complex problems. Since the early days of humanity, observing nature has been a source of innovation [3]. The 1960s marked a turning point with the emergence of bionics, primarily focusing on robotics. Then, the term "biomimetics" was introduced by American biophysicist Otto Herbert Schmitt in 1963, defining the examination of biological phenomena in the hope of generating ideas and inspiration to develop physical or biophysical systems modeled after life. Over the following decades, biomimicry found resonance in various fields, including urbanism, landscape architecture, and industrial ecology. However, it was thanks to the innovative work of Janine Benyus in 1997 that the concept of biomimicry was refreshed and integrated the notion of sustainable innovations inspired by living organisms [3],[8].

Janine Benyus [2], a renowned American author, and graduate in forestry emphasized that the reductionist approach of the time did not allow understanding the deep relationships between elements of nature. In her book, she mentions how forestry students were encouraged to study each element of the forest separately. However, Benyus questioned this approach and wondered about a different perspective:

"What if, I wondered, I went back to university? Would I find researchers who had decided to observe organisms and ecosystems to draw inspiration and learn to live intelligently and less devastatingly for the Earth? Could I work with inventors or engineers who would delve into biology texts in search of ideas? Was there anyone in our time who would consider organisms and natural systems as the best teachers? Fortunately, I didn't find one, but many biomimics." (Benyus, 2011 p. 21, translated from French) [2].

In her search for researchers, inventors, and engineers who would draw inspiration from organisms and natural systems, she discovered numerous biomimics who recognized nature as the best teacher. She emphasized the importance of learning to live intelligently and less destructively for the Earth by drawing inspiration from nature. Despite the absence, at the time, of official movements, think tanks, and university degrees dedicated to biomimicry, Janine Benyus expressed her desire to see this idea spread:

"If I wrote this book, it was partly because I wanted to see this gene [the biomimetic approach] spread to the point of becoming the backdrop of our research in the next millennium." (Benyus, 2011, p. 22, translated from French) [2].

Thus, the history of biomimicry testifies to the evolution of our approach to nature, shifting from a reductionist understanding to a recognition of interdependence and valuable lessons that we can draw from nature to solve our most complex problems and develop sustainable innovations. This desire has borne fruit through books, international networks, working groups, conferences, and many other means of spreading the American naturalist's intuition.

2.2. Epistemological specificities of Benyusian Biomimicry

Engineers and designers throughout history have drawn inspiration from living organisms to conceive inventions [9]. However, the contemporary approach of biomimicry, theorized by Janine Benyus in 1997, focuses on sustainability. As seen earlier, the author defines the concept and its typology of applications and establishes a methodology. The approach she theorized is often described as a technological and philosophical paradigm shift. Indeed, this approach breaks away from the philosophy of technology, which traditionally rejects nature as chaotic and values human production of knowledge, where technologies are considered extranatural [4]. Biomimicry, on the other hand, views nature as an almost inexhaustible source of knowledge and adopts a humble attitude toward living.

Indeed, Henry Dicks (2018) [4] in an attempt to develop the philosophical concept, shows that the epistemological foundations of biomimicry, primarily the principle of "Nature as Mentor," represent a true rupture where knowledge is inherent to natural entities or systems and not merely a human description of them. Thus, biomimetic epistemology would be the branch of epistemology concerning the learning from nature, "from nature," rather than "about nature." The author also attempts to justify the relevance of this approach from an epistemological standpoint. He draws a parallel between biomimicry and natural sciences, where models are tested and validated through measurements, whereas biomimicry employs models from living organisms that are tested against the standards by which human-made systems or entities are evaluated. Thus, like Benyus, he argues that biomimicry is a science in its own right. The principle of "Nature as Measure" ensures that the solution adheres to ecological standards and the accuracy of innovation. Its three initial virtues are based on what works, what is appropriate, and what endures. They guarantee the effectiveness, adaptability, and resilience of solutions. Therefore, biomimetic human design is based on ecosystem standards. In summary, Dicks presents biomimicry as the science that produces "know-how" knowledge from nature, based on the dialectical interaction of model (Nature as Model) and measure (Nature as Measure). Table 1. summarizes how biomimicry differs from traditional epistemology in terms of its perspective on nature [4].

Table 1. Difference between traditional and biomimetic epistemology [4].

	Learning approach	Type of knowledge about nature	Source of knowledge

Traditional Epistemology	Learning about nature	Knowing-about (description)	Human cognition
Biomimetic Epistemology	Learning from nature	Knowing-how (mimicry)	Nature itself

Seen as an epistemological and philosophical rupture, this approach describes nature as an unlimited innovation potential and, at the same time, invites a new understanding of nature, no longer reducing it solely to the matter and energy it offers [4]. In this regard, biomimicry distinguishes itself from bioinspiration, biophilia, and bioclimatic engineering, although these semantically related terms are often confused. Although they are not incompatible, they are distinct design approaches. Therefore, Table 2. presents a summary of "what biomimicry is" and "what it is not" considering the numerous misuses of this term.

Table 2. Summary of what biomimicry is and what it is not.

	What biomimicry is	**What biomimicry is not**
Source of Knowledge	Nature itself	Human cognitive abilities
Object of the mimicry	The function (expressed as form, process, or system)	Appearance or aesthetics only
Knowledge production process	Modeling the function	Copying nature or Using nature without modeling the function
Objective of the inspiration process	Aiming optimality & sustainability	Business as usual
Rigor of the process	Dialectic between Model and Measure	Not rigorous process, only a poetic inspiration
Representation of nature	Nature as an endless source of knowledge	Nature as an endless source of resources

3. Methodology

This study employs a qualitative approach by conducting a literature review related to the given topics. Qualitative research is a method primarily concerned with comprehending concepts, thoughts, or experiences. In the context of a systematic review, a qualitative approach involves the inclusion and synthesis of the review process, which aims to collect, integrate, and interpret data from qualitative studies to achieve a deeper understanding of a specific phenomenon or research question [10]. In this study, a narrative review technique is specifically employed. A narrative review seeks to summarize and synthesize existing literature on a particular topic but does not aim to generalize or accumulate knowledge from the reviewed sources [11]. To implement the qualitative approach, this study follows the six generic steps outlined by Templier and Pare [12] for conducting a review article:

- Formulating the research question(s) and objective(s).
- Searching the existing literature.
- Screening for inclusion.
- Assessing the quality of primary studies.
- Extracting data.
- Analyzing data.

In accordance with the research aim, three primary research questions have been formulated:

- Can the concept of biomimicry be applied to urban systems?
- How is the concept of biomimicry applied to urban systems?
- What are the benefits and challenges of applying biomimicry to urban systems?

In this regard, some reported works have been selected to analyze the existing study cases of systemic approach in the built environment. This selection is based on three criteria. The first is the availability of paper, only open access papers have been chosen. The second is the presence of ecosystem-level biomimicry applied at a neighborhood-scale or a city-scale, so we can think about the analogy between biological systems and social systems. The last criterion is about the presence of a real analysis of the study cases presented, at the opposite of a simple description. Finally, three articles have been highlighted as regard to these three criteria:

- Blanco E, Pedersen Zari M, Raskin K and Clergeau P 2021 Urban Ecosystem-Level Biomimicry and Regenerative Design: Linking Ecosystem Functioning and Urban Built Environments *Sustainability* **13** 404
  In this article, Eduardo Blanco presents the use of biomimicry in the urban context and argues that it is one of the most relevant solutions for aiming at sustainability and the regeneration of urban spaces. The study specifically focuses on the ecosystem level of biomimicry and aims to analyze practices and conduct a literature review to understand current trends in practice and identify opportunities. He analyzes the benefits and challenges of two study cases [6].

- Hayes S, Desha C and Gibbs M 2019 Findings of Case-Study Analysis: System-Level Biomimicry in Built-Environment Design Biomimetics 4 73
  This article offers an analysis of six biomimetic urban projects. All of them are examples of system-scale biomimicry. The analysis combines documentary research and fieldwork through a series of interviews. The objective is to analyze the results of these experiences and identify common challenges and difficulties faced in these projects [13].

- Buck N 2017 The art of imitating life: The potential contribution of biomimicry in shaping the future of our cities *ENVIRONMENT AND PLANNING B-URBAN ANALYTICS AND CITY SCIENCE* **44** 120–40
  The author presents biomimicry as an opportunity for cities and a new way to address contemporary urban challenges. He conducts a literature review to understand the positive effects of biomimetic urbanism and to identify barriers to its implementation. Three study cases fit with our analysis framework [5].

4. Results and Discussion of the literature review

This section presents an explanation of thematic focus, the literature review results and its discussion.

4.1. Review of Systemic Application to Built Environment

Biomimicry can be applied at three levels: form, process, and system-level. The form level involves emulating the function derived from the specific form of an organism, a part of it, or its production. This level focuses on the morphology found in nature. The process level of biomimicry mimics the behavior or production processes of organisms or groups of organisms. Lastly, the system-level biomimicry emulates the functioning, principles, and strategies of ecosystems [14]. In the context of cities, which are complex systems comprising humans, infrastructures, environmental context, and relationships, ecosystems serve as the most relevant and fitting level of inspiration. Ecosystems consist of biotic elements, analogous to the built components of a human city, as well as abiotic elements, which can be compared to the urban environment and context. Additionally, ecosystems encompass interactions among these elements. We propose a parallel between an ecosystem composition and an urban system composition and functioning in Figure 2. While ecosystem-level biomimicry can incorporate form and process-level biomimicry, it does so in a systemic manner that considers the larger-scale benefits. This approach provides more comprehensive and attuned solutions to the systematic challenges faced by cities. Past analogies between the human organism or current works on urban metabolism are limited and primarily address the issue of urban flow [7].

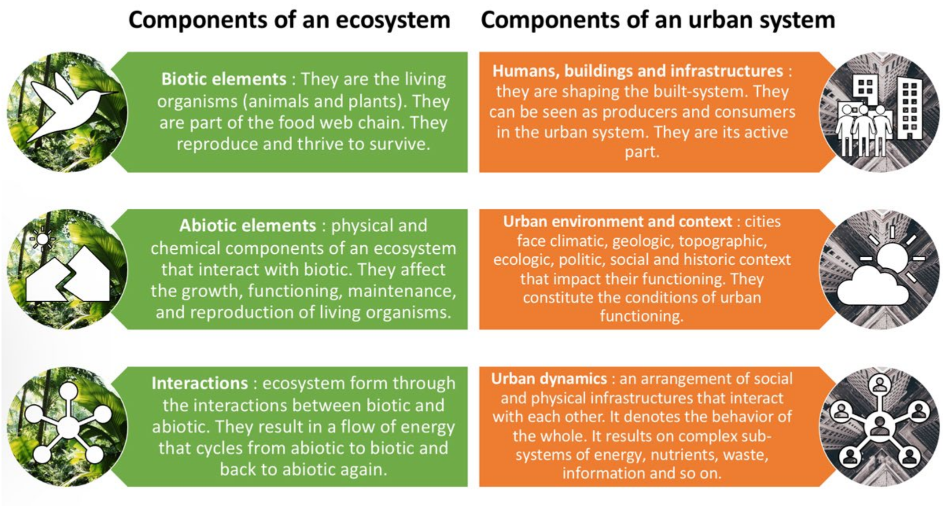

Figure 2. Parallel between ecosystem and urban system composition and functioning

Dicks [7] argues in favor of using the forest ecosystem as the model for urban biomimicry, based on three arguments. Firstly, the "fittingness" argument suggests that forests are the most common native ecosystems before cities development. Secondly, the "scale" argument posits that forests and cities share a relatively similar scale. Lastly, the "complexity" argument highlights forests as being among the most intricate terrestrial ecosystems from which we can derive solutions for cities. These arguments can also be employed to support the preference for the ecosystem level over the form or process level in general. This section will present and analyze the primary methodologies of urban biomimicry that align with the ecosystem level.

4.2. Different methodologies of urban biomimicry

Three main methodologies of system-level biomimicry have been developed to apply ecosystem teachings to the built environments as system. The first one is the application of Life's Principles (LP) which are the "design patterns and strategies commonly adopted by organisms within ecosystems" [13]. These LP can be used as guiding principles for a project as well as measurement principles. They are supposed to draw a regenerative and resilient framework for any project but there is no consensus about them. Benyus and her teams have developed this idea as a tool and a guide for any type of design to emulate the general strategies of nature to be resilient and sustainable. This approach is the simplest and can be translated into any field. When speaking about urbanism, these principles could be applied in the general strategies of a project. Figure 3. depicts a visual way of presenting life's principles to guide designers.

Figure 3. The Biomimicry DesignLens by Biomimicry 3.8 Institute.

Then, "Genius of Biome" (GoB) consists of looking at the local ecosystem strategies to local challenges in order to define a sustainable design framework. It implies the emulation of functioning principles and biophysical attributes. In other words, the concept of GoB explores the tactics and structures employed by organisms residing in a specific biome. It elucidates the biological principles and recurring patterns observed in organisms and ecosystems within this particular biome. By leveraging this knowledge, designers can extract principles that foster innovation and establish specific criteria for location-specific design in their projects. Developed by HOK Architecture and Biomimicry 3.8, this approach can help designers, architects, and planners to integrate locally attuned nature's solutions to their designs. Going further than the LP, the GoB addresses the different systems and elements of a system: energy, water, materials, nutrients, and communication. Therefore, by biologizing the urban challenges, designers can find new solutions coming from the local biomes described by its climate conditions, its nutrient conditions, its interactions, and temporal conditions. However, it allows a systemic way to innovate as the solution comes from a biome approach and not an individual organism approach, so the solution is part of a bigger system functioning and has to be thought accordingly. The LP still plays the role of measurement principles which can be quantitative or qualitative metrics. [15]

The last recognized methodology is Ecological Performance Standards (EPS) like the Ecosystem Services Analysis (ESA) conceptualized by M P Zari [16]. It proposes to base the design from ecosystem functioning by asking "What would nature do here" and "How could an ecosystem function here" [13]. The concept is to mimic ecosystem services, using them as guiding principles for urban planning but also as metrics. Notwithstanding, not all ecosystem services can be mimicked by the built environment. It is why Zari selected the most relevant ones according to three criteria to assess the relevance of an ecological service: 1) the possibility of mimicked; 2) the impact on the overall ecosystem health; 3) the negative impact urban environments have to the considered service [16]. The establishment of ecosystem-level biomimicry metrics will establish a strong standard to urban development or renovation, aiming for regeneration [16],[17]. Zari's ESA approach (Figure 4) will first assess the local ecosystem services of the land, or, if the land is already urbanized, the ones of the ecosystem which would have been there before human development. Then, the ecosystem services of the post-urbanization context must be assessed to compare the two contexts with relevant ecological metrics. Finally, the project will try to find solutions to come closer to the ecosystem functioning [6].

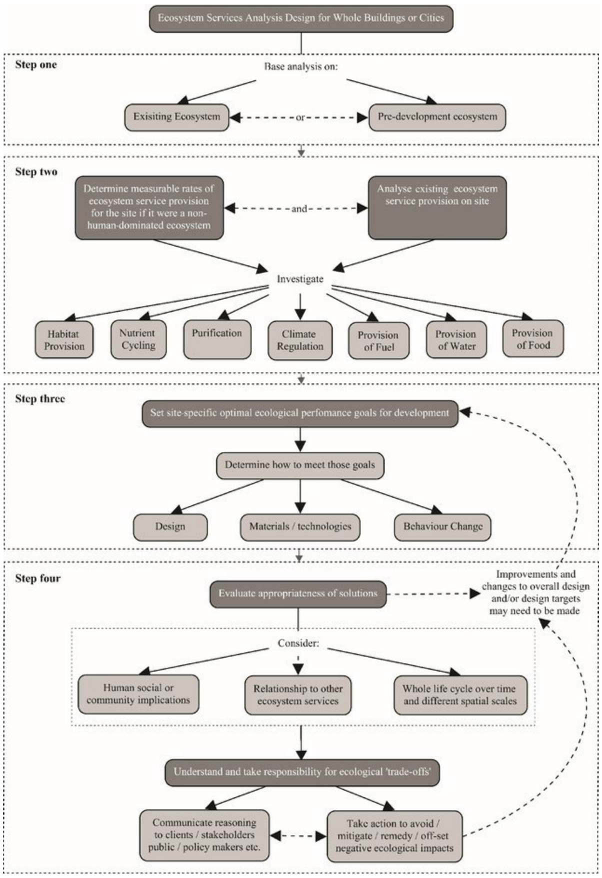

Figure 4. ESA detailed methodology [16].

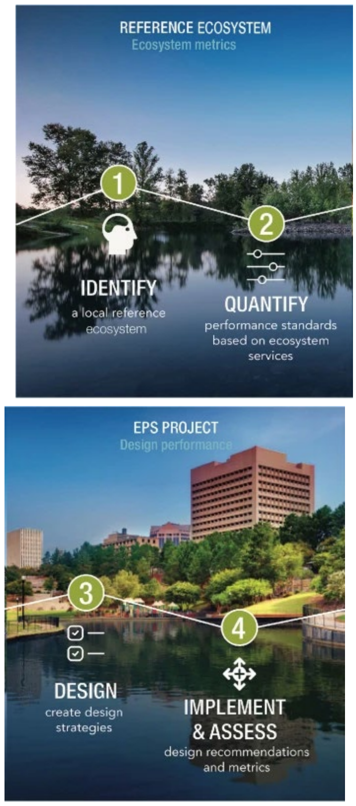

Figure 5. Biomimicry 3.8 EPS steps – Biomimicry 3.8.

As for Biomimicry 3.8 EPS (Figure 5), it does not include a comparison process, but it quantifies from a chosen local reference ecosystem some ecosystem services to produce metrics. Afterwards, the design will be led by the will to reach the same levels in the EPS metrics as the reference ecosystem. To finish, the design will be implemented and assessed according to the "Nature as measure" principle [17].

A well-known case of EPS is the Lloyd Crossing project. This project of 800ha urban development and renovation used thirteen metrics emulated from local ecosystems. In fact, the project evaluated the ecological situation before the development by simulating a native conifer forest. Then the existing built environment was assessed according to these metrics. Finally, the comparison between the two situations would help to undermine the gaps between the ecosystem and urban functioning. For instance, regarding wildlife habitat, predevelopment mixed-conifer forest model present 90% of tree cover whereas the current development has only 10% [18]. So, designers aimed to increase the increase up to 25-30% by implementing green streets, rooftop gardens, and habitat corridor by inspiring from the forest (Figure 6). The project has not been implemented until now.

Figure 6. Example of EPS used in Lloyd Crossing project. Mithun/KPFF

4.3. Lessons learned from the literature study cases.

Although application cases of ecosystem-level biomimicry are few, the existing experiences could help designers to understand the pros and cons of urban biomimicry. This is the objective of the three selected papers which analyze study cases to underline the benefits and the challenges of the new methodologies explained above. They all agree about the potential of biomimicry to guide regenerative design for cities but also that we still have a long way to go. Blanco [6], Hayes [13] and Buck [5] proceeded to discuss the different study cases by interviewing the main stakeholders and by evaluating the documented results. Our analysis will be held in four times. First, we will discuss the different models and concepts used in these study cases. Then, the urban and social benefits will be summarized, followed by the deficiencies of this approach. To finish, the limits and barriers of adoption will be discussed. Overall, this analysis will help us to point out the challenges of urban biomimicry. The known projects included in the overview are presented in Table 3.

Table 3. Study cases of urban system-level biomimicry.

Name	Location	Ecosystem model	Designers
Lavasa Hill Project	Maharashta, India	EPS approach based on moist deciduous forest.	HOK
The Lloyd Crossing Project	Portland, USA	EPS approach based on local conifer forest.	Mithun
Langfang Eco-Smart City	Langfang, China	Genius of Biome approach based on mixed deciduous forest.	HOK

The Urban Greenprint project	Seattle, USA	Restoring predevelopment ecosystem functions.	The Urban Greenprint, Biomimicry Puget Sound

4.3.1. Models and concepts used. The study cases encompass each one of the methodologies presented. In the case of EPS approaches, the reference ecosystem can vary. For instance, the moist deciduous forest inspired urban water management and a mixed-conifer forest as previous local ecosystem inspired metrics to reduce ecosystem impacts and improve sustainability. Among the metrics used in the EPS approach, either quantitative or qualitative and coming from the reference ecosystem services, we can find water collection, solar gain, carbon sequestration, water filtration, evapotranspiration, nitrogen and phosphorus cycling, tree canopy cover, wildlife species, total precipitation, storm water runoff, groundwater recharge, carbon flows (production and sequestration), oxygen released, water flows. The least used approach is the LP which only gives general guidelines for a project and the most used approach is the EPS that can be completed by another approach. Thus, biomimicry in urban development considers as a model the predevelopment ecosystem and local habitat types, including biophysical structures, biological characteristics, landscape configuration, ecosystem functions, and socio-ecological systems. Forest seems to be the most used model for urban biomimicry among the study cases which strengthen the opinion of Dicks (2018) [7] that the forest biome is the better model for ecosystem-level biomimicry for cities.

4.3.2. Benefits of urban biomimicry. The use of EPS metrics helps to aim a regenerative urban environment by raising the ecological standard. It ultimately can reduce the impact on the environment by replacing partly the ecosystem services by the regenerative design based on its metrics. Regarding Genius of Biome, seeking solutions to urban challenges by looking to how the local ecosystems tackle similar problems can stimulate the creativity during the design process, but it can also give concrete solutions which needs few levels of abstraction, like using the natural landscape to manage water flows instead of concrete storm channels. Finally, biomimicry offers unique and creative solutions to complex urban challenges such as urban heat island effect, stormwater management, and sustainable infrastructure development.

Moreover, urban biomimicry makes built environment professionals, policymakers and biologists work altogether. It is strengthening not only transdisciplinarity but also engagement of the different stakeholders instead of working in silo. In fact, biomimicry can appear as a common ground to share expertise and to speak the same language while coming from different backgrounds.

Lastly, biomimicry can influence human behavior and how we relate with nature. It fosters values like to be locally attuned, to adapt to changing conditions, to take care of ecosystems health, and so on and so forth. Mainstreaming biomimicry could change the representation of nature among the built industry stakeholders, and simultaneously make sustainable development principles more understandable through nature's analogy.

4.3.3. Deficiencies of urban biomimicry. At present, ecosystem-level biomimicry is simplistic, and the integration of biological knowledge can be improved. In addition, ecosystems are complex and dynamic objects that are difficult to imitate. It is therefore essential to propose models based on the latest knowledge on this subject and to strengthen cooperation with ecologists. However, the backlash could be more complex exchanges between ecologists, urban designers, and biomimicry experts.

Misapplication of analogy between the living and the urban environment – resulting of poor problem-solution pairing, over-simplified and incomplete approaches, lack of data, and inconsistency are important challenges to be addressed in order to enhance the practices.

4.3.4. Limits and barriers of adoption. As said previously, urban biomimicry requires ecological knowledge that can be a limit to a more complete application but also in the process of sharing knowledge between different disciplines. It can result in superficial use of biomimicry, or even just as a greenwashing tool.

On the other hand, the more complexity is considered, the greater the time and financial cost, as well as the difficulty in convincing the various stakeholders of the usefulness of the approach. There is sometimes a gap between political and economic expectations and the ecological motivations of biomimicry. In fact, profit-driven projects will widely limit the potential of biomimicry in the context of a competitive and risk-averse construction industry. Biomimicry can also be seen as a greenwashing label itself.

Regarding the concretization of biomimicry, two other barriers have been highlighted. The first one is the lack of benchmark projects. Indeed, the literature and expert documentation are poor of documented study cases and even more when speaking about comparative results of this approach with others. Moreover, there is a growing need among practitioners for centralized documentation that encompasses the various methodologies, practices, results, and challenges related to biomimicry in urban planning.

4.4. Synthesis and discussion of the results

This synthesis aims to address practitioners' need by providing valuable insights and contributing to the existing body of knowledge in the field. By consolidating information and analysis on the application of biomimicry in urban planning, it seeks to provide a comprehensive resource for practitioners, enabling them to navigate the subject more effectively and make informed decisions. Figure 7. is an attempt to visually summarize the results. Firstly, practices of biomimicry in urban development consider the predevelopment ecosystem and local habitat types, including biophysical structures, biological characteristics, landscape configurations, ecosystem functions, and socio-ecological systems. Table 4. Aims to summarize the different approaches presented.

Table 4. Summary of the different approaches of systemic urban biomimicry.

Type of approach	Most common approaches	Developer
Application of general ecosystem principles	Life's Principles through the Biomimicry Design Lens	Biomimicry 3.8 (co-founded by Janine Benuys)
Emulating local ecosystems' strategies and biophysical structure	Genius of Biome	HOK Architecture and Biomimicry 3.8
Comparing ecosystem services provided by urban development and initial ecosystem	Ecological Performance Standards	Biomimicry 3.8
	Ecosystem Services Analysis	Maibritt Pedersen Zari

It was highlighted that urban biomimicry has the potential to improve ecosystem functioning and can be applied on a larger scale in urban development projects to regenerate and create new ecosystems. Its positive impact has already been observed in various green infrastructure and urban ecosystem services projects.

However, the practices also depict some challenges. Among them, the complexity of knowledge transfer from ecology or biology to the built environment limits the "Nature as model" application because of the oversimplified analogy and the language barrier between the fields. Furthermore, the time, money and engagement needed to develop this kind of solution conflict with market incentives. Therefore, biomimicry practitioners are in need of benchmark and ready-to-use documentation so they can overcome these constraints. Otherwise, urban biomimicry could become a new way of greenwashing where the ecosystem model is very simply, or even more incorrectly, applied to urban environments.

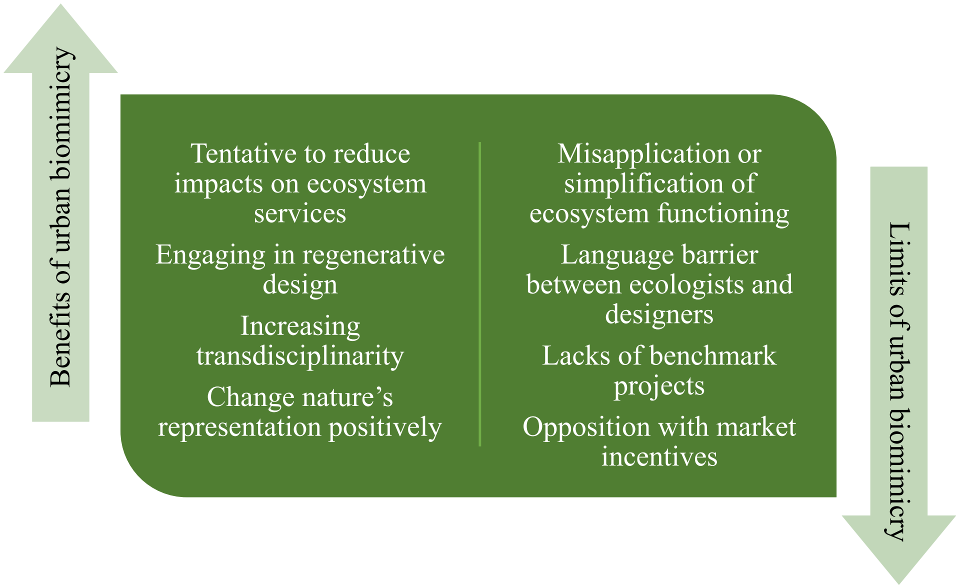

Figure 7. Synthesis of benefits and limits of urban biomimicry

5. Conclusion

Urban biomimicry could provide new models to rethink the way we develop or redevelop our cities. In fact, by aiming ecosystem functioning, built environments could have less impact to ecosystems and to the climate. It could lead to a sustainable and regenerative urban design that tries to replace the initial ecosystem services provided by nature, and by inspiring from it to make its sub-systems sustainable. Therefore, biomimicry could teach us how to find systemic solutions for cities. However, currents experiences of urban biomimicry are too few to prove the benefits of this approach and the limits and barriers are still important. Likewise, studies examining the concrete results of these projects are scarcely available. Thus, while theoretically ecosystem-level biomimicry applied to cities seems to be an opportunity to shift the way we build urban environments, assessed results are not convincing enough to show that this approach is relevant. There are still big challenges to tackle as mentioned before. To finish, these challenges can be seen as opportunities to improve the current approaches and develop new ones. In this process, ecologists should be included at the very beginning of the process and benchmarks must be made to convince stakeholders that the approach is relevant and economically viable. Without forgetting that human and social sciences also have their role to play in assessing urban biomimicry relevance.

5.1. Research Recommendations in Urban Design

Research in urban design could be focused on three levels. The first one is to continue to assess the current and past practices of urban system-level biomimicry using Life's Principles, Genius of Biome or Ecological Performance Standards. Secondly, urbanists must evaluate the relevance of urban biomimicry theoretically as well as practically by discussing the results of realized projects and by comparing them with mainstream sustainable urbanism. With this regard, Table 4. presents two potential biomimicry-oriented projects that could be investigated in Southeast Asia. The last one is to continue to develop these approaches by making them more practical and more relevant, but also to propose new approaches by collaborating with biologists and ecologists. However, practitioners should include within these ideas social, economic, and political issues that can be brought by complementary approaches.

Table 5. Potential urban biomimicry projects to be investigated in SEA.

Name	Location	Year of development	Ecosystem model	Designers
Nhon Tracy Residential Development	Dong Nai Province, Vietnam	2010	Ecosystem principles and landscape	H+B Architects
Nusantara	Borneo Island, Indonesia	2023	Ecosystem biophysical structures and landscapes	Urban+ (Jakarta)

5.2. Research Recommendations in Human and Social Sciences

Social sciences are also very important to understand the knowledge production and sharing of biomimicry. In fact, sociology could help to understand the emergence of organizations promoting biomimicry and spreading methodologies among the stakeholders. It can also contribute to biomimicry criticism to a great extent by examining social and urban effects of these practices. Moreover, there is a lack of serious examination of biomimicry epistemology and philosophy [19]. However, some previous works can be used as a basis. Indeed, the works of Mathews [20] and Dicks [4] have initiated a philosophical and epistemological analysis and criticism. Notwithstanding, the works in other human and social sciences are completely missing. This is an important gap in the literature as it could bring beneficial knowledge about real urban impacts of biomimicry, impacts on nature's representation, ethical limits, knowledge production process, social context of emergence, public and private stakeholders' acceptance, economic issues, philosophical consequences, communication between biologists and other sciences, and so on.

References

[1] Steffen W, Richardson K, Rockström J, Cornell S E, Fetzer I, Bennett E M, Biggs R, Carpenter S R, de Vries W, de Wit C A, Folke C, Gerten D, Heinke J, Mace G M, Persson L M, Ramanathan V, Reyers B and Sörlin S 2015 Planetary boundaries: Guiding human development on a changing planet *Science* **347** 6223
[2] Benyus J M 2011 *Biomimétisme: Quand la nature inspire des innovations durables* (Paris: Rue De L'echiquier)
[3] Chekchak T and Lapp K 2011 Biomimétisme, la nécessaire resynchronisation de l'économie avec le vivant *Écologie & politique* **43** 159–66
[4] Dicks H 2018 Nature as Mentor: Foundations of Biomimetic Epistemology
[5] Buck N 2017 The art of imitating life: The potential contribution of biomimicry in shaping the future of our cities *ENVIRONMENT AND PLANNING B-URBAN ANALYTICS AND CITY SCIENCE* **44** 120–40
[6] Blanco E, Pedersen Zari M, Raskin K and Clergeau P 2021 Urban Ecosystem-Level Biomimicry and Regenerative Design: Linking Ecosystem Functioning and Urban Built Environments *Sustainability* **13** 404
[7] Dicks H, Bertrand-Krajewski J-L, Ménézo C, Rahbe Y, Pierron J and Harpet C 2021 Applying Biomimicry to Cities: The Forest as Model for Urban Planning and Design pp 271–88
[8] De Swaef T 2018 *Homo imitator : La surprenante histoire des inventions que l'on doit à la nature* (Paris: Editions Jourdan)
[9] Barles S 1999 *La ville délétère. Médecins et ingénieurs dans l'espace urbain. XVIIIe-XIXe siècle* (Seyssel: Champs Vallon)
[10] Paré G, Trudel M-C, Jaana M and Kitsiou S 2015 Synthesizing information systems knowledge: A typology of literature reviews *Information & Management* **52** 183–99
[11] Green B N, Johnson C D and Adams A 2006 Writing narrative literature reviews for peer-reviewed journals: secrets of the trade *J Chiropr Med* **5** 101–17
[12] Templier M and Paré G 2015 A Framework for Guiding and Evaluating Literature Reviews *Communications of the Association for Information Systems* **37**
[13] Hayes S, Desha C and Gibbs M 2019 Findings of Case-Study Analysis: System-Level

Biomimicry in Built-Environment Design *Biomimetics* **4** 73
[14] Jain A, Cummings A, Lim G S, Shah I, Haan L, Teo L, Fadnavis M, Toh M M, Hays N, Dhuri R and Swaminathan S 2023 *Biomimicry for tropical building skins, a design toolkit to manage thermal comfort using Nature's genius* (Singapore: bioSEA Pte. Ltd.)
[15] Biomimicry Guild and HOK 2023 Genius of Biome. Temperate broadleaf forest
[16] Zari M P 2018 *Regenerative Urban Design and Ecosystem Biomimicry* (New York: Routledge)
[17] Benyus J, Dwyer J, El-Sayed S, Hayes S, Baumeister D and Penick C A 2022 Ecological performance standards for regenerative urban design *Sustain Sci* **17** 2631–41
[18] Hayter J 2005 Lloyd Crossing Sustainable Urban Design Plan and Catalyst Project - Portland, Oregon Places 14-17
[19] Kamili L 2019 Biomimétisme et bio-inspiration : nouvelles techniques, nouvelles éthiques ? *Techniques & Culture. Revue semestrielle d'anthropologie des techniques, Varia*
[20] Mathews F 2011 Towards a Deeper Philosophy of Biomimicry *Organization & Environment* **24** 364–87